From UAV survey to 3D printing, geomatics techniques for the enhancement of small village Cultural Heritage

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Abstract: - Italy is rich in cultural heritage villages and places of interest. This work illustrates the methodology utilized by the Geomatics Laboratory (DICEAM of the Mediterranean University of Reggio Calabria) to create a archaeological structures' 3D model. 3D modeling is based on the utilization of imaging techniques, such as computer vision and digital photogrammetry. The outcomes obtained determine the value of the technique used in the field of cultural heritage to create a digital models and to replicate them through 3d printing. Furthermore, in the renewed interest in the context of the studies of ancient villages, the implementation of open GIS represents a new method to amplify the number of visitors to the villages despite concerns about returns on investments. In fact, the use of 3D acquisition and modeling tools to enhance the Cultural Heritage represents one of the study's areas in quickly development in the near future.

Key-Words: - 3D model, UAV, Laser Scanner, GIS, 3D printing, Cultural Heritage

1 Introduction

Italy has the largest cultural heritage in the world. Over 6,000 archaeological areas, 4,000 museums, , 85,000 churches subject to protection and 40,000 historic homes registered. However, it is very frequently subject to major earthquakes which constantly put this immense heritage at risk. We are therefore all called to intervene in order to safeguard, digitize and better protect our artistic and cultural heritage.

The cultural heritage sector has always found in the techniques of metric survey a valid ally for the conduct of its research and studies. The geometric documentation of the archaeological heritage and of the context in which they are inserted has today reached a high degree of technological innovation also thanks to the key role of geomatic techniques.

These data are functional to an increase in knowledge and documentation, preparatory to the definition of safeguarding and protection interventions and to the design of multimedia tools for valorisation, dissemination and modern museumization. For some time, the Geomatics Laboratory of the Mediterranean University of Reggio Calabria Italy has been carrying out studies and research for the monitoring, dissemination and dissemination of Cultural Heritage in order to provide a product that can be fully used both for research and for institutions, both for tourists. In the specific case, in this note the case study of a Saracen tower in Cardeto (RC, South Italy) will be presented,

In the last decade, the large application of 3D scanning methodology in cultural heritage field, allows some scholars to use digital 3D technology to map and register villages.

For example, Zhang et al. proved the practicability of close range photogrammetry and 3D laser scanning for landscape mapping [1].

Generally, many reaserchers made considerable studies on digital data acquisition of boroughs.

However, several research on areas have centered only on digital acquisition and digital model analysis. Through digitization, a village can be replicated three-dimensionally. However, tourists are more persuaded to access a real artifact than to provide a replacement in virtual reality. In fact, even if digital technology saves information on the model, from the point of view of learning and intuition, a reliable visualization is much more beneficial than a scene of 3D digital model.

3D printing was used to protect cultural heritage [2] to support digital models, for example in the restoration of historic buildings [3,4, 5, 6] and cultural relics [7]. A 3D printed model are really important to protect the Cultural Heritage, in fact they are continuously damaged by human (eg. Pollution [8] and human activity load [9]) and natural (earthquake sun, rain, wind) factors. Furthermore, as already mentioned, given the large number of small Italian villages is scattered throughout the territory, which means that visitors cannot experience close contact with each of them. In this regard, a model obtained through 3D printing can build models of different scales, and can be exhibited to visitors throughout the year in the nearest metropolitan cities in order to have the possibility of a first tourist screening, a factor increased by the possibility of aggregation and disaggregation of several elements that make up the final 3D. To all this is added the possibility of moving its digital and printed copy which would guarantee its cultural transmission and promote its exposure all over the world.

1.1 Historical geographical framework
The origins of Cardeto probably date back between the 10th and 11th centuries. The town owes its name to the presence, throughout the area surrounding the village, of the thistle plant (lat. Carditum "place of thistles") or, according to another version, to the Roman thistle. It hosted the first inhabitants around the year 1000, when the Byzantines, in order to better face the Arab threat, built various fortifications in the hinterland of the cities of Reggio Calabria, building kastre, also called motte, among which we remember the nearby Motta Sant 'Agata of which Cardeto was a farmhouse until 1783 (hence the current division of the town into "Sopra Casale" and "Sotto Casale"). It was probably the same agatini who, in search of a safer place to escape the continuous incursions, going inland, founded Cardeto.

To confirm this thesis we find at the entrance of the town, the ruins of an ancient fortification, a watchtower called by the inhabitants "Saracen tower", located in a strategic position on the strait, ideal for preventing the continuous Saracen assaults, which are very frequent. at the time.

