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Generation of a digital archive of heritage, with drones in rural areas

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The enhancement of heritage, both cultural and natural, must be considered as a resource for revitalizing the territory. In this context, Aragon has a great landscape and cultural heritage that is scattered throughout the territory and is not very accessible. It needs to be properly documented and inventoried as a means of activating new processes of knowledge, enhancement and use of rural development. This work is devoted to the creation of the Digital 3D Inventory of the Aragonese Mudejar Architectural Heritage, which includes buildings that currently have little graphic and imprecise documentation, since many of them are located in small towns of less than 500 inhabitants, with urban fabric of narrow streets. To carry out the registration, the use of drones to capture images and later the construction of the point cloud with photogrammetry, it is an adequate technical and economically sustainable solution since it deals with populations plagued by depopulation and with few resources. A generalized methodology is proposed to collect, store and disseminate 2D/3D geometric and geospatial documentation of inventoried buildings, providing more graphic information than traditional architectural inventories. As a novelty, for the dissemination of information, the creation of a web platform composed of a cartographic viewer (WebGIS) and a point cloud manager based on WebGL technology is proposed as a valuable tool to relate buildings with their environment, characteristic of great importance in the case of heritage located in rural areas.

Keywords:
Architectural heritage; Heritage inventory; WebGIS; WebGL; Rural areas

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INTRODUCTION

The Community of Aragon is located in a strategic location in the northeast of Spain, equidistant from the most important cities (Madrid and Barcelona) and the south of France. However, despite its key location, it is characterized by the unequal distribution of the population in the territory. The capital, Zaragoza and its surroundings, brings together more than 50% of the population in front of an extensive territory with a large number of scattered settlements and a reduced and aging population density. This situation causes rural environments to suffer from large imbalances, with a basic provision of equipment and a high cost of services. To reverse the trend, the administration promotes territorial development actions with the aim of establishing the young and female population. For this, access to training is required, as well as the promotion of innovation and entrepreneurship through the attraction of professionals to establish a qualified population in the territory (Gobierno de Aragón, 2014).

Likewise, territorial development is influenced by heritage, which includes both cultural and natural heritage elements. Heritage management stands out as a fundamental economic resource as a means of establishing population as well as promoting cultural construction by promoting its conservation. For this reason, it should be considered as a resource that is part of the territorial system that constitutes a dynamic factor from an economic and cultural point of view.

Aragon has a great landscape and cultural heritage that can be used as a means of rural development through the promotion of tourist activities that help in the conservation of cultural assets. In the specific case of architectural heritage, there is a legal framework that promotes the integration between the different types of heritage, be it cultural, territorial or landscape, with the aim of promoting its safeguarding and protection through its cataloguing and declaration of cultural interest. To achieve this goal, it is a priority to have a properly inventoried and documented cultural heritage that allows knowing its current state to be able to act in any of the uses and needs that can be made of them for purposes of dissemination, promotion, conservation, rehabilitation or management between others.

The study area concentrates a large list of assets, an example of the Mudejar heritage, exclusive to the Iberian Peninsula, whose era ranges from the 12th to the 17th century. While Gothic predominates in the Christian West, Mudejar art is developed in Aragon, a reflection of the survival of Muslim culture in the peninsula and with its own peculiarities in the Aragonese territory (Fig. 1). The first samples of Mudejar date from the middle of the 13th century and extend until the end of the 15th century. From the 16th century its decline began, although there are survivals until the 17th century, after the expulsion of the Moorish.

The geographical characteristics of the Aragonese territory represent a natural barrier to the diffusion of artistic styles. In order to analyze the distribution of Mudejar architecture in the territory, it is necessary to compare the information with the distribution maps of the Moorish and Mudejar population (Borrás, 1985). These settle mostly around the Ebro river valley and its tributaries, mainly in the southern ones on the right bank and with greater density in the low plains (Lacarra, 1960). The monuments are concentrated in large urban centers (→ 5,000 inhabitants) such as Zaragoza, Calatayud, Teruel, Tarazona, Daroca or Borja, which acommodate 21% of the Mudejar buildings inventoried, however, the highest percentage of buildings (52%) are located in rural areas close to them, whose population is less than 500 inhabitants and are scattered throughout the territory. Despite this, they preserve the main monuments representing the Aragonese Mudéjar, such as the churches of Torralba de Ribota, Cervera de la Cañada, Belmonte or Tobed. Some of the assets are especially representative with unique architectural elements and are part of the World Heritage. This situation requires a complete re-

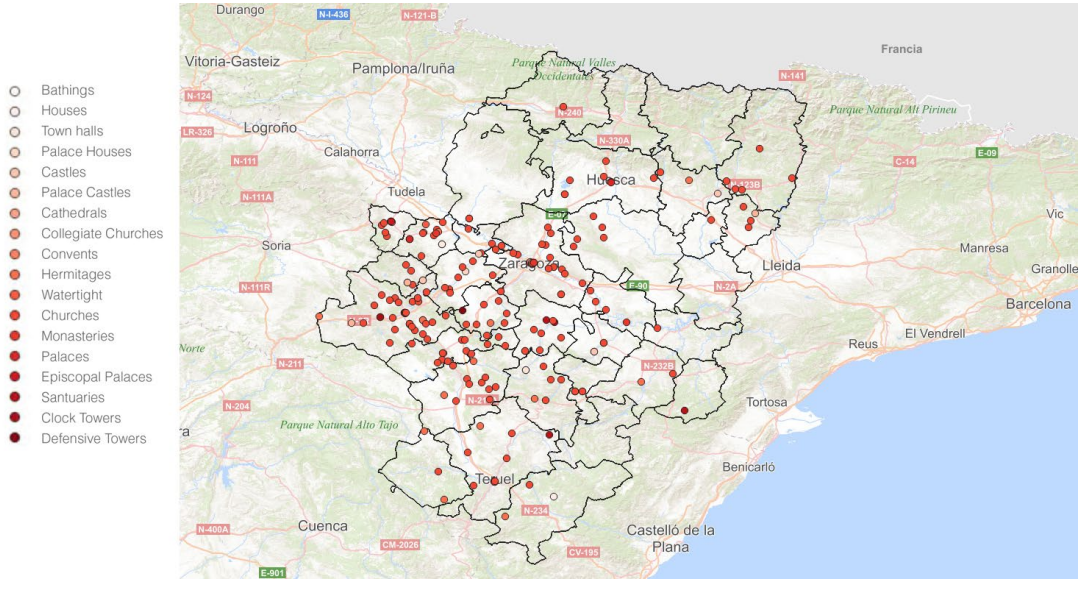

Fig. 1 - Location of the buildings that are part of the list of inventoried Mudejar assets.

