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DIGITAL 3D INVENTORY FOR THE PROMOTION AND CONSERVATION OF THE ARCHITECTURAL HERITAGE

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ABSTRACT:

Heritage graphic representation combining building spatial location and urban/land planning supports the decision-making of government agencies and simplifies the development of protection and conservation projects. The evolution of web-based open-source representation systems, able to store 3D graphics information and to make it accessible by web platforms, allows to develop novel heritage catalogues which simplify the exchange of information between administrations and citizens. This work is devoted to the creation of the Digital 3D Inventory of the Aragonese Mudéjar Architectural Heritage, a list of 225 buildings with unique architectural elements which are part of the UNESCO World Heritage. We propose a generalized methodology for collecting, store and disseminate friendly 2D geospatial and 3D geometric documentation of the historical buildings, ensuring that valuable information is stored and providing greater graphic and documentary resources than traditional inventories of architectural heritage. The main novelty is creation of a web platform which allows the exploitation of the architectural information through a cartographic webGIS viewer and a 3D environment based on webGL for rendering large point clouds. The proposed web platform enables to delivery 3D content through generic web browsers natively supported by all devices and without installing third-party applications neither downloading massive data files.

1. INTRODUCTION

Heritage graphic representation combining building spatial location and urban/land planning provides a powerful tool for government agencies. These techniques support the decision-making, simplify the development of protection and conservation inventories and allow the treatment of buildings from an integral urban/land scale view. From a technical perspective the representation of information at various detail levels, and involving different types of data and supports, provides a complete vision with multiple applications. Furthermore, this graphical representation of historical buildings offers an informative contribution that can be used to promote the architectural heritage with educational and touristic purposes.

The evolution of web-based open-source representation systems, able to store 3D graphics information and to make it accessible by web platforms, allows to develop novel heritage catalogues which simplify the exchange of information between administrations and citizens. Furthermore, new web-based developments aim to include real-time information, multiple data-base interaction and user-friendly graphics environments, but also taking into account the OS flexibility, the treatment of multiple data formats, the security updating, the cost reduction and the user feedback (Myers, 2016).

Regarding architectural heritage, the so-called Mudéjar is a unique style from the Iberian Peninsula and represents the influence of the Muslim Andalusi culture in art and architecture between the 12th and 17th centuries within the territories conquered by Christians. The Autonomous Community of Aragón was one of the most influenced territories and hence the Aragonese Mudéjar gained its own peculiarities that differentiate it from the rest of the territory (Borrás Gualis, 1985). Thanks to the mixture of styles and cultures, on December 14, 2001, some representative Aragonese Mudéjar buildings were declared as World Heritage Sites by UNESCO.

Figure 1. Some of the most representative buildings of the Aragonese Mudéjar Heritage.

In the field of architecture, the typologies of fortress-churches and single-nave churches with a polygonal apse and simple ribbed vaults are representative from the Aragonese Mudéjar. The bell towers have a characteristic structure, with a morphology similar to that used in the minarets of Muslim mosques. They are made up of two towers, one surrounding the other and with a staircase in the middle of them, crowned

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with a polygonal bell-shaped tower (Figure 1). The use of traditional materials such as brick, plaster, stucco, ceramics and wood in the construction processes and the use of geometric shapes and plant themes for ornamentation also stand out, derived directly from the muslin tradition (Borrás Gualis, 1985, Quintilla-Castán, 2022).

This work presents the development of a 3D digital system to document and inventory the Mudéjar architectural style in Aragón, involving a list of 225 buildings with unique architectural elements which are part of the World Heritage. This digital inventory includes not only administrative, historical and artistic description for each of the included buildings, but also 2D and 3D graphic representations and associated technical information on a accessible and user-friendly web environment. This paper is structured as follows: Section 2 is devoted to the procedure and methodology for creating the digital inventory of the Aragonese Mudéjar; in Section 3 the main features, capabilities and future possibilities of the web-based tool are detailed; and finally, the main conclusions are summarized in Section 4.

