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Web-based Visualization for 3D Data in Archaeology: The ADS 3D Viewer

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Abstract

The solid geometry of archaeological deposits is fundamental to the interpretation of their chronological sequence. However, such stratigraphic sequences are generally viewed as static two-dimensional diagrammatic representations which are difficult to manipulate or to relate to real layers. The ADS 3D Viewer is a web-based resource for the management and analysis of archaeological data. The viewer was developed to take advantage of recent developments in web technology, namely the adoption of WebGL (Web Graphics Library) by current web browsers. The ADS 3D Viewer combines the potential of the 3D Heritage Online Presenter (3DHOP), a software package for the web-based visualization of 3D geometries, with the infrastructure of the Archaeology Data Service (ADS) repository, in the attempt to create a platform for the visualization and analysis of 3D data archived by the ADS.

Two versions of the viewer have been developed to answer the needs of different users. The first version, the *Object Level 3D Viewer*, was implemented to extend the browsing capability of ADS project archives by enabling the visualization of single 3D models. The second version, the *Stratigraphy 3D Viewer*, is an extension which allows the exploration of a specific kind of aggregated data: the multiple layers of an archaeological stratigraphic sequence. This allows those unable to participate directly in the fieldwork to access, analyse and re-interpret the archaeological context remotely. This has the potential to transform the discipline, allowing inter-disciplinary, cross-border and 'at-distance' collaborative workflows, and enabling easier access to and analysis of archaeological data.

Keywords: 3D documentation; archaeological excavation; archaeological stratigraphy; web-based 3D visualization; 3D web; online repository; 3D data analysis

1. Introduction

The analysis and interpretation of archaeological stratigraphic sequences is a complex process which requires specific skills and expertise. The interpretation made on site is subjective and cannot be repeated, since the archaeological excavation is a destructive and one-off process. It is therefore important to develop innovative methodologies and tools that allow archaeologists or other specialists unable to participate in the fieldwork to re-interpret the data collected on-site, by preserving the stratigraphic sequence by means of digital 3D metric sampling. It is also valuable to document individual excavation finds accurately and to allow remote visualization and inspection. The active integration of traditional and innovative 3D practices can increase the accuracy and realism of documentation, enabling richer and more complete recording.

Interest in digital visualization systems to facilitate the creation, exploration and presentation of stratigraphic relationships began in 1975 with Wilcock's STRATA program (1975). A decade later, Ryan prepared the foundation for several subsequent developments, developing an interactive system called *gnet*, which allowed interaction with and exploration of the stratigraphic matrix diagram (Ryan 1985: 404-414), and this later evolved into *jnet* (Ryan 2001: 11). Several 2D applications for stratigraphic data presentation were developed in the late 1980s (Alvey 1989; Boast and Chapman 1991; Herzog and Scollar 1991) but these had limited take-up.

In 2004, researchers from the Department of Computer Science of Columbia University developed VITA (Visual Interaction Tool for Archaeology; Benko et al. 2004: 132-140), a collaborative mixed reality system for off-site visualization of an archaeological dig (Benko et al. 2004: 132). The system supported the interaction of multiple users with the 3D replica of the archaeological site, giving information about artefact location within the represented space. It had great potential in terms of visualization, interaction and engagement, but lacked a well-designed and solid database.

During the International Conference on Computer Applications and Quantitative Methods in Archaeology 2007, Bobowski et al. (2008) presented a dynamic 3D visualization of Harris matrix data. This tool, inspired by *jnet* and *Strat* (Bobowski et al. 2008: 2) is simple in terms of visualization, but challenging in its attempt to combine 3D visualization and analysis. Bobowski et al. (2008) created a virtual reality application that could access a database server to integrate the vertical stratigraphy with horizontal topography of 3D Harris Matrix visualization data.

Together, these projects developed 3D visualization for stratigraphic analysis, allowing archaeologists to analyse stratigraphic units with their real spatial relations, but none were

taken up in day-to-day archaeological practice. Whilst the majority of the visualization systems were underpinned by well-made and solid databases, they provided only a schematic 3D graphic representation of the layers (Ryan 2001; Bobowski et al. 2008; Mills and Baker 2009). Others had powerful visualization systems but lacked a solid database (Benko et al. 2004). No one was able to create a solid database linked to a visualization system that could display realistic 3D representations of archaeological stratigraphy, although there have been some attempts to create prototype management systems for the visualization of 3D representations of archaeological stratigraphy (Losier et al. 2007; Doneus et al. 2011; Stal et al. 2014), or for visualizing 3D data using WebGL technology in other adjacent fields, such as palaeontology (Michaux et al. 2015; Michaux et al. 2012), geology (Herzig et al. 2013; Silvestre et al 2013) and digital humanities (Bozia et al. 2014; Matsushita et al. 2014).

The advent of WebGL brought to the availability of free or commercial solutions (i.e. Sketchfab, Autodesk Smithsonian X3D) that provide high quality visualization and interaction. Nevertheless, the features provided may not be enough to cover for the necessities of peculiar applications, and no strong customization is possible. For this reason, and ad-hoc system (possibly built on existing, more flexible tools) can be the solution.

Presently, a major challenge for Information Technology (IT) specialists and for archaeologists working with archaeological 3D data consists of the long-term preservation and dissemination of those data. It is essential that 3D visualisation tools are integrated within stable long-term digital archives. In archaeology, the creation of digital data archives began in the late 1980s (Richards 1998: 333-335), but the potential to visualize data in an interactive and simple way has not yet been realized. Up to now, a large number of 3D digital data archives have been produced but most focus on data preservation issues without considering the accessibility of these data for the scientific community. The projects discussed above, for instance, highlight increased interest in 3D aspects of data sharing and archaeological analysis. Yet, most of these projects are conceived using off-line platforms, such as GIS. The project developed by Stal et al. (2014) is the only example of a management system accessible using a web browser.

Today, when developing an online interactive visualization system it is critical to integrate it with existing databases and to provide access to the archived data in a simple way for all kinds of users, including those unfamiliar with these technologies. To meet this need the ADS 3D Viewer, a 3D web-based environment for the management and analysis of archaeological data, was developed on top of an existing and well known repository of archaeological data,

the Archaeology Data Service (ADS), a UK-based cyber-infrastructure hosted at the University of York.