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cord of the Mudejar Architectural Heritage, a database that can incorporate information related to identification and location, historical data, type of protection, geometric and construction characteristics, state of conservation and types of intervention; a common support that allows to contain all the available materials of a patrimonial asset (Fig. 2). The differentiating element of the inventory to be carried out is the inclusion of two-dimensional and three-dimensional graphic documentation that will provide more information regarding the registered buildings in a digital and accessible environment.

DOCUMENTATION OF HERITAGE IN RURAL AREAS

The graphic representation of architectural heritage through the combination of spatial and urban/territorial planning information, together with descriptive and dimensional information of buildings, provides a powerful tool for local and regional administration. The ability to represent information at various levels of detail, including various types of data and media, offers a comprehensive view of heritage with multiple applications. It provides the necessary tools to carry out inventories of architectural heritage with the aim of promoting tourism, the economy, protection and conservation.
In this context, to carry out the inventory of the Mudejar Heritage, it is proposed to establish a methodology to collect, store and disseminate 2D spatial information and 3D geometric information, in order to favor the execution of analyzes by relating the heritage element to its immediate environment. The objective is to obtain a complete inventory that provides greater documentary and graphic resources than those used up to now by the local administration.
The choice of the methodological process to register the Mudejar monuments is driven by the need to document and inventory the architectural heritage scattered throughout the territory and not very accessible as a means of activating new processes of knowledge, enhancement and use. The inventory of Mudejar Architecture includes buildings

Fig. 2 - Partial index of buildings that are part of the inventory of the Mudejar Architectural Heritage of Aragon.

that currently have little graphic and imprecise documentation, since many of them are located in small towns with fewer than 500 inhabitants, with an urban fabric of narrow streets. The integration of the building in intricate urban fabrics and sometimes located in landscapes and topographies with limited access, requires the choice and combination of techniques and digital representations capable of recording the heritage and its surrounding environment with the precision and detail required (Liuzzo et al., 2020).The application of unmanned aerial vehicles (UAV) equipped with digital cameras has proliferated in recent years as a useful tool in the field of heritage, thanks to its ability to cover large areas in a short period of time. The functions of flight planning, stabilization, control and management, collision prevention and the equipment with cameras that have the latest technologies, have favored their use for the documentation of architectural heritage in rural environments, since these are populations hit by depopulation and with few resources. It is an economical solution, minimally invasive and very suitable for rural areas, where there are no roads or technological conflicts and UAV technology can be used without impediments (Fig. 3).

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Fig. 3 - Photograph taken with an unmanned aerial vehicle (UAV) of the exterior of the Church of San Félix (Torralba de Ribota).

To carry out the registration, the combination of the use of drones to capture images with laser scanner technology to complete the information is an easily replicable procedure with reduced time and cost (Lo Brutto et al., 2014; Achille et al., 2015; Fatta et al., 2017). It is an appropriate and economically sustainable technical solution suitable for capturing architectural elements that are difficult to access (Centofanti et al., 2018; Mascort-Albea et al., 2014) that require great detail and precision (Barba et al., 2019; Diara y Roggero 2022) for documentation in widely varied application contexts, such as tourism and promotional purposes (Sestras et al., 2020), conservation and protection (Tache et al., 2018; Croce et al., 2019), maintenance and management (Parrinello et al., 2019).
The use of digital photography through the use of drones for the documentation, survey and modelling of heritage, has favored the "democratization" of the dissemination of three-dimensional geometric models through applications and web repositories (Brusaporci et al., 2020). Through the use of 3D graphic information representation systems of heritage accessible through web platforms, it is possible to develop heritage catalogues that help disseminate and exchange information between administrations and citizens (Germanese et al., 2019; Parrinello y Dell´Amico, 2019). In addition, the combination of these applications with geographic information systems is a valuable tool for relating buildings to their surroundings, a characteristic of great importance in the case of heritage located in rural areas (Domínguez-Ruiz et al., 2020; Castilla et al., 2021).

Fig. 4 - Examples of some of the representative buildings of the Mudejar of Aragon located in rural areas. Church of Santa María (Tobed), Church of Santa Justa and Santa Rufina (Maluenda), Church of Nuestra Señora del Castillo (Aniñón).

CASE STUDY: MUDEJAR ARCHITECTURE IN ARAGON

The Aragonese Mudejar has differentiating characteristics with respect to the rest, due to the influence of the Catalan Gothic, Renaissance formulas, the adaptation of Islamic structures, the creation of new architectural forms and the development of a unique ornamental style (Condor, 2010). This singularity arose as a consequence of the isolation following the Christian conquest, Huesca in 1096, Zaragoza in 1118 and Teruel in 1171. However, the city of Teruel, close to the Levante area, fostered the connection with Almohad Muslims with a ceramic tradition, who settled in the city and manufactured glazed and painted pieces that are characteristic of the Mudejar of the area, as can be seen in the towers of San Martín and El Salvador de Teruel. In addition, the scarcity of stone quarries in the Ebro valley area influenced the use of brick as a construction and ornamental material, due to the abundance of sedimentary soils.
Mudejar art stands out for several characteristics, such as ornamentation, the survival of structures derived from Islamic art and a set of its own materials such as brick, plaster, ceramics, wood, and to a lesser extent alabaster and lime, due to due to its low cost and ease of obtaining (Fig. 4).
Mudejar ornamentation is made up of motifs from the Islamic tradition, such as stylized plant elements (ataurique), geometric elements (bows, stars) and Arabic epigraphic elements (kufics, nesjíes), which use repetitive rhythms, the tendency to completely cover surfaces or the use of patterns without spatial limits, as compositional principles (Borrás, 2006). The versatility of the compositional principles used favored the inclusion of ornamentation from the Christian tradition, such as the Gothic naturalistic flora, which used a different treatment and composition to adapt to Mudejar art.