2. METHODOLOGY

The development of useful graphic representations of the architectural heritage requires to exceed the classical inventory description level and to design graphical environments able to contain further information about the cultural assets. It is necessary to clarify a methodology to collect, organize and disclose information to common users and urban managers following a standardized procedure. Regarding the structure of the information and the data base content, it is necessary to embrace international standards, such as the Core Data Index to *Historic Buildings and Monuments of the Architectural Heritage*, in order to define a base list of required data fields and the suitable syntax for them. The content of the data fields must be also standardized using ontologies and thesaurus. The most widespread for the cultural heritage documentation is the *CIDOC Conceptual Reference Model* but also the *Thesaurus for Art and Architecture* elaborate by the Getty Institute should be considered.

First, administrative, descriptive and historical information was collected for each one of the Mudéjar buildings included into the UNESCO World Heritage Sites declaration. Furthermore, geospatial data, urban planning information, photographies and data regarding the relation of the Mudéjar building within its urban environment were also included. This information was structured following standardized criteria and stored in digital sheets, creating a complete descriptive inventory of the Aragonese Architectural Heritage. For each building, these data include the identification and UTM geolocation, its historical evolution, the protection level, geometrical and constructive characteristics, the state of conservation conservation and future required actions, as well as graphical information. This data base stores multi-disciplinary information within an organized structure which allows technical, educational and promotion applications. Figure 2 shows, as example, the digital sheet created for the Santa María church in Tobed (Spain). This structured digital inventory ensures that the information lasts organized over time, as well as helps to design conservation measures and promotions actions (Quintilla-Castán, 2021).

Second, 3D digital models were created for some of the most representative buildings included into the UNESCO World


7-INM-ZAR-020-255-001

01_IDENTIFICACIÓN

Denominación: Iglesia de Santa María
Código: 7-INM-ZAR-020-255-001
Categoría: Religiosa
Tipología: Iglesias

02_LOCALIZACIÓN

Provincia: Zaragoza
Comarca: Comunidad de Calatayud
Municipio: Tobed
Localidad: Tobed
Dirección: Plaza la Virgen, 16
Coordenadas geográficas: 41,33852; -1,40056
Catastro: 3977303XL3737H

03_DESCRIPCIÓN

Iglesia de nave única de tres tramos y testero recto con capillas abiertas a la nave mediante arcos ojivales y capillas entre las torres-contrafuertes con estructura de alminar almohade. Los tramos principales se cubren con bóvedas de crucería mientras que los de separación se cubren con cañón apuntado que apoyan en las torres-contrafuertes. Estas torres son, junto a la tribuna o andador, los elementos que dan el carácter defensivo-militar a la Iglesia. La decoración exterior se compone de paños de ladrillo resaltado formando bandas con motivos geométricos y bandas de azulejos en punta de flecha. La decoración interior es a base de pintura y agramilados en los muros y celosías muy elaboradas en los vanos y óculos.

04_DATACIÓN E HISTORIA

Construcción: Edad Media-S. XIV-1356-1385, Mudéjar.

Restauración: Desde Edad Contemporánea-S. XX-1986-1991, fachada oeste del templo, saneamiento y drenaje. 2001-2004, restauración integral. 2006, retablo de la Virgen, en la capilla mayor, el retablo de Cristo y el retablo de San José.

05_PROTECCIÓN

Clase: Bien de Interés Cultural
Categoría: Monumento
Patrimonio Mundial de la UNESCO
Historial administrativo: Declaración. Resolución: 03/06/1931. Publicación: 04/06/1931
Número de expediente:

Figure 2. Digital sheet containing descriptive and graphical information for the Santa María church (Tobed, Spain).