The layout of the inhabited center of Cardeto does not follow any precise urban planning model, as it developed spontaneously in a particularly steep area.

Figure 1 - Cardeto, RC southern Italy.

Figura 2 - Saracen Tower Remains

2 Survey and Modeling
In the authors' idea, the survey activities of a village must be aimed at surveying both the village itself in its entirety, and as a union of each single element that composes it.

The purpose of the activities was, therefore, to reconstruct the 3D model of the entire "village" in question by integrating and replacing the individual assets that are inside with more performing 3D models. The acquisition phases involved the use of two main techniques: UAV and laser scanner.

2.1 UAV surveying
The advantages of the drone coupled with the use of digital photogrammetry in the field of Cultural Heritage are innumerable, as they can be used in situations characterized by a high danger to human life and in inaccessible or dangerous areas, they have very low costs and times compared to other activities, are very easy to use and do not need large space for maneuvering.

In the case study, for example, given the particular location of the village, the drone survey was the only methodology applicable to the restitution of a 3d model in its entirety.

A UAV, or a remotely piloted aircraft, DJI Phantom 4 Pro model, equipped with the high-resolution OcuSync transmission system, with a 20 megapixel 1 "sensor, capable of producing videos in 4K at 60fps, was used for the aerial photogram take photos at 14 fps.

A double grid flight plan was designed with an inclination of the chamber of 70 degrees, in such a way as to acquire an overlap of 80% in both directions. A flight height of 20 meters was set in order to obtain a GSD on the ground equal to 0.68 cm / pixel. The acquisition time was found to be 42 minutes, taking 881 images overall [27].

The flights were performed in the optimal lighting conditions for the next stage of processing.

Figure 3 - UAV DJI Phantom 4 Pro

2.2 Metashape and creation of the 3d model

The Metashape software was used to process the images, a program suitable for creating 3D models starting from a set of photographs. The algorithm used by Metashape is called Structure for Motion (SFM) and consists precisely in the production of 3D models from two-dimensional images. The automatic photogrammetry allowed us to automatically identify easily recognizable key points in three or more images, which served to create correspondence between the images and connect them together. Starting from these key points through a triangulation process, the camera was automatically calibrated and the position of the individual photographs was recognized[28,29].

The 3D model construction comprises four main steps.

1. Camera alignment. Metashape obtains common points on the photographs to obtain a scattered points cloud.

2. Dense point cloud construction. Metashape generates a point cloud denser and more detailed based on the estimated photos positions.
3. Mesh generation. Metashape merge the dense point cloud to reconstruct the surface of a 3D polygons.
4. Build Texture and 3D model. The generated mesh is corrected and a texture is built.

To resize the model we defined as markers the edge of the tower and using GPS methodology we acquired their coordinates, subsequently assigned to the tower's 3d Model to georeferenced it and improving the metric precision of the model. The same procedures were used to create the 3D models of the assets that are difficult to acquire otherwise[13]. For example, for the Saracen tower, given its particular location, the drone survey was the only methodology applicable for the purpose of returning a complete 3d model.
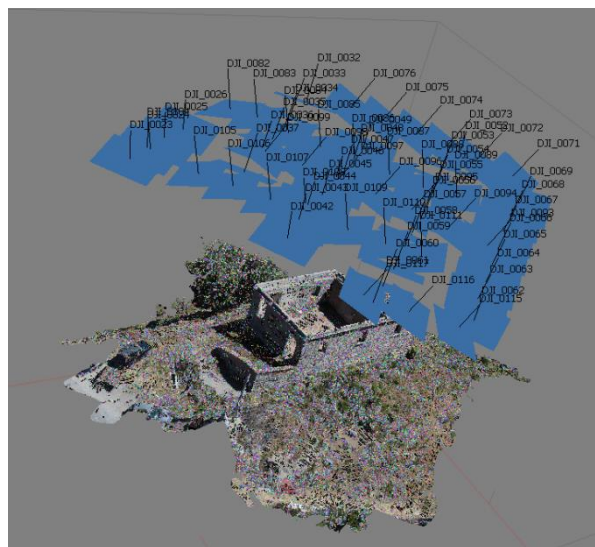

Figure 4 – Sparse cloud

Figure 5 – Dense cloud

2.2 Terrestrial Laser Scanners

Laser scanners have proved to be very useful tools in the field of Cultural Heritage, as they are non-

invasive systems that allow to obtain a high degree of inspection without damaging the historical, cultural and economic value of the site[24].