The extensive experience of the ADS in long term data preservation and access was an essential element for the development of a robust 3D web-based platform. Solid cyber-infrastructures such as ADS can facilitate the long term use of this new 3D tool not only in academia but also among professional archaeologists and the general public. In this paper two resources implemented in the ADS Viewer project are presented: the *Object Level 3D Viewer*, which extends the browsing functionality of ADS project archives and allows the dynamic visualization of single 3D models directly in the project webpage; and the *Stratigraphy 3D Viewer*, which allows the visualization and analysis of a very specific kind of aggregated data such as the different layers of an archaeological stratigraphic sequence.

The development of a 3D web-based platform for the analysis and visualization of archaeological records is important for various reasons:

1. It facilitates decision-making about the continuation of archaeological campaigns, since the holistic interaction with 3D metric reproductions of archaeological sequences can facilitate the selection of new areas of interest and adjustments to excavation strategies;
2. It simplifies the real-time interaction between excavators and other specialists working out of the field. The possibility to upload online a 3D metric reproduction of archaeological stratigraphy with related information enables archaeologists who excavated the site a real-time remote interaction with other specialists who did not take part in the fieldwork, establishing a collaborative interpretative process;
3. It builds upon existing 2D software and approaches for the analysis and visualization of archaeological excavation sequences (i.e. Harris Matrix composer software), adding realism and the third dimension;
4. It provides a new and more effective way to interrogate archives. The possibility to link the archive dataset to a dynamic and realistic 3D reproduction of the excavation enhances the understanding of the spatial relationship between units, features and finds contained in the stratigraphic sequence. It provides a more user-friendly and effective means of navigating stratigraphic and associated data than lists of isolated files and images.

2. Design

The advancement of web technology has caused a paradigm shift in the use of the web, especially for 3D contents. Web browsers have become an effective computation platform, as they are able to execute JavaScript code quite efficiently, and the HTML5 standard now includes WebGL, a porting of the OpenGL 3D graphics library that runs directly inside the browsers. The advent of WebGL has made possible the creation of many JavaScript graphics libraries and 3D applications, transforming the way in which it is possible to access and visualize 3D data on the web. This new technology allows the creation of platforms where data archived in repositories can be viewed and explored dynamically, and used for data analysis and interpretation directly within the web browser. WebGL produces an advance in usability with respect to the obsolete explicit data download mode, which requires the use of an appropriate application to open the specific data file type. The ADS 3D Viewer was therefore developed so as to combine the expertise of ADS in digital data archiving with the potential of the 3D Heritage Online Presenter (3DHOP; Potenziani et al. 2015). This permits web-based visualization of 3D geometries in a simple way without the need for specific computer graphic skills, whilst ensuring long-term preservation of the data.

3DHOP was preferred to other common tools for displaying 3D contents on the web, such as Unity (Unity 2015), Sketchfab (Sketchfab 2015) and X3DOM (Behr et al. 2009), because it seemed the best solution for the web-integrated visualization of single, high-resolution 3D representations of artefacts and archaeological stratigraphy (for a more detailed comparison between 3DHOP and other platforms see Potenziani et al. 2015 and Ponchio et al. 2015). This choice is reinforced when looking at examples of interactive visualization systems for archaeological stratigraphy developed using Unity (Trautner 2015). The viewer developed by Thomas Trautner (2015) is a real-time renderer which allows the comparison of Harris Matrix with measured 3D data and their manipulation. This research highlights Unity's limit in vertex count per mesh (65.534). When a high-resolution mesh is imported in Unity, the software will automatically divide it into sub-meshes (Trautner 2015). This approach represents a significant limitation when dealing with high-resolution 3D models, since the fragmentation of the data is not recommended for their optimal long-term preservation and archiving. 3DHOP was also preferred over the Adobe 3D navigation tool (Adobe 3D 2015). Whilst providing a very powerful instrument for the publication and basic visualization of 3D data, the Adobe tool does not allow fast and dynamic visualization of complex 3D data and the integration of related archived datasets directly in the 3D view.

One of the most important aspects of 3DHOP is its ability to manage very high resolution 3D meshes and point-clouds using a multi-resolution approach. The goal of a Multiresolution approach is to convert a standard 3D model into a different data structure, which can be effectively rendered at a specific optimized resolution and accuracy for each single frame. For each view position and direction, the Multiresolution structure produces an optimal representation based on a minimal number of triangles/points. Most of these methods divide the model into multiple small portions of the input mesh (patches), build up other patches which more synthetically represent the patch or groups of patches (i.e. having a reduced resolution), and finally organize all those data with a representation structure (usually a graph) that is consulted at rendering time to produce a specific view-dependent representation. 3DHOP adopts the Nexus (2015) multi-resolution representation and rendering library. Nexus is a documented, open source library (2015) and it has been integrated in a WebGL context in the framework of the 3DHOP project. The Nexus multiresolution library provides very good performances in terms of rendering speed and data compression. Since the 3D model is divided in smaller patches, and only a small amount of patches is needed to render the model at any given time, the use of the Nexus multiresolution structure also reduces the data loading time and bandwidth, thanks to a progressive transmission feature (Potenziani et al. 2015).

2.1. Object Level 3D Viewer

Recent development of tools such as 3DHOP or Sketchfab demonstrate that it is now technically possible to upload and visualize complex 3D models on the web. Nevertheless, the integration of this type of media in the context of archaeological datasets is still difficult to achieve. For this reason, the first step tried to find a way to include interactive visualization in a standard archive. This had to be obtained in an automatic way, without any intervention by the user. Hence, starting from the standard ADS project archives layout, the project browsing functionality was extended to provide on-demand visualization of the data. Each standard ADS project archive has a short introduction and a download section at the very least. In the download section it is possible to view project data produced in different file formats, such as JPG (2D images) and ASCII and OBJ (3D data). Before the development of the ADS 3D Viewer it was only possible to interrogate archives by downloading individual files on the user's computer and reassembling the 3D geometry locally, which demands medium-/high-level IT skills and access to software by the end user.

Since the granularity of the data preserved in the repository is at object level, an automatic 3D model viewer was implemented to browse 3D geometry directly in the repository page,

which contains all the other information related to the digital model. This was easily achieved by exploiting the features of the 3DHOP tool (Potenziani et al. 2015) and was tested on the Virtual Amarna project's 3D data archived in ADS (DOI: 10.5284/1011330).