Heritage Sites declaration. Laser scanning and UAV aerial photogrammetry techniques were used to create a complete high-resolution 3D point cloud of the interior rooms, façades and roofs of the building. The photogrammetric images of the roofs were recorded using a Phanton 3 UAV which includes a 12.4Mpx CMOS camera and a GPS positioning system. The reconstruction of the photogrammetric data was carried out using the software Metashape (Agisoft). The laser scanner Faro Focus 150 allowed to obtain multiple high-density overlapping points clouds inside the building and from the façades. The laser scanner device includes GPS positioning and offers geometrical measurements with a spatial resolution of $6\,mm$ within a distance range from $0.6\,m$ to $130\,m$ and with $\pm 2\,mm$ accuracy. Data coming from both the laser scanner surveys and the UAV fotogrammetric measurements were geo-referenced and combined using the software package Recap (Autodesk) into a raw point cloud with size up to 120 millions points.

This raw point cloud obtained from the laser scanning and the UAV photogrammetry was post-processed using the open-source desktop application Cloud Compare (Cloud Compare, 2022). In this post-processing stage, duplicate points were neglected and small missing-data holes were interpolated. The point cloud was sub-sampled with a spatial resolution of $20\,mm$ for general parts and $10\,mm$ for significant architectural elements. Furthermore, the resultant point cloud is segmented into significant architectural elements, creating a new point attribute related to the architectural element identification (Figure 4). The final results is a high-density 3D point cloud of 26 million points which stores RGB color information and the element identification attribute for each geometrical point. Figure 4 shows a general view of the result point cloud for the Santa María church in Tobed (Spain).

Figure 3. Segmentation by architectural element of the raw point cloud collected inside the Santa María church (Tobed, Spain).

Figure 4. Final 3D point cloud of the Santa María church (Tobed, Spain).

In order to make the inventory accessible for end-users and administrations, a geospatial web platform has been developed to organize and show architectural data of the buildings collected during the previous stages. The 2D geospatial data and the 3D point cloud model have been enriched with the descriptive information provided by the digital inventory sheets. The proposed web platform allows the dissemination and exploitation of the architectural information by different users through a website that integrates a cartographic viewer (WebGIS) and also offers access to a point cloud manager based on WebGL (Di Benedetto et al., 2014). The geospatial structured data are accessible through an interface with different visualization styles that are adaptable depending on the purpose, such as technical studies, reconstruction actions, informative campaigns, etc., opening up the possibilities of use of the available information (Molero-Alonso et al., 2016). Furthermore, the 3D point cloud viewer supports the creation of a user-friendly repository of geometric information of the registered heritage assets (Figure 5).

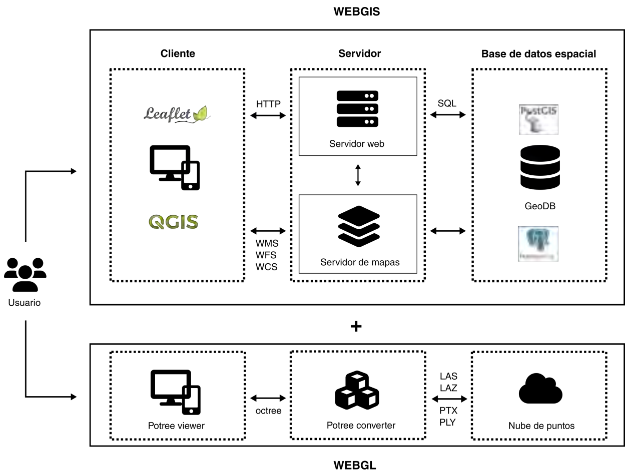

Figure 5. Conceptual structure of the web platform created for the Aragonese Mudéjar Inventory.

3. 3D DIGITAL INVENTORY

For the development of the Digital Inventory of the Aragonese Mudéjar Architectural Heritage, the 2D geospatial data have been enriches with the descriptive and complementary information regarding the building geolocation, the architectural description, the urban planning and the relation with the surrounded area available in the digital inventory sheets. The creation, edition, managing and visualization of the 2D geospatial information was performed using QGIS (QGIS Development Team, 2022), a multiplatform Geographic Information System which allows the manipulation of raster and vectorial data sets. QGIS uses PostGIS (PostGIS, 2022), a spatial database extender for PostgreSQL (PostgreSQL Global Development Group, 2022), which allows the creation of attribute tables with geometric and spatial information and the analysis of the information by spatial SQL queries. A geo-data base (Geo-DB) of the Aragonese Mudéjar Heritage assets was created and exported including all the complementary information for each building (Figure 6).