They are direct measurement systems capable of measuring at very high speed the position of hundreds of thousands of points that define the surface of the surrounding objects. The result of the acquisition is a very dense set of points commonly referred to as "point cloud"[25].

In order to obtain the 3D model from a laser scanner a 3D survey with FARO Focus 3D was carried out. The data were processed with the Faro Scene v. 4.1 software. We procede with a semi-automatic cleaning of the point cloud in order to eliminate any noise elements; then a Cloud processing was carried out to obtain the triangular model (or another type); finally (using the frames captured by the integrated camera, obtaining a 3D representation of the artefact) a texturing of the polygonal model was made.

In Fig. 6 shows all the laser scanner phase to obtain the complete 3D model (from the data acquisition to the volume computation).
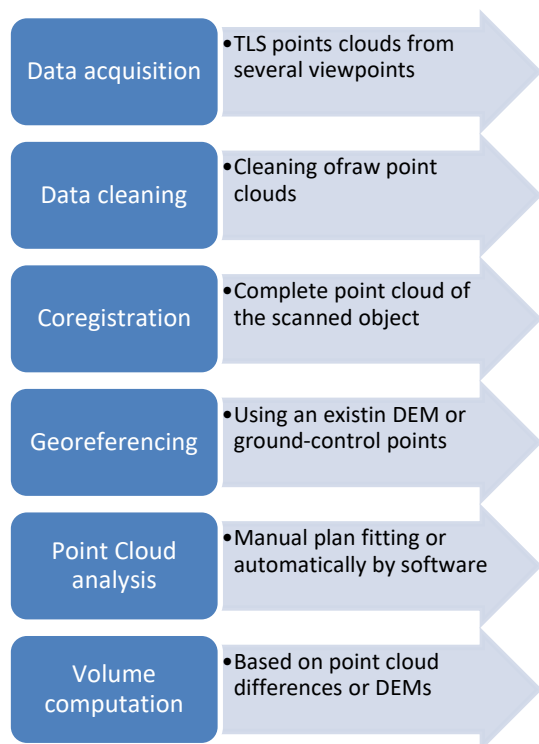

Figure 6 – Laser scanner flowchart: Acquisition – Data processing

Since the Saracen tower is not a complex structure, only two scans (therefore two point clouds) acquired from different points of view, each in its own reference system originating in the center of the laser

scanner, were sufficient for the survey of both internal environments[14,15]. To obtain the 3D model we oriented the two clouds according to the same reference system. This operation was made possible by ensuring a suitable overlapping area between the adjacent scans, in order to recognize some common parts and by carrying out a spatial roto-translation. The scans were set up with a resolution of one dot every 4mm in both directions. The combination of laser scans made it possible to create a complete three-dimensional model that described the geometry of the embankment with a high degree of accuracy. The result obtained from the laser scanner scan was processed with the software Faro Scene v. 4.1. which allows the visualization of the point cloud within the platform, the extraction of plans, elevations and sections, the management of the scan workflow - direct 3D model and the control of the accuracy of the CAD model. Thanks to the software we treated the raw data acquired from the laser scanner, then we proceed with the registration phase dividing it in two parts. In the first part, the internal point clouds were examined by cleaning them at the points with high alignment errors (Figs. 7). Then we reiterated the process to check the obtained errors. In particular, we aligned the clouds guaranteeing the geometric information acquired by each scan. The alignment errors identified by the software in the various attempts ranged from 3 to 7 mm. For this reason, a largely manual editing process was performed to eliminate all unsuitable points. The collimation and registration operations were performed by recognizing the characteristic points of the detected structure (edges and vertices). After repeating the registration procedure, the new alignment errors identified by the software were between 1 and 3 mm. The union of the scans through the classical procedure, identifying the homologous points, generated a point cloud with a pitch in the lower region of about 1 mm and in the upper region of about 3 mm [5,6].