The ADS 3D Viewer, following the features of the 3DHOP tool, allows the user to browse 3D geometry using a simple trackball-style functionality directly in the webpage, and contains all the information related to the digital model without the need for plugins. The 3D viewer offers users the possibility to interact with, manipulate and analyse the 3D model in the 3D window embedded in the download web-page of the project, but also in full-screen mode using a trackball and different features (viewpoint, zoom, solid colour and lighting; see fig.1).

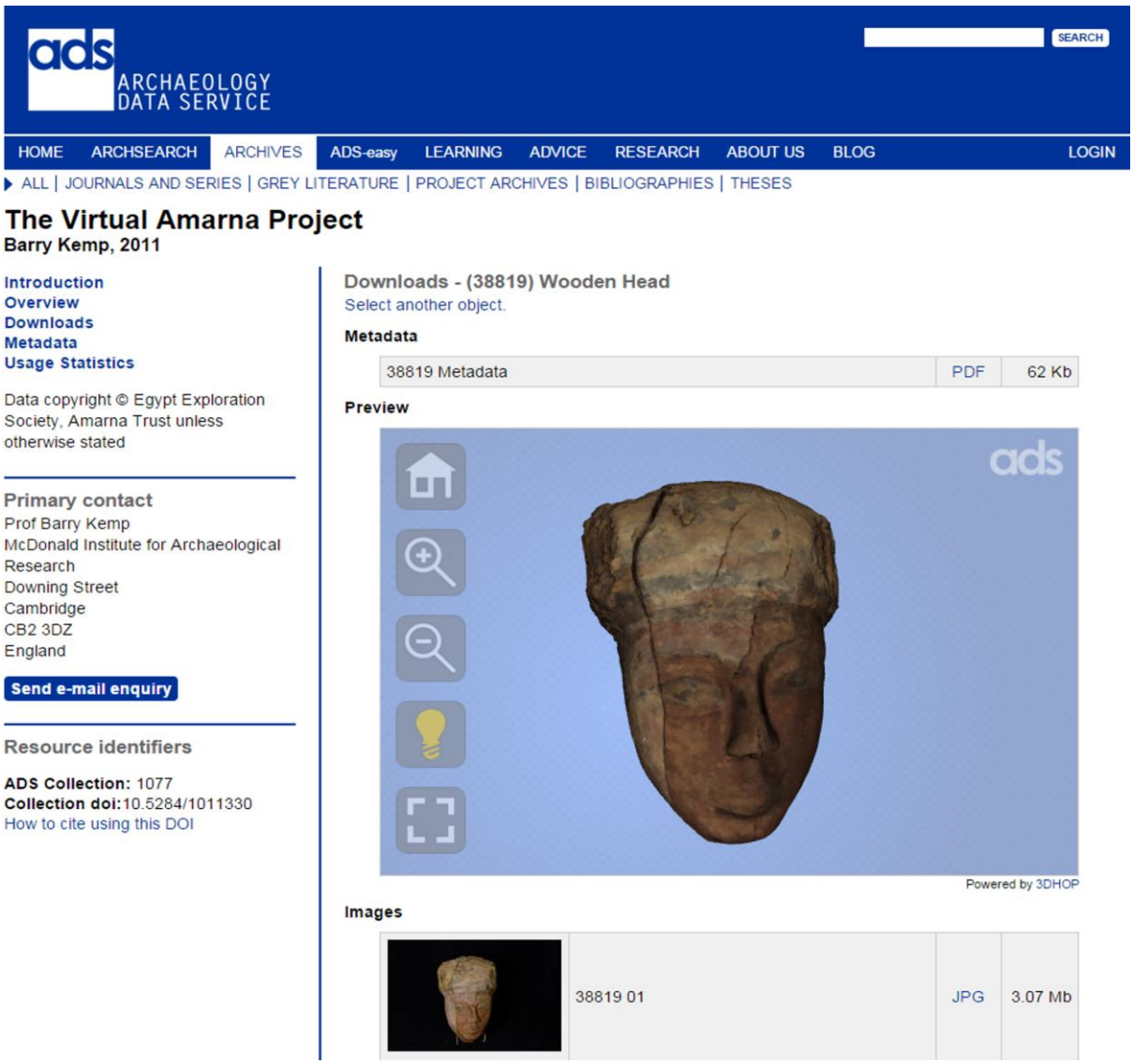

Figure 1. Screenshot of the *Object Level 3D Viewer* embedded in the Virtual Amarna Project download page (DOI: 10.5284/1011330).

The 3D viewer also allows users to take point-to-point measurements on the 3D model and, using a "share view" feature, export the current settings of the 3D viewer (viewpoint, zoom, and lighting) as a link that can be shared with other users (in the same way it is done in Google Maps). Simple as they may seem, these features are nevertheless a way to directly use the 3D models in the repository without having to download them and download/install/use specialized 3D software.

The implementation of the ADS 3D Viewer was also simplified by creating reusable components that could easily be deployed in other archives containing 3D data and models. The middleware solution used by the ADS, as with most other middleware choices, allows for the creation of components that can accept variables which are applied to a template. This approach ensured that there is minimal effort required by the archivist when deploying the ADS 3D Viewer and consistency across archives is guaranteed. A workflow was devised which guides archivists through the process of enabling a deposited 3D model to be deployed in the ADS 3D Viewer, with as much automation as possible. This ensured that the usability and creation of the ADS 3D Viewer interface is simple and practical.

2.2. The *Stratigraphy 3D Viewer*.

Once a simple visualization tool was reached the next goal was to provide a more specialized set of functionalities to achieve the goal of performing visual analysis of a very specific kind of "aggregated" data such as the different layers of archaeological stratigraphy.

The Stratigraphy 3D Viewer was developed and tested using the 3D data of the *3D Recording Las Cuevas Project* (Galeazzi 2015). Before the development of the 3D viewer the ADS repository stored the 3D models of each stratigraphic unit as single objects, without the possibility to explore their spatial and temporal relationships. The Stratigraphy Viewer aggregates the different geometric layers in a single 3D environment, whereby the user may turn layers on and off, control their transparency, and explore the layered geometry using a simple mouse- or touch-based navigation mechanism, especially designed to manipulate this kind of geometries. The Stratigraphy Viewer not only permits exploration and interaction with the different stratigraphic layers, but it also provides the option to take measurements and to select hyperlinks that provide extra information about the features contained in the layer (i.e. text, pictures, stratigraphic unit sheet, etc.; see fig. 2).