The JavaScript library Leaflet (Leaflet, 2022) is used to create a webGIS platform which make available the 2D spatial information to the end-users (Figure 7). The documentation is shown with different levels of detail (LoD), allowing the representation of the same heritage object in multiple scales and resolutions simultaneously. This provides an easy and efficient access to the heritage data, reducing the loading time and the required compression for the data formats (Scopigno et al., 2017). The geospatial information is organized from the most generic scale to the smallest level of detail. The Spatial Data Infrastructure (SDI) standardized services offered by the

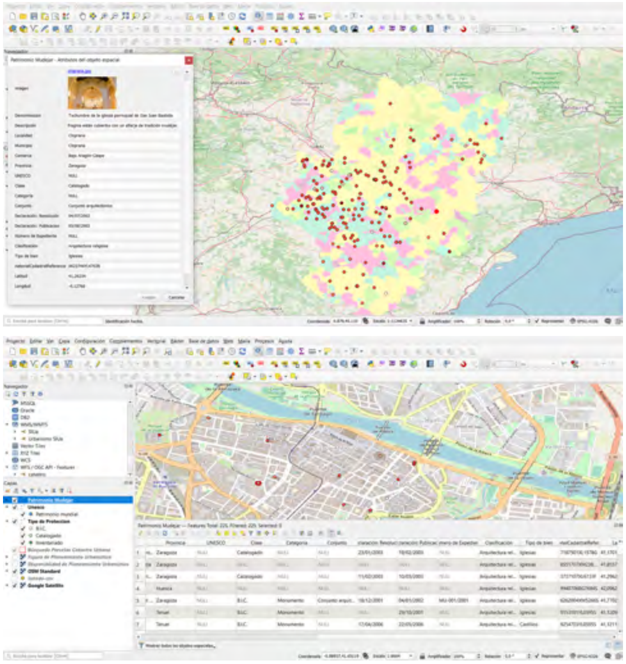

Figure 6. Creation of the Aragonese Mudéjar Geo-DB in QGIS.

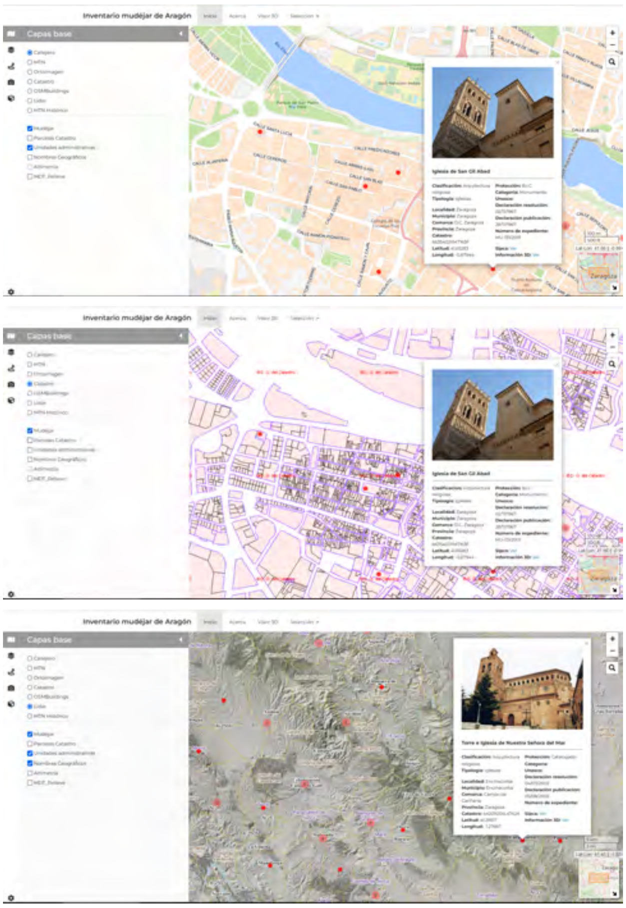

Figure 7. WebGIS viewer including (top) the street base map, (center) the cadastral plane and (bottom) the LIDAR layer, together with the lateral main menu and the pop-up building descriptive information.