Figure 7 – Point cloud from Laser Scanner

There are therefore two point clouds available (one from laser scanner and one from photogrammetry), as a result of the different processing performed. The two point clouds can be visualized and analyzed using specific software that allow to obtain different information including the coordinates of each point of the cloud. Since there are two point clouds specifically, it is necessary to integrate them. An integration was then carried out between the point cloud generated by the laser scanner and that from the drone using the Cloude Compare software (association of the same markers to the two clouds). The identification of common points can be done automatically using pre-marked points with reflective stickers, or manually, trying to recognize homologous points between two adjacent scans. Once the final point cloud is obtained, it is possible to:

- view the detected area in 3D;
- measure distances between points;
- make comparisons between models

We therefore generated a mesh model that connects each measurement point with triangular surfaces, respecting their spatial position. This procedure, in addition to providing the user with a simple graphic display, is also useful for determining the thickness of the walls between the different environments (useful information for any structural studies). Having obtained the two clouds (or the two 3ds) [11], a check was carried out on the accuracy of the two methodologies and it was clear that in the area immediately closest to the laser scanner the point cloud was much denser and therefore detailed, however the result obtained by drone does not denote any particular significant and substantial differences[10].

Figure 8 – 3D model

3 Use Conservation and enhancement: 3D printing and web GIS

Thanks to the growing market of increasingly cheaper 3D printers, having the 3D model obtained thanks to the use of the minimally invasive techniques described above, we can create low-cost reproductions that can be sold as souvenirs. Unlike current souvenirs, thanks to the methods we use we can have a very faithful return.

3D printing allows the creation of physical models from a digital model, setting by the user the scale and the definition.

The three-dimensional digital model of the artifact can be obtained also using photogrammetry techniques, that don't require any physical contact between the artwork and the instrumentation.

In the field of cultural heritage, the applications of 3d print technology can be applied to:
• make copies to be temporarily or permanently used for example to replace a artifact subjected to restoration or replace a part of historical building that is undergoing excessive degradation;
• make copies to support blind people, that have to "touch" a work to be able to appreciate it;
• make high quality copies for the mass production of merchandising that corresponds to the original work;
• make copies to realize 3D printed pieces exhibitions with;

Moreover, it is also thinkable to use this expertise for the restoration of a damaged work, in fact it is possible to digitally create a missing piece of the original work, print it with suitable material and then mount it on the original artwork with a final aesthetic effect will depend exclusively on the materials and the definition chosen.

The printer used to produce the Tower scale model is a "Bq Hephestos 2" which for the realization, or rather the printing, of the object exploits the subsequent deposition of layers of molten material or FDM (Fused Deposition Modeling).

It is a single-extruder printer for which it was possible to print with a single material at the time, the material chosen to print the model was polylactic acid (PLA) which now represents a standard for printing through this technology thanks to its relatively low temperature of fusion (starting from 180°C), to its low retraction index, to the discrete mechanical properties, but mainly because unlike the ABS, its predecessor, it does not release toxic fumes during the extrusion operations.

The software used to translate the three-dimensional model into commands in G-Code, that is the programming language of the CNC, those codes and commands that position the extruder and start to execute the print, was Repetier-Host.

The steps to print the model consist in different phases:

1) verify the integrity of the three-dimensional model, namely the absence of damage, gaps or cuts in the mesh and above all its structural integrity.

This control is necessary because if the model is not manifold, the slicer is not able to design the printing path since it would be found with an open and not closed three-dimensional model.

2) create some supports for the suspended parts of the model,

these supports are essential since in FDM printing operations. Clearly these supports will then be eliminated subsequently in a mechanical way through special pliers [4].

3) Slicing phase, that is the creation "slices" (horizontal planes- layers), that will be extruded one above the other, by depositing molten material, from the printer extruder.

The slight horizontal scoring of the model (obtained by the overlapping of the various layers printed) can be reduced by reducing the printing speed (in particular on the external perimeter).

Similarly to the external perimeter we can define the type of Infill or filling of the model. Since there are no reasons to completely fill the extruded PLA model, it is used to fill with geometric motifs. In our case, to get good mechanical skills we made use of an Infill Honeycomb that has excellent mechanical capabilities and does not go too far in prolonging printing times[2,3].

The software that allowed us to define the above is Slic3r, it is one of the internal slicers in Repetier Host released with an Open Source license that effectively transforms the three-dimensional model into instructions that can be understood by the printer (G-Code).

Clearly a printing of large models is difficult and economically inconvenient. For the application we chose to print the model with a scale of 1:50

In fig. 9 a first printing example is reported. This print was made setting a layer height for the print quality of 0,2 mm; a Shell of 1 mm, a filling density of 20 %,

with a average print speed of 60 mm/s and a overhang angle of support of 50 °.