Figure 2. Screenshot of the *Stratigraphy 3D Viewer*: *3D Recording Las Cuevas Project* (DOI: 10.5284/1036099).

Archaeological sites characterized by complex archaeological sequences may require the integration of high-resolution 3D representation of stratigraphic units from different areas of the site or acquired in different fieldwork seasons. For this reason a 2D interactive map interface was developed to support easier and faster selection and loading of the different models and to allow the user to more easily interact with units coming from different areas of the site (Fig. 3).

The partition of 3D data by area also allows the integration of new models over time, making this tool suitable for archaeological projects characterized by multiple fieldwork seasons. In this way the 3D representations of the units can be grouped either by fieldwork seasons or areas (including units of the same area acquired in different seasons).

The 3D viewer also allows the simultaneous visualization of different areas of the site in case it is required by a specific case study, to help the analysis and interpretation of adjacent areas of the excavation. During tests, the infrastructure managed the simultaneous visualization of 3D models from two areas selected for the *3D Recording Las Cuevas Project* (combining a total of 6 high-resolution 3D models, see table 1), still sustaining interactive and smooth

rendering performances. Nonetheless, the ADS 3D Viewer should be tested with more complex stratigraphic sequences to give a complete and effective assessment of its performance and limitations. The Graphical User Interface (GUI) of the Stratigraphy Viewer is presented in figure 4.

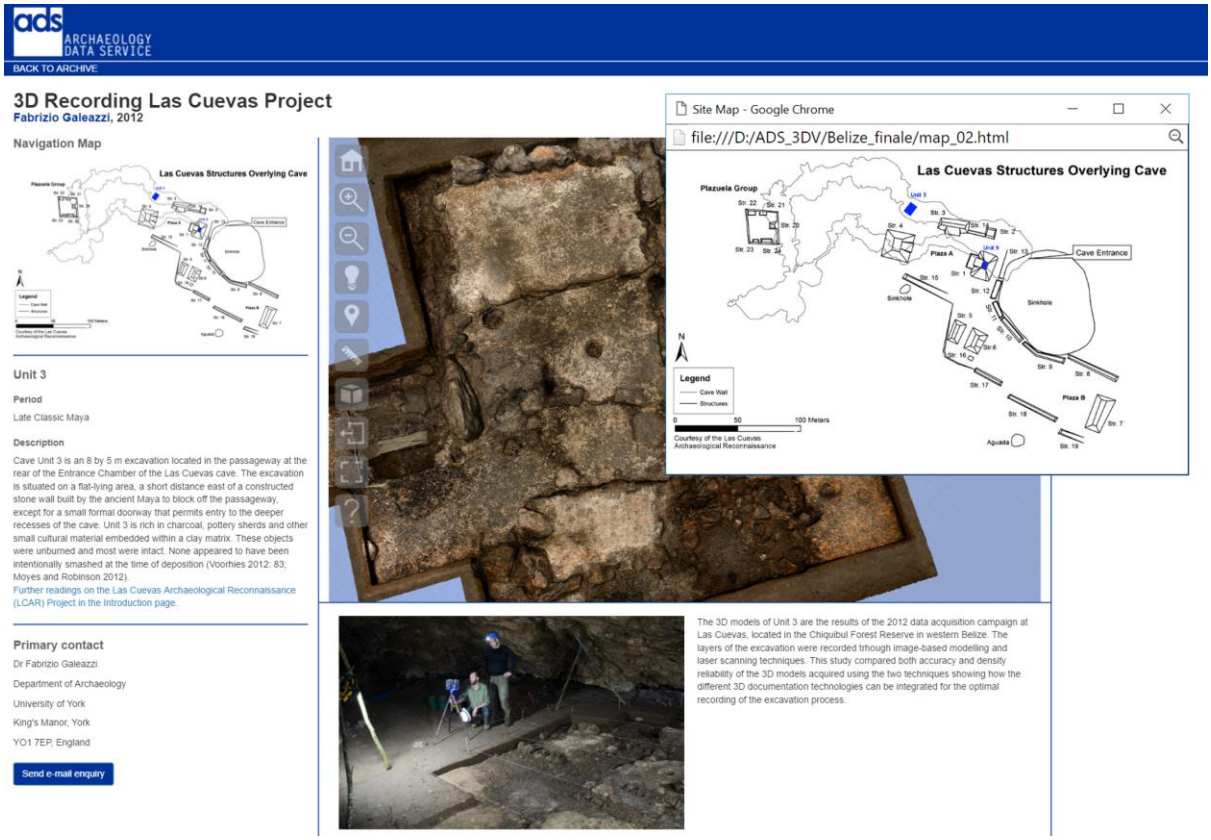

Figure 3. Screenshot of the *Stratigraphy 3D Viewer* while selecting the area on the 2D interactive map of the site.

Table 1

Number of vertices and faces of the units' 3D models.

	Number of vertices	Number of faces
Unit3_level2	5,232,038	10,456,690
Unit9_level3	3,969,735	7,928,481
Unit9_level6	1,638,052	3,270,816
Unit9_level9	1,112,204	2,220,257
Unit9_level10	1,532,443	3,060,647
Unit9_context	6,888,121	13,762,181

Figure 4. Screenshot of the *Stratigraphy 3D Viewer* GUI (Graphical User Interface).

3. Advanced features

3.1 Dynamic Harris Matrix

The Harris Matrix is a graph-based structure which enables the description of topological and chronological relations between archaeological objects and stratigraphic units (Harris 1979). Harris introduced the term "unit" stressing the physical relationships between the elements, creating a system recognizable everywhere as stratigraphic entities (Harris 1979: 120). The stratigraphic excavation method and Harris's use of the term "unit" or "context" to describe the individual deposition events revealed by the excavation process is in widespread usage today. However, there are some exceptions where the method of excavating in arbitrary spits (or "levels" in American archaeology) is still frequently used. The use of this method is common on sites which lack any visible or reconstructable stratigraphy, or when excavating through intrusive or fill deposits (Roskams 2001: 112). For example, one of the main reasons for the use of the arbitrary excavation unit in the arid western United States or in a cave environment, where material coming from the roof over many years may bury artefacts and features, is that many such sites are not physically stratified (Praetzellis 1993: 72).