Spanish National Geography Institute (Instituto Geográfico Nacional. Gobierno de España, 2022), the Land Registration Office (Sede Electrónica del Catastro. Gobierno de España, 2022) and the Aragonese Spatial Structure Data (Infraestructura de Datos Espaciales de Aragón IDEAragon. Gobierno de Aragón, 2022) have been used to support the 2D geospatial architectural information. The 2D spatial data have been included in the webGIS viewer through OGC standardized formats, such as WMS (Web Map Service) and WMTS (Web Map Tile Service), and referenced to the ETRS89-UTM 30 coordinate system.

Figure 7 depicts examples of the 2D geospatial and descriptive information available through the webGIS viewer. The following geospatial layers have been included: Street base (Instituto Geográfico Nacional. Gobierno de España, 2022), National Topographic Map (Instituto Geográfico Nacional. Gobierno de España, 2022), Orthophoto images (Instituto Geográfico Nacional. Gobierno de España, 2022), Cadastral plane (Sede Electrónica del Catastro. Gobierno de España, 2022), OSM Buildings layer (OpenStreetMap Foundation, 2022), LIDAR data (Instituto Geográfico Nacional. Gobierno de España, 2022) and urban planning layers (Infraestructura de Datos Espaciales de Aragón IDEAragon. Gobierno de Aragón, 2022).

Furthermore, the lateral menu allows to access to tourist itineraries related to the Mudéjar Heritage (Territorio Mudéjar. Diputación de Zaragoza, 2022) and to the 360° photography catalogue created by the Aragonese government (Zaragoza Provincia 360. Diputación de Zaragoza, 2022) which includes some of the most representative Mudéjar buildings (Figure 8).

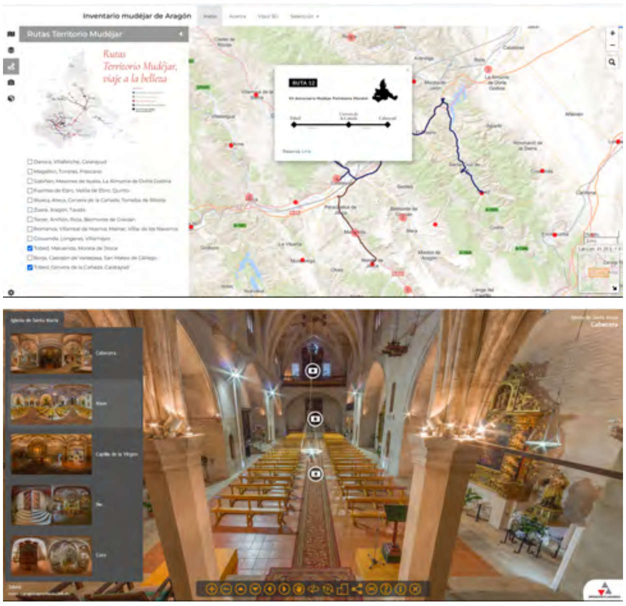

Figure 8. WebGIS viewer including (top) tourist Mudéjar itineraries and (bottom) the 360° photography of the Santa María church (Tobed, Spain).

The 3D point cloud of the historical building is made available by means of an interactive webGL environment designed using the Potree library (Potree, 2022). The Potree library provides not only viewer functions but also the converter tool which allows to translate the point clouds obtained using laser scanner and aerial photogrammetry (LAS, LAZ, PTX or PLY) to the octree data structure required by the Potree viewer.