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The typologies of fortress-churches are especially significant from this period, as well as churches with a single nave with a polygonal apse with five or seven sides and simple ribbed vaults. The structure of the towers is representative, which resembles the minarets of Muslim mosques, composed of two towers, one inside the other, between them the stairs are located and the body is crowned with the bell tower, usually with a polygonal format.
Thanks to the mixture of styles so characteristic, the Mudejar architecture of Teruel was declared a World Heritage Site by UNESCO on December 28, 1986. Subsequently, on December 14, 2001, the protection was extended to a selection of representative buildings of the Mudejar architecture of Aragon.

SURVEY METHODOLOGY

The methodology for carrying out the inventory of Mudejar heritage in rural settings must consider the necessary aspects to carry out in an orderly manner, the methods and instruments for gathering information adapted to the specific requirements and needs during the registration process. This procedure is made up of different phases that organize the documentation process. The first phase of the work begins with a preliminary search for information sources, with which basic and useful information is acquired to address the following phases. Then, during the field work phase, the data to be collected, the capture tools and the recording methods will be defined. Finally, the three-dimensional geometric model faithful to reality will be generated that will allow the reality of the building to be documented, which will later be accessible through a web platform for its dissemination.
This methodology has the vocation to help and serve as a model in the process of creating a digital graphic inventory of architectural heritage in environments of difficult accessibility such as rural areas, with the purpose of obtaining a global vision of the geometric documentation process and addressing the problems arising from the measurement, representation and synthesis of heritage assets. The purpose is to develop a graphic support for the registration of information that supports decision-making related to the conservation and protection of heritage, through restoration, intervention, consolidation, rehabilitation, etc.

PRELIMINARY DOCUMENTATION

Before starting the heritage documentation protocol, it is necessary to gather all the previous information on the real estate on which the documentary registration is going to be carried out. In this way, the necessary knowledge is acquired to carry out an initial analysis of the buildings and thus identify the aspects where it is necessary to influence the registry.
Basic documentation sources such as bibliographic and technical information should be considered (Fig. 5). Architectural heritage requires going to specialized libraries in the field, to access publications that allow you to know the state of the art. The sources will provide information on the historical-artistic evolution of the property, as well as social and territorial considerations that will reveal the lesser-known details of the property. The documentation that makes up this section includes previous inventories of the study area, reports, intervention reports, diagnoses or planning catalogues, information preserved and managed largely by the administrations. In the particular case of architectural heritage, access to the intervention and restoration projects of the assets is essential, since they contain information of great value, such as archaeological and historical studies or surveys, which are of great interest. In the case of rural environments, many of the buildings are not catalogued or have scarce and imprecise documentation, which makes the initial investigation process more difficult.
Cartographic documentation can display different types of information. Historical cartography provides information on the original context of the assets, on the other hand, recent cartography provides administrative, legislative or territorial aspects, which include spatial, cadastral, urban information, road network, altimetry, etc. Additionally, the consultation of historical and current images allows evaluating the changes registered by the properties over time. In addition, the aerial images and orthophotos help to relate the building to the territory, as well as its location.

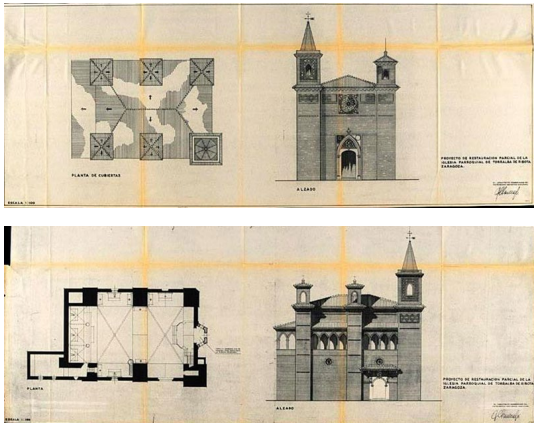

Fig. 5 - Preliminary documentation. Partial restoration project of the parish church of Torralba de Ribota, 1971, architect Fernando Chueca Goitia, (AGA) (03) 116 26/333

DATA COLLECTION

The field work continues the work begun during the previous phase of searching for sources of information. Once the collected documentation has been analysed, it allows expanding the information, by acquiring new photographs, as well as completing the existing planimetry of the property and generating new, updated, exhaustive and precise graphic documentation. To carry out the data collection, it is necessary to take into account its location, to anticipate the conditions that it may have during the capture and registration process. Accessibility to the property must be considered and obstacles must be located to take photographs and measurements. This information will be useful to define the appropriate tool for data collection and the points where to locate to collect the best information without interference.

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Fig. 6 - Three-dimensional geometric model obtained by combination of photogrammetric survey and laser scanning of the church of San Félix de Torralba de Ribota (Zaragoza). Prepared by Area of Architectural Graphic Expression of the University of Zaragoza.

The Mudejar monuments located in rural environments have limited dimensions, which allow data collection campaigns of 1-2 days to be carried out. These campaigns must be thoroughly planned in advance, since as a general rule accessibility to the building environment is difficult, with small side streets and elements that hinder taking measurements.

Taking into account the formal characteristics of the Mudejar building typologies, the data capture must include the exterior elevations of the walls, in addition to the roofs, towers and eaves. Inside the building, it is necessary to obtain information on the vaults and chapels, as well as the interiors of the buttress-towers and the galleries that surround the perimeter of the nave through the towers, spaces that are difficult to model due to their narrowness. Likewise, Mudejar art is characteristic for its ornamentation, so it is necessary to obtain products with an adequate level of detail that allows registering the pictorial wear of the walls, the laces, holes and other constructive elements and ornamentation (Fig. 6).

The definition of the appropriate tool to carry out data collection depends on various criteria such as scope, degree of detail, time or economy. In the case of the inventory of architectural heritage in rural environments, the information must be able to be used for multiple uses, so it will require reaching a level of detail that allows delving into the details of the asset and that in turn favors a comprehensive view of this. The scope of the heritage registration project must be defined from the initial phase of the documentary project. This is conditioned by the nature of the heritage asset, the needs and purposes of evaluation and the relationship between the available resources and the limitations. It is necessary to specify the choice of the appropriate level of detail, the skills and experience with the different registration methods, the definition of the time frame and the results that are desired to be obtained. In the end, the scope must reflect a balance between all the factors listed and the adaptation to the restrictions of time and economic resources available. The definition of the level of detail and precision that you want the resulting graphic information to contain will affect the selection of the methods and tools to be used. In the case of Mudejar heritage, due to its characteristics, it is necessary to obtain a high level of detail, which favors delving into the details of the property. The approximate precision to be obtained is ±2 mm and 5 mm for construction details and between ±10 mm and 25 mm for con-

Fig. 7 - Photogrammetric survey carried out with UAV in a difficult accessibility environment. Church of Santa María (Tobed).