Starting from the assumption that an arbitrary excavation method is frequently used in those archaeological contexts where it is not possible to recognize physical layers and interfaces between the strata (Carandini 1981: 51; Harris 1975: 20), the ADS 3D Viewer structure was developed considering both methods. The viewer can easily be adapted to cases that use either arbitrary or stratigraphic excavation methods.

The Harris Matrix element of the interface has been built dynamically using the D3 library (http://d3js.org/) and JavaScript Object Notation (JSON) data files. Each context is represented by a rectangle (or node in D3 parlance) and then relationships are represented by lines (or vertices). The nodes and relationships are defined in a simple data structure using JSON format (basically nested key-value pairs) which is then read by the D3 JavaScript library. Basic JavaScript actions are wired to the nodes that represent the contexts in the matrix, so that when a user clicks on the node the corresponding layer or context in the model is made visible or hidden. This approach enables data-driven interface design, and therefore a more loosely-coupled interface and model in the sense that data can be generated to represent the Harris Matrix and so the interface to represent that matrix does not have to be manually generated for each viewer. The Las Cuevas exemplar provides a very basic matrix, but this approach can support more complex matrices with forking vertices and multiple branches. The only current limitation is screen real-estate and readability, but that could easily be addressed by sophisticated scaling and zooming if required.

3.2. Visualization: interactive illumination, solid colour & transparency

Previous studies have demonstrated the importance of flexible visualization for the understanding of textural information while analysing 3D replicas (Di Giuseppantonio et al. 2015). In the absence of a tactile experience with the real object, the possibility to use different light settings, zooming in and out and removing original colour from the 3D models helps users to grasp geometrical, textural or high-frequency detail information. One of the first aims of this research is to give the user the possibility to interact with digital 3D replicas, allowing the remote analysis and interpretation of the archaeological record. For this reason visualization features that allow a better understanding of the 3D object texture qualities such as *lighting* and *solid colour*, were integrated in the 3D viewer.

The interaction with the object can be greatly enhanced by adding some basic interaction mechanism. The first one is the possibility to change the light direction: a controllable light makes the surface details more visible in a straightforward way (Fig. 5).

The different 3D models associated with the layers can be rendered in a variety of ways, in addition to the photorealistic rendering. For example, it is possible to make a layer (partially) transparent, providing the option to analyse underlying layers without losing the relationship with the current one. It is also possible to disable the colour information (acquired while sampling the real archaeological site and encoded in the 3D model with recent *texture* or *colour-per-vertex* mapping technologies), and render the layer with a solid colour; while

colour information is useful in many situations, it is also true that the "naked" geometry may reveal important information about the shape of the layer. These features have been easily integrated in the tool, being part of the set of basic features of 3DHOP.

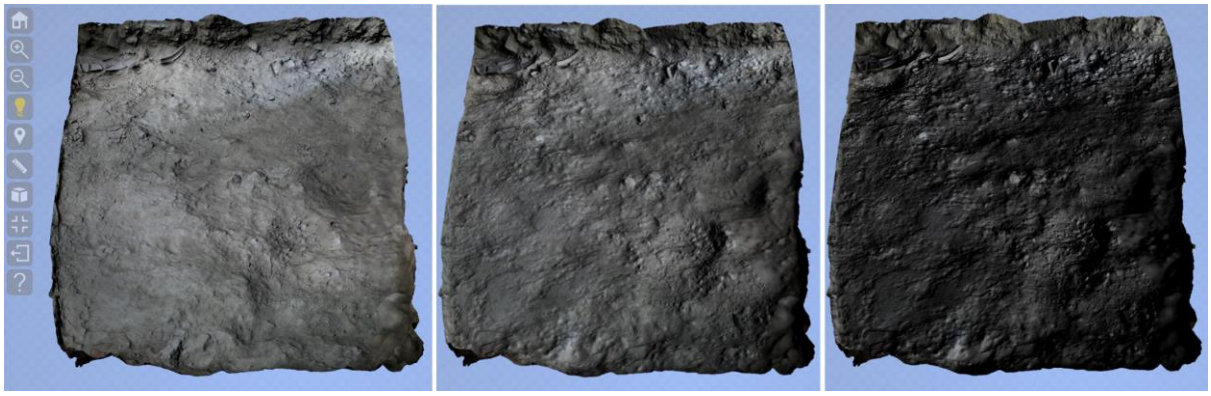

Figure 5. Screenshot of the *Stratigraphy 3D Viewer*: *interactive illumination* feature.

3.3. Units and finds selection tool (hotspots)

The 3DHOP hotspot feature was implemented and integrated in the Stratigraphy Viewer to allow the user to interrogate the 3D units and have access to related information in the ADS project archive. This information is represented by spots of different colours (the same colour is assigned to finds of similar material). The transparency and size of the spots can be changed based on the different needs of the case study. By selecting the spot (clicking on them) the user can extract the associated information from the project archive (i.e. text, images, unit recording sheets, etc.), viewing this data in a dedicated section of the ADS 3D Viewer webpage (Fig. 6). This feature was integrated in the Stratigraphy Viewer, because the development of new and more effective ways to interrogate archived data is a crucial element in current archaeological practice. The *units and finds selection tool*, increasing the understanding of the spatial relationship between units, features and finds contained in the stratigraphic sequence, will allow the development of a more effective methodology to interrogate digital archives.

The hotspot can be created as an independent geometrical entity or it could be a portion of the 3D model itself. In the example, a small sphere was used, but any geometry may be utilised. The event of the user clicking a hotspot can be easily linked to several possible functionalities, like presenting textural description, images, activating a link to other web pages, or even moving to a pre-defined point of view.