This webGL environment is accessible from different elements of the webGIS platform, as the lateral main menu or the pop-up descriptive sheet of each Mudéjar building. The Mudéjar building point cloud is rendered over a base layer created using CesiumJS (Cesium, 2022), an open-source JavaScript library for streaming 3D tiles, and the Open Street Map source layer (OpenStreetMap Foundation, 2022). Traditionally, presenting models to the end user required transferring large amounts of data and installing third-party applications to view it (Martinez-Rubi et al., 2015). However, this point cloud viewer is based on the WebGL technology which enables the delivery of 3D content through web browsers without and installing third-party applications and which is natively supported by all devices (Schütz, 2016). Figure 9 shows the main view of the webGL environment for the the Santa María church (Tobed).

Figure 9. WebGL environment with the 3D point cloud of the Santa María church (Tobed, Spain) over the OpenStreetMap layer.

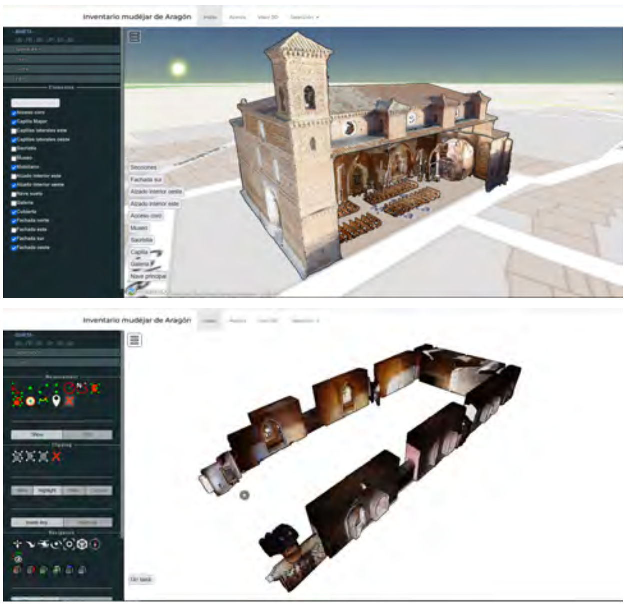

Figure 10. WebGL environment: (top) lateral check-boxes used to segment the complete point cloud in the main viewer window and (bottom) secondary viewer window created for the 3D point cloud of the superior gallery.

In the lateral main menu of the webGL environment, a check-boxes list allows to show/hide the different architectural elements in which the complete 3D point cloud has been divided during the post-processing stage in Cloud Compared (Cloud Compare, 2022). This allows explore the historical building with more detailed perspectives (Figure 10).

Furthermore, different link buttons appear at the right side of the webGL main window, which link to single 3D point clouds created for the some of the most representative architectural elements of the Mudéjar building. The navigation between the main building point cloud and the secondary point clouds created for the significant architectural elements is always possible thanks to *ad-hoc* buttons placed at the right side of the main webGL viewer window.

Figure 11. WebGL environment: point cloud visualization of the Santa Tecla church (Cervera de la Cañada, Spain) with different rendering features.

The lateral main menu of the webGL environment allows to control the rendering features of the 3D point cloud, such as the point budget (number of points rendered), the background color, the edge-dome-lighting characteristics, the rendering quality and the field of view angle, improving the visualization of massive points clouds and the loading time. Figure 11 shows the view of the 3D point cloud collected for the Santa Tecla church (Cervera de la Cañada, Spain) with different rendering features. The correct selection of the point budget and the rendering quality is essential for improving the visualization without requiring an marked increment in the loading time.