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Fig. 8 - Drones used for photogrammetry survey. DJI Inspire 2 model (left) and DJI Mavic 2 Zoom model (right).

struction planimetry (Quintilla and Agustín, 2022). To obtain a complete survey of the buildings both from the outside and from the inside, data collection is carried out by combining acquisition techniques such as photogrammetry and laser scanning. The choice of the survey method takes into account the accessibility limitations in the vicinity of the buildings, as well as the architectural particularities of the typologies to be recorded, which require a great level of detail (Fig. 7).
In the first place, the photogrammetric survey is carried out with UAV, for which, two types of drones with different characteristics are used to capture the exterior and interior of the buildings (Fig. 8). Outside, the DJI Inspire 2 model is used, which has great agility, going from 0 to 80 km/h in 5 seconds, with a maximum speed of 94 km/h and a maximum descent speed of 9 m/s. In addition, it enables flying in low-temperature environments, includes a two-way anti-collision system, transmits live video from the on-board FPV camera and the main camera simultaneously, and creates clear, low-noise images in low-light environments. For indoor captures, the DJI Mavic 2 Zoom model is used, a drone with four motors, very light and small in size. It has a 1/2.3-inch 12-megapixel sensor capable of four-times zoom. Additionally, a Nikon D810 camera and a focal length between 24 and 70 mm with an AF-S NIKKOR 24-701: 2.8G ED lens are used.
As a complement to photogrammetry, a Faro 3D_HW_LS_Focus M 70 laser scanner is used, which allows obtaining photorealistic textures and mapping with an accuracy of ±3 mm and a range between 0.6 and 70 m for short-range measurements and applications. who need to work in small areas. It has a wavelength of 1550 mm, a color resolution of up to 165 megapixels and a field of view of 300º vertical and 360º horizontal. In addition, it has a dual-axis compensator with a precision of 19 arcseconds valid within a margin of ±2º, a height sensor using an electronic barometer, compass and GNSS with integrated GPS and GLONASS. All the models that make up the Mudejar inventory are positioned in the UTM ETRS89 Huso 30N coordinate system, to be later integrated into a geographic information system and thus facilitate interoperability and subsequent dissemination.

DATA PROCESSING

As a result of the interior and exterior data collection by means of photogrammetry and laser scanning, a three-dimensional geometric model is obtained that provides all the geometric information of the buildings and their correct formal characterization.
The point cloud model is obtained after photogrammetric processing using the Metashape software (Agisoft), and the incorporation of the information collected by the laser scanner (Fig. 9). The combination of both information is processed by Autodesk Recap software (Fig. 10). The result is a high-density point cloud with 6 mm density volu-

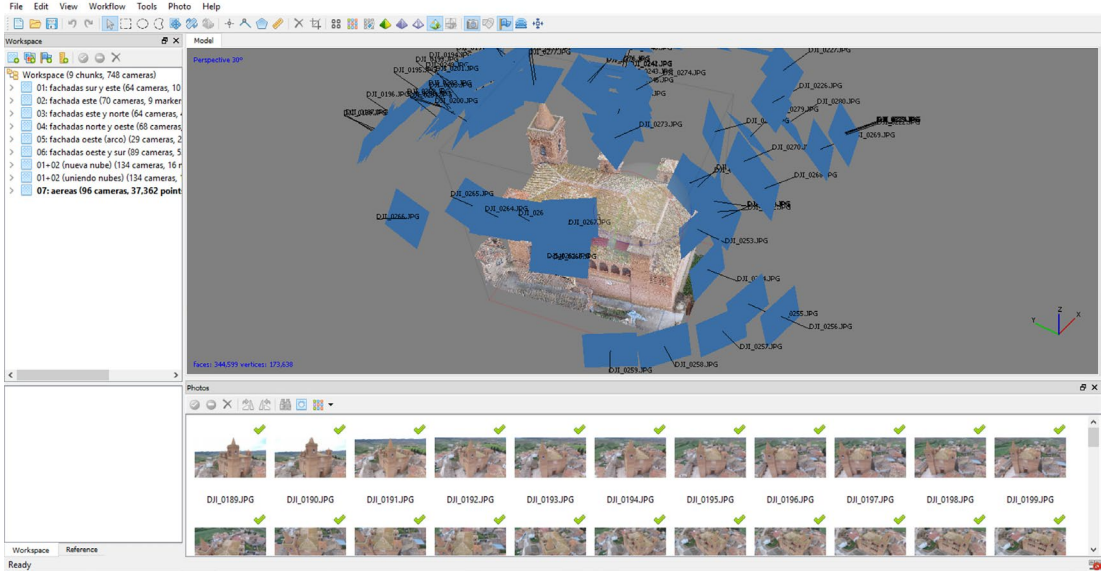

Fig. 9 - Point cloud model obtained after photogrammetric processing. Church of San Félix (Torralba de Ribota)

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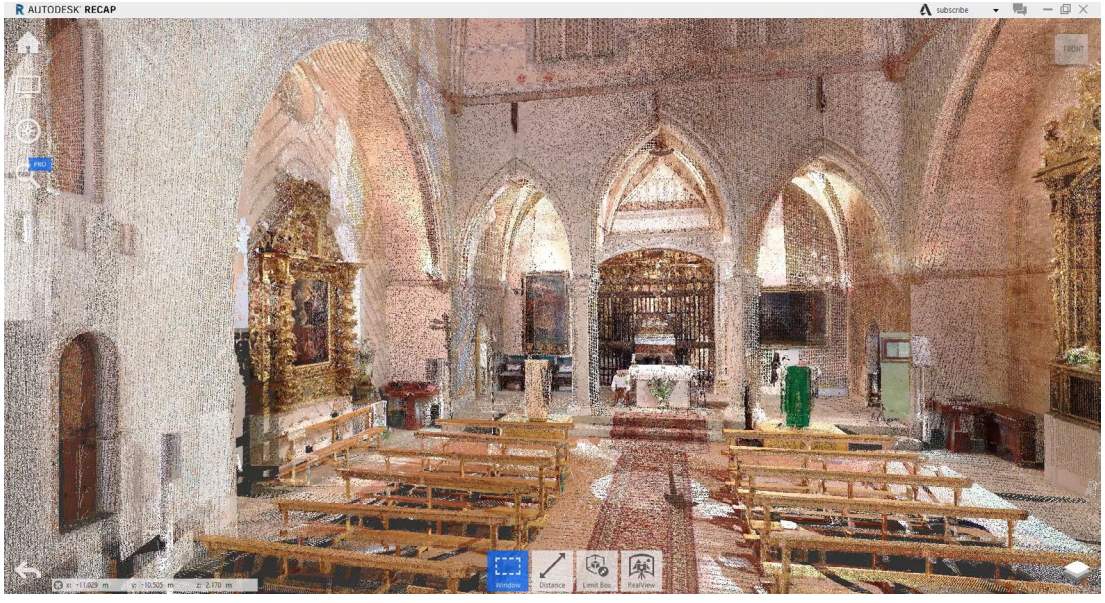