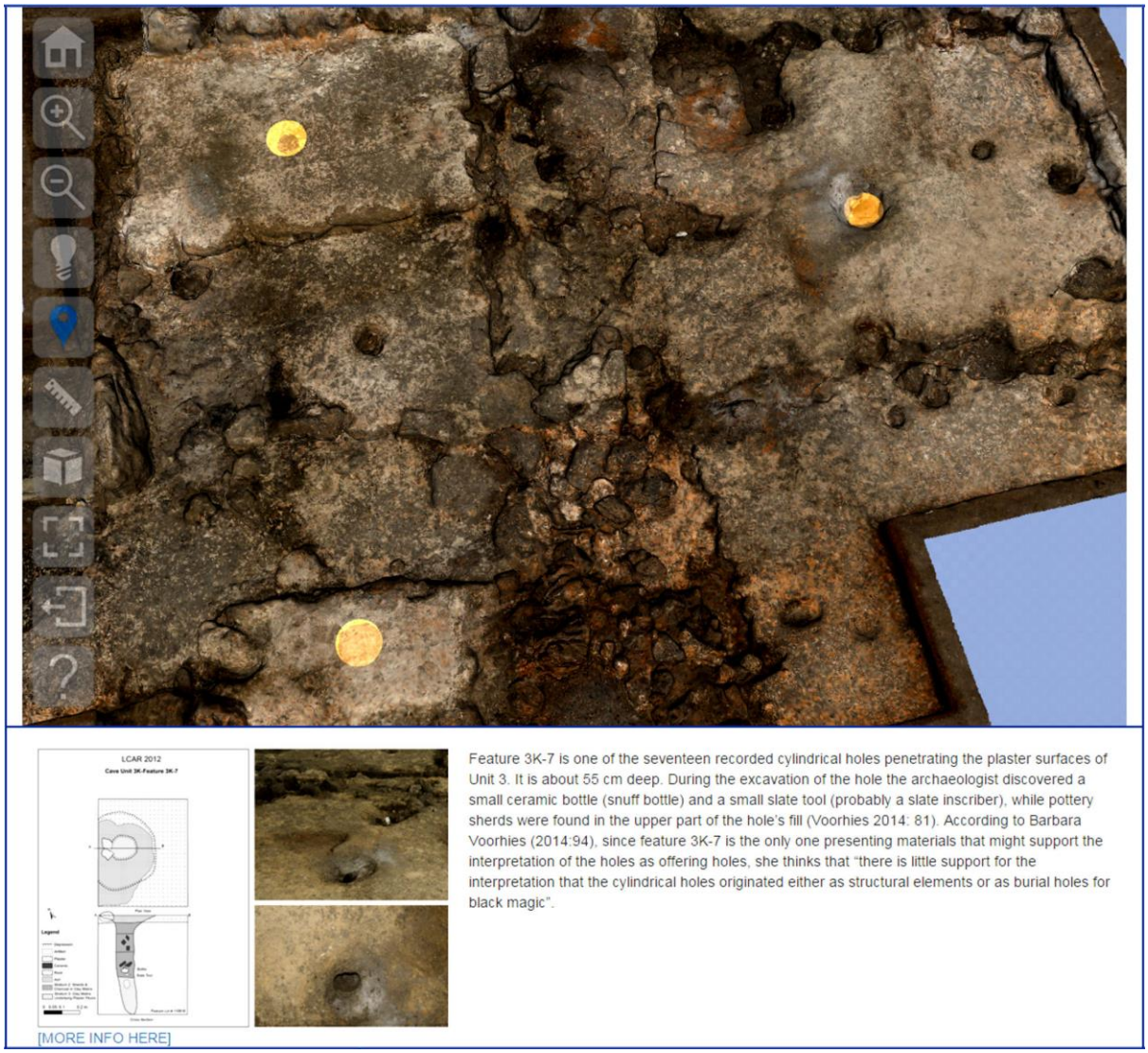

Figure 6. Screenshot of the *Stratigraphy 3D Viewer*: Units and finds selection tool (hotspots).

3.4. Measuring and section tools

Several operations that may be useful when excavating a site cannot be put in practice with the usual documentation. One of them is the possibility to take measurements directly on the geometry. Since 3D acquisition techniques (either active 3D scanning or image-based modelling) can provide accurate metric models of the excavation, a simple interactive measurement tool is part of the viewer (Fig. 7).

The measurement tool works in a very simple way: the user can pick two points on the models, and the corresponding point-to-point (Euclidean) distance is calculated. This simple tool can provide valuable information; other more advanced functionalities, like surface area, volume measurement, or "on-the-surface" length measurement (geodesic distance) will be added in the future.

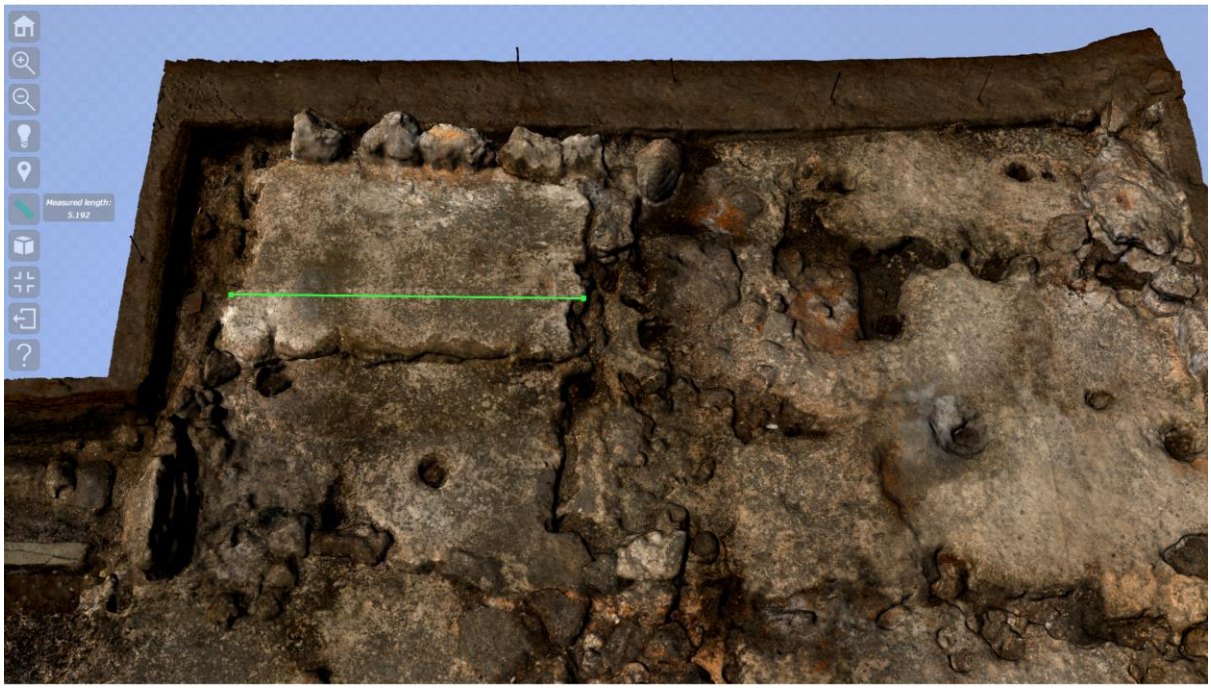

Figure 7. Screenshot of the *Stratigraphy 3D Viewer*: Measuring feature.