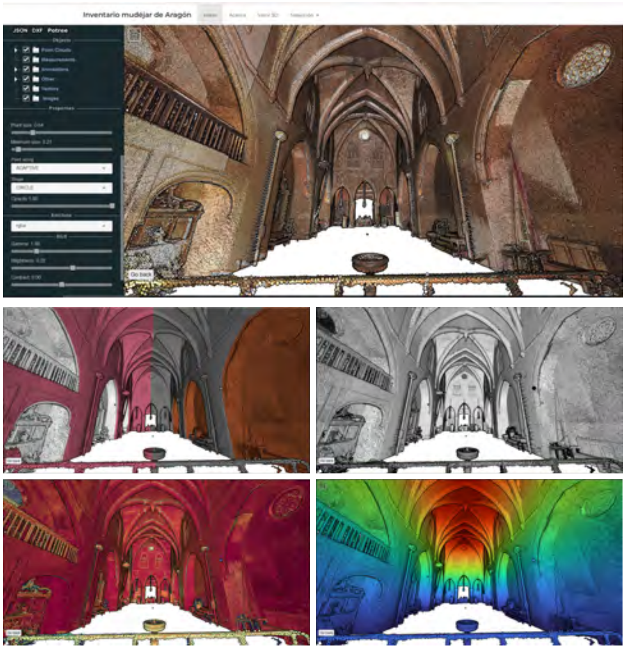

Figure 12. WebGL environment: rendering of the Santa María church (Tobed, Spain) using (top) RGB color, (middle left) architectural elements, (middle right) scanner intensity, (bottom left) intensity gradient and (bottom right) elevation.

Furthermore, the lateral main menu also allows to control specific characteristics of the individual three-dimensional points, such as the shape, size, brightness, contrast and gamma. But also different point attributes can be selected for visualization. Figure 12 shows the rendering of the Santa María church (Tobed, Spain) using different point attributes. This feature opens the possibility to include spatially distributed technical data into the 3D point cloud, allowing the digital inventory can be used for conservation and management projects. However, the addition of new attributes into the information stored in the the geometrical points is not straightforward and requires specific tasks during the point cloud post-processing stage, as well as re-programming the Potree libraries in order to be able to show this new attributes in the webGL viewer.

Besides the visualization possibilities, one of the main technical features of the webGL environment based on the Potree library is that it provides support to measure real angles, distances, heights, areas and volumes over the 3D point cloud (Figure 13–top). This feature allows the digital inventory can be applied to elaborate restoration and construction projects. Moreover, the webGL viewer can also be used to extract 2D constructive sections from the 3D point cloud interactively (Figure 13–bottom). These tools supported by the webGL environment improve the collecting of the building geometrical features and promote a suitable and innovative application of the obtained 3D models. This application solves partially the difficult task of generating realistic geometrical documentation for construction and restoration projects in historical buildings.

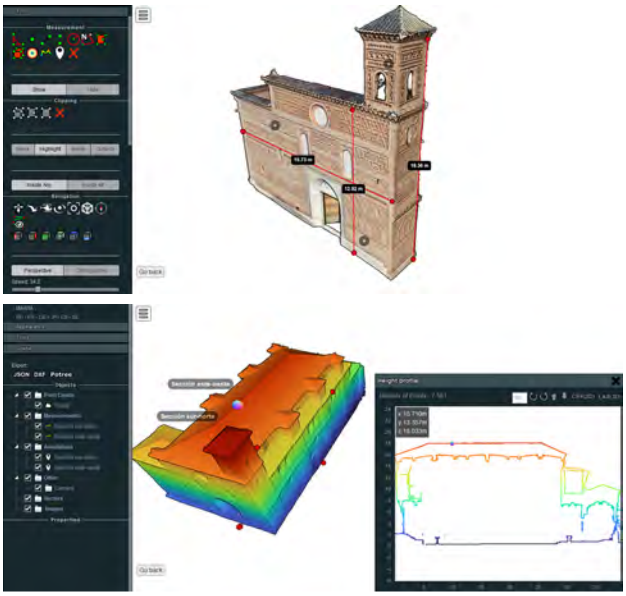

Figure 13. WebGL environment: .

Additionally, the high-resolution point cloud model is also used as support where the complementary data provided by the different technicians involved in the documentation process can be incorporated. The annotation tool provided by the webGL environment is used to associate graphical and descriptive information to differenced 3D architectural elements within the point cloud of the historical building (Figure 14). This complementary information can consist of descriptions, images, schemes, documents, links, etc. This helps to analyse the architectural information easily by the creation of thematic documentation layers within the 3D model. Furthermore, the annotation tool allows to specify the camera position, allowing to remark specific parts of the 3D model related to the associated information.