Fig. 10 - Interior view of the nave of the Church of Santa María (Tobed). Point cloud obtained in Autodesk Recap software. Prepared by Area of Architectural Graphic Expression of the University of Zaragoza.

Fig. 11 - High density point cloud of the Church of Santa María (Tobed). Prepared by Area of Architectural Graphic Expression of the University of Zaragoza.

metric and colorimetric information, which allows the materials and paints of the building to be recorded (Fig. 11).

The 3D model obtained with all the complete geometric information of the building is used as a base on which to incorporate the information coming from the technicians involved in the documentation process. Depending on the use to be made of the registered information, it will allow organizing heterogeneous information, such as physical characteristics, construction systems or descriptive characteristics of the historic building. The result is a useful instrument to display and interact with geometric information through web environments thanks to the use of the WebGL standard that allows complex 3D models to be shared.

Using the point cloud model and WebGL technology, large repositories of useful information can be generated as a source of information in architecture inventories. This type of model serves to get an idea of the shapes and volumes, but when approaching it, legibility is lost and the elements are not recognized. For this reason, cloud processing is also carried out to obtain other types of three-dimensional models such as surface or mesh models. The generated 3D models are created in standard exchange formats (ply and obj), with the aim of favoring data interoperability, and not depending on specific software.

Before converting and including the point cloud model in the WebGL environment, it is necessary to process the cloud to manage the model in the viewer. The objective is to create a product compatible with WebGL technology and thus promote efficient information management, as well as interoperability and accessibility between data-

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bases. To do this, it is necessary to segment the model to group data with similar properties and thus create a semantically enriched structure of hierarchical relationships. The building must be segmented externally, differentiating the different facades and roofs, and internally, according to the structure, distinguishing the main naves and the different chapels that make up the construction. This division will facilitate the dissemination of information and its subsequent classification.
Cloud Compare software (Cloud Compare, 2022) has been used to perform targeting, hierarchical-segmentation and sub-sampling of the cloud, as well as the classification of the different groups of clouds. This prior classification is important, since it will be used later in the viewer to show or hide the different sets of clouds into which the model has been segmented, thus facilitating information management. The objective is to obtain a segmented model, rich in classes and properties that allows capturing each degree of granularity required for the description of 3D models, for subsequent enrichment with annotations and thus obtain a complete repository that allows queries and information management organized. This division will later facilitate the system used for dissemination, display the information in an orderly manner, as well as the understanding of the building through the different sections (Fig. 12).
Once the point cloud has been processed, it is necessary to convert the cloud to a suitable file format for web viewing. The input file (LAS, LAZ, PTX, PLY) is converted to an octree data structure in order to reduce initial load times for data display (Martínez-Rubi et al., 2015).
As a result of the work carried out and the methodology used, a more complete and exhaustive documentation of the building is obtained, in comparison with the information examined in the previous phase of documentation, thus generating a documentation that did not exist until now. The volumetric model obtained after the combination of photogrammetry and laser scanner, allows obtaining all the geometric information of the building and its correct formal characterization, as well as recording its chromatic values.

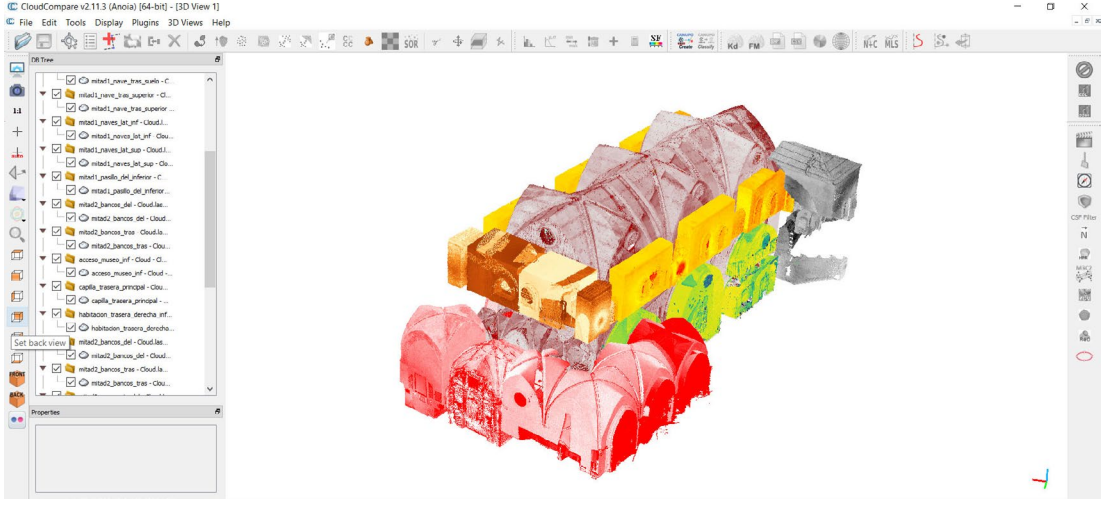

Fig. 12 - High-density point cloud segmentation of the interior of the church of Santa María (Tobed), differentiating the main nave, chapels and gallery.