Working in the digital realm allows operations which are not possible when working on the site. One of these is the sectioning of the excavation, in order to compare the different layers and analyse their evolution.

The sectioning tool lets the user cut the stratigraphy along the three cardinal planes (the planes orthogonal to X, Y and Z); with a simple interface, the user may activate either one, two or all of three section planes at the same time, flip the section (cut the positive or the negative side of the plane), and move the plane(s) across the extent of the stratigraphy with a slider (Fig. 8).

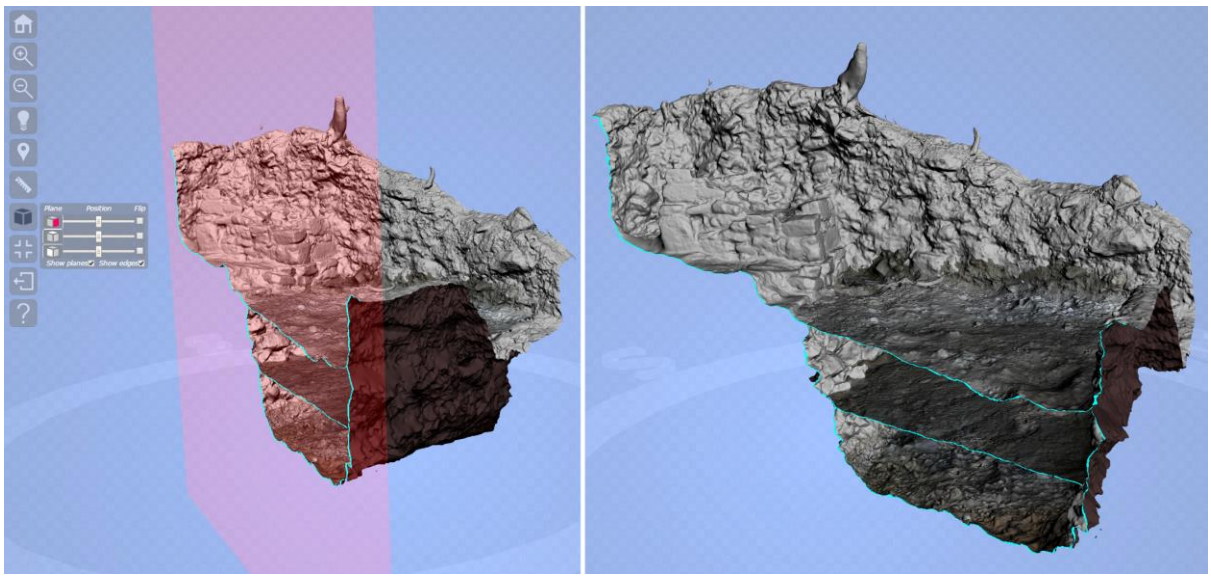

Figure 8. Screenshot of the *Stratigraphy 3D Viewer*: Sectioning feature.

3.5. Share view feature

The *share view* feature was also implemented for the Stratigraphy Viewer and works similarly to the corresponding feature of the Single Object Viewer. The user may share their current view with a colleague, who will be able to see the excavation from the same point of view, the same illumination and the same layer visibility and rendering parameters.

The idea is that the state of the visualization is exported as a string containing a series of couples *property:value*, and the link is provided in a format such as: http://www.domain/pagename. html?propetry1=value1&property2=value2

This solution follows the standard web protocol of webpage parameters. It enhances the capability to support remote collaborative work between scholars, favouring remote discussion of specific features/finds described in the 3D reproduction of the stratigraphic sequence.

4. Data capture and 3D data pre-processing preparation

The first stage of the implementation of the ADS 3D Viewer was 3D data optimization and conversion. The 3D data of the *3D Recording Las Cuevas* project were acquired using both active laser scanning and image-based modelling techniques, further processed using the open source software MeshLab (MeshLab 2015; Galeazzi 2015). 3D data were exported and archived in OBJ and PLY formats. Those initial data were standard triangle meshes encoded at a single resolution (the full quality model produced from the sampled raw data). As already presented before, the ADS 3D Viewer uses 3DHOP technology and thus the *Nexus* multi-resolution format (Nexus 2015). Therefore, input data have to be converted from plain PLY files to the Nexus format; this is accomplished entirely within Nexus with an automatic process. The data conversion is a pre-processing operation, which has to be performed once at the beginning of the page creation. The amount of time needed for the conversion is proportional to the size of the mesh: a 9M triangle mesh is processed in less than 10 minutes. There's is no need for strong hardware resources, being the process parallelized and characterized by low memory usage. Additionally, the Visual Media Service of the Ariadne EU Infrastructure (http://visual.ariadne-infrastructure.eu/) can provide a conversion in a web-service fashion.

Nexus builds the multiresolution encoding by applying controlled geometric simplification to small patches and stores all intermediate results in a data structure. Nexus supports also compression of geometric data and progressive transmission (view-dependent, driven by each specific rendering task). The view-dependent rendering engine allows production of an

optimal model for each single frame, by assembling different portions of the multi-resolution model on-the-fly and building view-dependent representations at variable resolutions (Potenziani et al. 2015). Thanks to the Nexus rendering library, the ADS 3D Viewer can render a large variety of 3D data, from low resolution models (manual or image-based modelling) to very high-resolution geometries (laser scanning or Structure-from-Motion technologies). Nexus support both triangulated meshes, textured meshes and point-clouds.

File-naming standards were developed to make data management and archiving as independent and compact as possible. File-naming is flexible and changes according to the excavation method used by each case study (i.e. arbitrary or stratigraphic excavation methods). For the *3D Recording Las Cuevas* project the data were preserved using a hierarchical description. The file name always starts with the name of the site and continues with unit (area) and level (layer/unit) numbers, e.g. LasCuevas_Unit1_Level3.