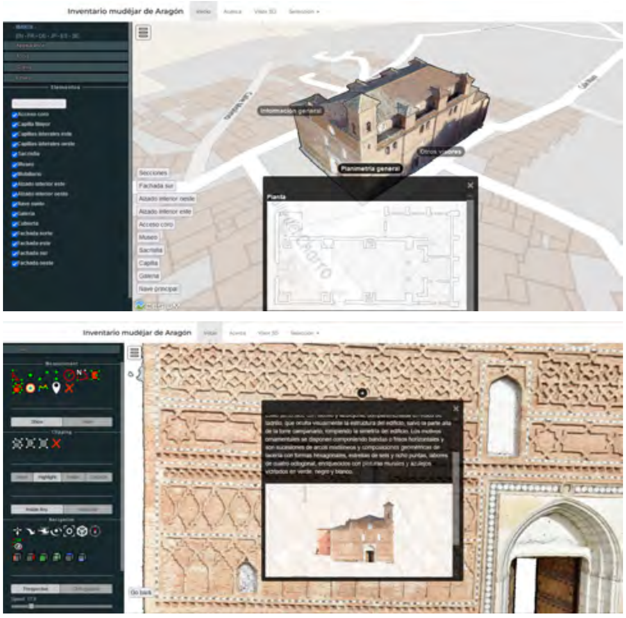

Figure 14. WebGL environment: examples of complementary information associated to (top) the general point cloud view and (bottom) an specific architectural element.

4. CONCLUSIONS

This work is focused on creation of the Digital 3D Inventory of the Aragonese Mudéjar Architectural Heritage. This consists of a digital repository with graphic material composed of photographic and 2D/3D volumetric information, which forms a complete documentation of the geometry of the building and achieves the correct characterization for metric or informative purposes. The proposed methodology for the geometric documentation of the Aragonese Mudéjar buildings ensures that valuable information is stored and provides greater graphic and documentary resources than traditional inventories of architectural heritage. The digital graphic inventory of the Mudéjar Architectural Heritage in Aragón can be consulted through the web address `https://www.inventariomudejar.es/`.

The methodology proposed is divided into three stages and works as a generalized work-flow for the creation of digital inventories of the architectural heritage. During the first, complementary information is collected for each of the historical buildings included into the heritage inventory. This information must include description and geolocation, 2D geospatial data, urban planning information, photographies, historical evolution, the protection level, geometrical and constructive characteristics, the state of conservation conservation and future required actions. In the second stage, a 3D digital point cloud model of the historical building is created using laser scanning and UAV aerial photogrammetry techniques. This 3D model is post-processed using open-source tools. The complete 3D data are sub-sampled and the point cloud is segmented into architectural elements. The final results is a high-density 3D point cloud segmented by architectural elements which stores RGB color information and other attributes for each point. In the third stage, a geospatial web platform has been developed to organize and make accessible the architectural data of the building to end-users and administrations.

The proposed web platform allows the dissemination and exploitation of the architectural information through a website that integrates a cartographic webGIS viewer and also offers access to a 3D environment based on WebGL for rendering large point clouds. QGIS and PostGIS allow the creation of attribute tables with geometric and spatial information and the analysis of the information by spatial SQL queries. The JavaScript library Leaflet is used to create the webGIS platform which make available the 2D spatial information to the end-users. The 3D point cloud of the historical building is made available by means of an interactive webGL environment designed using the Potree library. The WebGL technology enables the delivery of 3D content through web browsers without and installing third-party applications and which is natively supported by all devices. The tools supported by the webGL environment improve the collection of the building geometrical features and solves partially the difficult task of generating realistic geometrical documentation for construction and restoration projects in historical buildings. Furthermore, demonstrated to be a suitable tool for a friendly dissemination of the architectural heritage to end-users.

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