DISSEMINATION RESULTS

The creation of tools that help to disseminate architectural heritage through digital inventories capable of containing and representing complete information on cultural assets represents a great advance over traditional architectural inventories, as a means of valuing heritage for the generation of economic, conservation and knowledge activities around it.
In order to make the information collected accessible to end users, it is necessary to establish a methodology to collect, organize and disseminate the information following a standardized procedure.
First, the information collected from the historical Mudejar buildings was structured following standardized criteria and stored in digital sheets, creating a complete inventory of the Aragonese Architectural Heritage. This structured digital inventory of the Mudejar Heritage ensures that the information lasts over time, as well as helps design conservation measures and promotions actions.
Second, a geospatial web tool has been developed to organize and make available 2D and 3D architectural data of the buildings which enriches the descriptive information provided by the digital inventory sheets. The main goal is to provide a standardized basis for recording digital 2D/3D graphic documentation, supporting the use of this information in an understandable and coherent way in future conservation actions. The proposed geospatial web tool is composed of a cartographic viewer (WebGIS) that gives access to a point cloud manager based on WebGL technology (Di Benedetto et al., 2014). Structured geospatial data allow the dissemination and use of architectural information through a website that facilitates access to heterogeneous information on assets, opening up possibilities for use by multiple types of users (Molero-Alonso et al., 2016). Likewise, the integration of the 3D point cloud viewer favors the creation of an accessible and easy-to-use repository of geometric information on heritage assets (Fig. 13).

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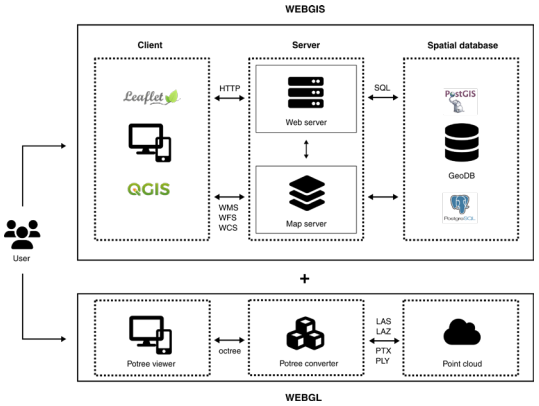

Fig. 13 - Conceptual structure of the web platform created for the Aragonese Mudejar Inventory.

The Digital Inventory of the Aragonese Mudejar Architectural Heritage has been developed using exclusively free and open source software. The creation, edition, managing, visualization and publication of the geospatial information is achieved using QGIS (QGIS Development Team, 2022), a multiplatform Geographic Information System which allows the manipulation of raster and vectorial data sets. PostgreSQL (PostgreSQL Global Development Group, 2022), supplemented with its PostGIS extension (PostGis, 2022), allows the creation of attribute tables with geometric and spatial information that are stored in Geo-DB (data base) and the analysis of the information by spatial SQL queries. The Spatial Data Infrastructure (SDI) services offered by different organizations have been used to support the geospatial architectural information using standardized web services. The data are published through OGC standardized formats, such as WMS, WMTS, WFS or WCS. The JavaScript library Leaflet (Leaflet, 2022) is used to create a web map application which make available the Mudejar Inventory the end-users (Fig. 14).
The 3D information collected for each historical building is made available to end-users by means of an ad-hoc interactive point cloud environment based on the Potree viewer project (Potree, 2022). The three-dimensional geometric information is

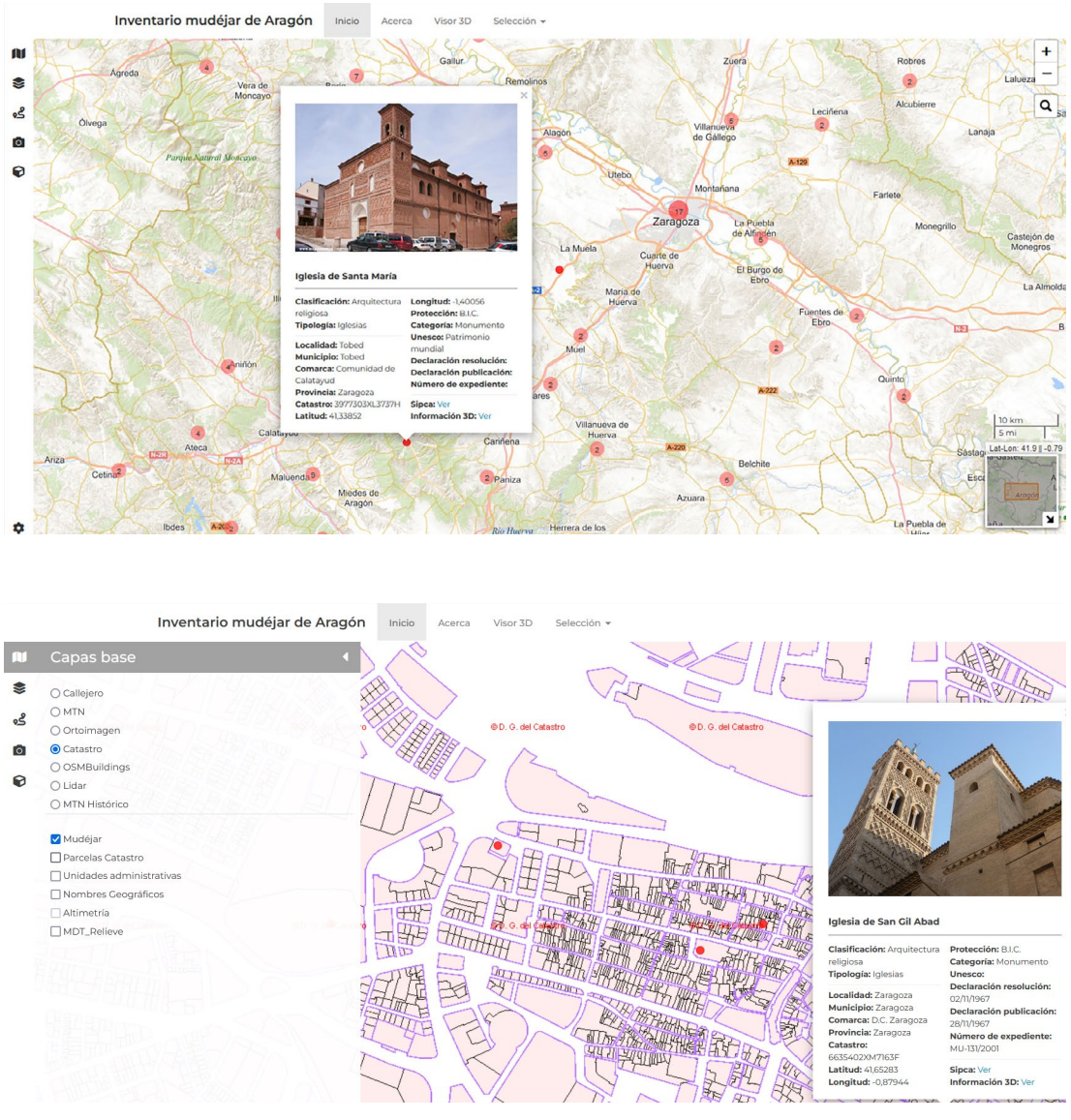

Fig. 14 - WebGIS prepared for the dissemination of the Mudejar Architectural Heritage in Aragon. https://www.inventariomudejar.es/