The webpage was designed in order to be re-usable: all the data definition, in terms of names of the files, names and ID of the layers, hotspots, and all the structured description of the stratigraphy are stored in a JSON JavaScript data structure. When the page is first loaded, the data structure is parsed and most of the page components are dynamically created, following the content of the structure. This structure may be easily edited, as it is human-readable, and it can also be generated directly from a database query. This, ideally, should make it easier to create other Stratigraphy Visualization pages. In order to make the visualization more effective, some excavations might need a specific set of features and some customization, but the strategy described in this paper can cover most of the standard situations, providing a reusable page template.

5. Sustainability

Working in the context of a digital archive requires sustainability to be at the forefront of every technical decision that is made. Whilst the ADS is less concerned with the sustainability of interfaces compared with the preservation of the underlying data, undertaking work on interfaces that have a short life expectancy makes little business sense. The official policy regarding the life-span of an ADS interface is that it should be functional for 10 years from creation and then supported under a ‘best-efforts’ basis beyond that. This is because the reality of working on the web is that interfaces beyond basic HTML can be difficult to maintain, given the rate at which web technologies change and in particular the variation and longevity in browser support. The issues around web sustainability can generally be alleviated by adhering to web standards. However, even technologies that adhere

to web standards can have inconsistent support across browsers, and relying on externally developed JavaScript libraries or frameworks can lead to problems when those libraries or frameworks are abandoned for whatever reason. The only time the ADS has been unable to sustain an interface was in regard to the ArcIMS mapping interfaces it developed between 2002 and 2007. Here the issue was due to the commercial and proprietary nature of the ArcIMS application produced by ESRI. When ESRI decided to discontinue support and licensing for ArcIMS in 2013 (effectively making the software unusable), it meant that all the ADS mapping interfaces that relied on ArcIMS were redundant. This lesson has led the ADS to pursue technologies that are not commercial or proprietary to help minimise the potential of a similar situation occurring again.

CNR has already demonstrated that sustainability and preservation of a 3D-enabled web repository is possible, with the development and maintenance of the CENOBIUM system (Corsini et al, 2010). This web system is a joint effort of Max Plank and CNR, started in 2006 and still alive and regularly updated (http://cenobium.isti.cnr.it/).

Therefore, the ADS 3D Viewers have been developed to ensure the greatest possible sustainability. Each interface is dependent upon HTML5, CSS, WebGL, and JavaScript, all standards with widespread support across most browsers. Therefore no plugins are required and any middleware or backend applications required for the ADS 3D Viewers implementation are proprietary or closed source. Likewise, the workflows and implementation have been designed to be as technology agnostic as possible, so middleware or applications currently used can be replaced as required. Because of all this, the interfaces will be usable and functional for many years, although there are variables outside of our control, such as browser support for WebGL and backwards compatibility for all technologies employed in this project.

Considering the long-term sustainability of the infrastructure, we decided to leave the file extraction and downloading at archive level. A link will direct the user from the 3D viewer interface to the 3D model's download page in the project archive. Since the 3D viewer allows the visualization of multiple 3D models archived as separate files, the downloading from the project archive instead than from the 3D viewer interface guarantees an easier management of the data and duration of the infrastructure. The metadata associated with the 3D data archived in ADS follow the Dublin Core metadata schema.

The ADS 3D Viewer open-source visualization platform could be easily adapted to other online repositories and extended to different stakeholders. This characteristics, which are the real strength of this platform, increases the transformative effect that this infrastructure will

have on the discipline. First, the ADS 3D Viewer is based on a documented open-source platform (3DHOP); therefore, managers of archaeological archives interested in replicating the experience of ADS can start from the same basic platform and implement the same or similar approaches. Moreover, there is a strong interest of ADS in sharing his experience and internal developments with the community: the work done to design and implement the two viewers presented in this paper can be shared with other archives, in case they found our solution effective. Due to the overall architecture of the basic 3DHOP platform, interfacing a different archive can be solved with a simple configuration fixing work.

6. Conclusions and future work

The ADS 3D Viewer infrastructure aims to contribute to an ongoing commitment of the European Research Council to support cyber-infrastructures which enhance and promote access to and preservation of European Cultural Heritage.

The ADS 3D Viewer is the first example of a web-based visualization system for the preservation and analysis of archaeological stratigraphy integrated within the framework of a trusted digital repository. One of the main strengths of the viewer is its flexibility and adaptability. As described above, the ADS Stratigraphy 3D Viewer can be adapted and applied to case studies that use different excavation methods (i.e. arbitrary or stratigraphic). Moreover the structure of the viewer and the partition of 3D data can be adapted to case studies that require different visualization and organisation of the archived data. In the case study selected for this research 2D and 3D data were organized and divided by excavation areas, but this can be easily changed if required by a specific project.

By increasing the accessibility of digital and metric 3D representations of the excavation process and facilitating the interpretations made by different scholars of the same context on the web, the ADS 3D Viewer will be a useful instrument for the remote, collaborative study of complex archaeological datasets, promoting the use of 3D representations for the analysis, interpretation and knowledge production in Archaeology.

One of the primary goals of the ADS 3D Viewer project was the development of a tool that could have a significant impact upon archaeological practice, integrating both traditional and innovative data acquisition methods. The ADS 3D Viewer will help us understand if the effective integration of 3D technologies in day-to-day fieldwork practice is really possible, favouring the ‘digital turn’ in the archaeological recording on site.

This study and its preliminary evaluation, however, suggest that future improvements to this research are necessary and they will take several forms. The adoption of an open-source 3D

visualization platform, rather than a commercial component, will allow ADS to further extend the supported features, addressing the specific needs of the community. Future extensions include the following: (1) The infrastructure developed so far enables the simultaneous and smooth visualization of the 3D models from the case study selected for testing the viewer (*3D Recording Las Cuevas Project,* consisting of a total of 6 high-resolution 3D models, Table 1). The ADS 3D Viewer will be further tested with more complex stratigraphic sequences to assess its performance and limitations. (2) Inclusion of support for managing annotations, to allow members of a working group to insert geo-localized comments. In the meantime it will be important to monitor user behaviour and feedback to assess if we have indeed met the challenge of visualising solid archaeological geometries.

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