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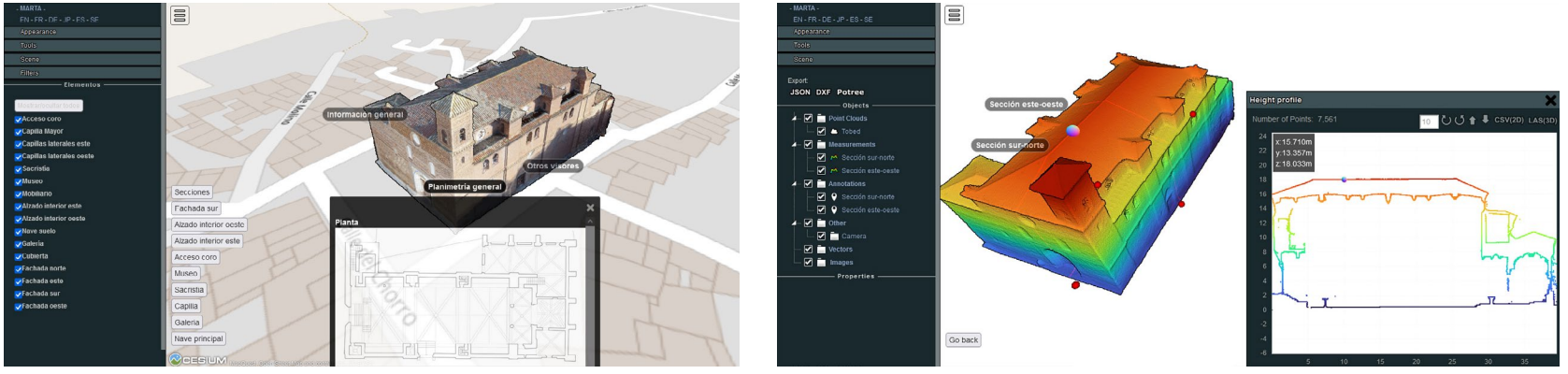

Fig. 15 - View of the point cloud viewer used to represent the 3D graphic information of the Mudejar Heritage of Aragon.

obtained by the combination of UAV aerial photogrammetry and laser scanner techniques. The result is a high-density point cloud model of the building that acts as a support for the incorporation of data from the technicians involved in the documentation process (Fig. 15).
The viewer contains numerous functionalities with the aim of facilitating access to the information contained in the point cloud model. Aspects related to the appearance of the point cloud can be modified, being able to define the level of detail of the cloud by increasing or decreasing the number of points to be displayed. Depending on the scanning devices used to capture the data and the post-processing algorithms used to augment it, intensity, RGB, elevation, level of detail, grading, and more may be rendered. In addition, the viewer allows navigation and interaction with the model, as well as the performance of measurements and access to linked annotations on the model that give access to complementary information, such as text, images, plans, links, etc.
Finally, the ability of the point cloud viewer to display information through web browsers without the need to install third-party applications is noteworthy, as well as its native compatibility with all devices, thanks to the use of WebGL technology (Schütz, 2016).

CONCLUSIONS

The work focuses on the creation of a Digital Inventory of the Aragonese Mudejar Architectural Heritage (https://www.inventariomudejar.es/) in order to facilitate access to information for uses such as conservation, protection, management or promotion. The objective is to promote the use of the inventory as a dissemination and analysis tool by the administration. Its use should be considered as a catalyst for the territory in which the architectural assets are implanted from an economic and cultural perspective.
A large part of the buildings that are part of the Mudejar inventory have little graphic and imprecise documentation, due to the accessibility constraints for data collection as they are located in rural environments. For this reason, the use of drones is an economical solution, minimally invasive and very suitable for rural areas, where there are no roads or technological conflicts and UAV technology can be used without impediments.
Thanks to the combination of photogrammetry and laser scanning, a graphic documentation of the assets that did not exist until now is obtained.
With the purpose of registering the Mudejar heritage in Aragon, 225 buildings have been inventoried which, due to their characteristics, must be registered. The documentation of a dozen buildings has been completed and in successive campaigns the registration of the rest of the inventoried assets will be completed.
The result is a digital repository made up of 2D/3D geometric information that constitutes a complete documentation of the building for metric or informative purposes. The proposed methodology to carry out the geometric documentation of Mudejar assets guarantees the storage of information and offers greater resources than the traditional inventories of architectural heritage. In addition, the integration of geometric information in a geographic information system provides the territorial vision and the necessary context to assess the identity and cultural values of the property.
The developed web platform should be considered as an instrument that provides visibility to heritage, as well as an analytical means to identify the potential of the site and the possible interventions necessary to manage it and guarantee its conservation.

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REFERENCES

Achille, C., Adami, A., Chiarini, S., Cremonesi, S., Fassi, F., Fregonese, L. & Taffurelli, L. (2015). UAV-based photogrammetry and integrated technologies for architectural applications – Methodological strategies for the after-quake survey of vertical structures in Mantua (Italy). *Sensors*, 15(5), 15520-15539.

Barba, S., Barbarella, M., Di Benedetto, A., Fiani, M. & Limongiello, M. (2019). Comparison of UAVs performance for a roman amphitheatre survey: the case of Avella (Italy). *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2(W11), 179–186.

Borrás Gualis, G.M. (1985). *Arte Mudéjar Aragonés*. Zaragoza: Colegio Oficial de Aparejadores y Arquitectos Técnicos de Zaragoza, Caja de Ahorros y Monte Piedad de Zaragoza, Aragón y Rioja.

Borrás Gualis, G.M. (2006). *Estructuras mudéjares aragonesas. Arte mudéjar en Aragón, León, Castilla, Extremadura y Andalucía*, (pp. 297-314). Zaragoza: Institución Fernando El Católico.

Brusaporci, S., Maiezza, P. & Tata, A. (2020). The gaze of the flying avatar: multirotor drones experiences for architectural heritage surveying, study and enhancement. *In D-SITE Drones – Systems of Information on Cultural Heritage for a spatial and social investigation* (pp. 50-57). Pavia: Pavia University Press.

Castilla, F.J., Ramón, A., Adán, A., Trenado, A. & Fuentes, D. (2021). 3D Sensor-Fusion for the Documentation of Rural Heritage Buildings. *Remote Sensing*, 13(7), 1337.

Centofanti, M., Brusaporci, S., Lucci, A., Maiezza, P. & Tata, A. (2018). Il Castello di Pacentro. Rilievo e conoscenza. In Marotta A., Spallone R. (Eds), *Defensive Architecture of the Mediterranean* (vol. VIII). Torino: Politecnico di Torino

Cloud Compare (2022). GPL software (version 2.11.3). http://www.cloudcompare.org/

Condor Abanto, L. (2010). La iglesia de Santa María de Tobed. *Cuadernos de Aragón* (vol.45). Zaragoza: Institución Fernando El Católico.

Croce, V., Caroti, G., Piemonte, A. & Bevilacqua, M.G. (2019). Geomatics for cultural heritage conservation: integrated survey and 3D modelling. *In IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage* (pp. 271-276). Florence: IMEKO.

Diara, F. & Roggero, M. (2022). Quality Assessment of DJI Zenmuse L1 and P1 LiDAR and Photogrammetric Systems: Metric and Statistics Analysis with the Integration of Trimble SX10 Data. *Geomatics*, 2, 254–281.

Di Benedetto, M., Ponchio, F., Malomo, L., Callieri, M. Dellepiane, M., Cignoni, P. & Scopigno, R. (2014). 3D Research Challenges in Cultural Heritage. *Lecture Notes in Computer Science* (vol. 8355, pp. 18-35). Berlin: Springer.

Domínguez-Ruíz, V., Rey-Pérez, J. & Rivero-Lamela, G. (2020). Contribution to the Knowledge of Cultural Heritage via a Heritage Information System (HIS). The Case of "La Cultura del Agua" in Valverde de Burguillos, Badajoz (Spain). *Sustainability*, 12(3),1141.

Fatta, F., Bassetta, M. &Manti, A. (2017). Survey Methodologies, Research and Technological Innovation for a Case of Medieval Archaeology: Torre Melissa in the province of Crotone. *Disegnarecon*, 10(19), 6.1-6.17.

Germanese, D., Pascali, M.A., Berton, A., Leone, G.R., Moroni, D., Jalil, B., Tampucci, M. & Benassi, A. (2019). Architectural Heritage: 3D Documentation and Structural Monitoring Using UAV. *In Visual Pattern Extraction and Recognition for Cultural Heritage Understanding* (pp. 1–12), Pisa.

Gobierno de Aragón (2014). *Estrategia de Ordenación Territorial de Aragón*. Zaragoza: Departamento de Política Territorial e Interior del Gobierno de Aragón.

Lacarra, J.M. (1960). *Aragón. Cuatro ensayos*. Zaragoza: Banco de Aragón.

Leaflet (2022). JavaScript library for mobile-friendly interactive maps. https://leafletjs.com/

Liuzzo, M., Caraccio, D., Di Maggio, E. & Alessandra, F. (2020). From the integrated survey to the virtual enjoyment of the ruined, fortified sites. The case study of the Castle of Nicosia (Enna). *In D-SITE Drones – Systems of Information on Cultural Heritage for a spatial and social investigation* (pp. 40-49). Pavia: Pavia University Press.

Lo Brutto, M., Garraffa, A. & Meli, P. (2014). UAV platforms for cultural heritage survey: first results. *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.,* II-5, 227–234.

Martinez-Rubi, O., Verhoeven, S., Van Meersbergen, M., Van Oosterom, P., Gonáalves, R. & Tijssen, T. (2015). Taming the beast: Free and open-source massive point cloud web visualization. I*n Capturing Reality Forum 2015*. Salzburg, Austria: The Servey Association.

Mascort-Albea, E. J., Ruiz Jaramillo, J., & Romero-Hernández, R. (2014). Analyzing Cultural Heritage by unmanned flights: new strategies researching rural and urban spaces. *Virtual Archaeology Review*, 5(11), 55–64.

Molero-Alonso, B., Barba, S. & Álvaro-Tordesillas, A. (2016). Documentación del patrimonio cultural. Método basado en la fusión de técnicas fotogramétricas y de escaneado óptico de triangulación. *EGA Expresión Gráfica Arquitectónica*, 21(28), 236–245.

Parrinello, S., Picchio, F., De Marco, R., & Dell'Amico, A. (2019). Documenting the cultural heritage routes. The creation of informative models of historical russian churches on Upper Kama region. *Int. Arch. Photogramm. Remote Sens. Spatial Inf.* Sci., XLII-2/W15, 887–894.

Parrinello, S. & Dell'Amico, A. (2019). Experience of Documentation for the Accessibility of Widespread Cultural Heritage. *Heritage*, 2(1), 1032-1044.

PostgreSQL Global Development Group (2022). https://www.postgresql.org

PostGIS (2022). Spatial and Geographic objects for PostgreSQL. http://postgis.net/

Potree (2022). WebGL point cloud viewer for large datasets. https://potree.github.io/

QGIS Development Team (2022). QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.org

Quintilla, M. & Agustín, L. (2022). Digital graphic repository of the Church of Santa María de Tobed. Dialogues. *In Visions and visuality. Witnessing Communicating Experimenting. Proceedings of the 43rd International Conference of Representation Disciplines Teachers* (pp. 1415-1432). Milano: FrancoAngeli.

Schütz, M. (2016). *Potree: Rendering Large Point Clouds in Web Browsers*. Vienna: Faculty of Informatics at the Vienna University if Technology.

Sestras, P., Rosca, S., Bilasco, S., Nas, S., Buru, S.M., Kovacs, L., Spalevic, V. & Sestras, A.F. (2020). Feasibility Assessments Using Unmanned Aerial Vehicle Technology in Heritage Buildings: Rehabilitation-Restoration, Spatial Analysis and Tourism Potential Analysis. *Sensors*, 20(7), 2054.

Tache, A.V., Sandu, I.C., Popescu & O.C., Petrisor, A. (2018). UAV solutions for the protection and management of cultural heritage. Case study: Halmyris archaeological site. International *Journal of conservation science*, 9(4), 795-804.

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