The printing time required for our model was 5h and 30min and we used 23.74m of PLA.

| Quality	Layer height	0.2 mm
Shell	Wall thickness	1
	Upper/lower layer thickness	1 mm
Filling	Filling density	20%
	Fill Configuration	Honeycomb
Material	Printing temperature	200 °C
	Type material	PLA
Speed	Filling speed	80mm/s
	Support speed	60mm/s
	Displacement speed	100mm/s
	External/internal wall speed	40mm/s
	Initial layer speed	30mm/s
Support	Support positioning	In all necessary point
	Overhang angle of support	50•
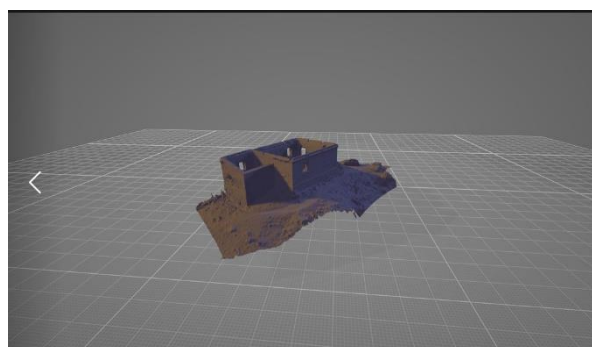
Figure 9 a – Printing 3D model repair phase

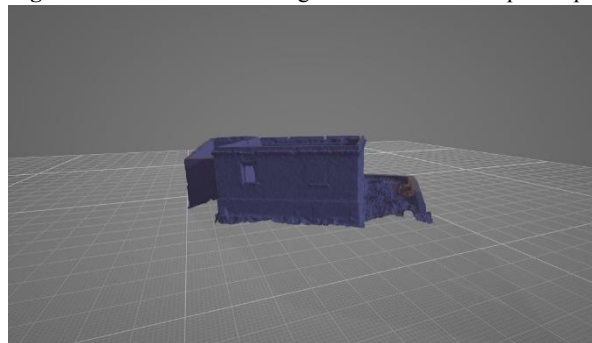**Figure 9 b** – Printing 3D model repair phase

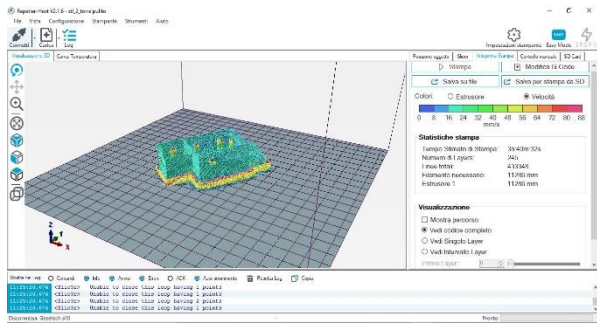**Figure 9 c** – Printing 3D model repair phase
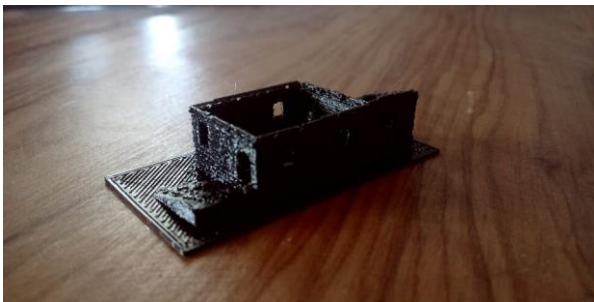
Figure 10 - Printing 3D model

Figure 11 – 3D print

Obviously in order to improve the use of the assets detected and exploit all the potential of the well-known methodologies. the entire job was inserted into a GIS that allows the user to state. This work has also been included in an interdisciplinary project aimed at defining some itineraries in Calabria between places of artistic, religious and cultural history. GPS surveys were conducted to determine the routes to be marked on a map. The preliminary analysis of the maps relating to the geographic area under study for the identification of the paths was followed through the spatial characterization of the places of interest by associating the position with the image. The routes were then detected and all photographic information, geographical and historical descriptions were acquired. The implementation involved the establishment of a well-designed geodatabase that contains all the relevant information for each territorial element. After processing and filtering of the data collected, the georeferenced maps were of support for the WebGIS. The WebGIS (fig. 12) was designed for the dissemination of information on the Internet, on mobile devices and cell phones with the Android operating system, so that each user can easily find information wherever they are. The information accessible from mobile phones / PDAs / tablets can also be used when these devices are used as navigators for identifying routes[26].

Among the innovative functions, it also makes it possible to support the recovery processes of Calabrian historic centers and encourage the use of local companies specialized in the extraction and production of the material necessary for recovery, with the aim of re-proposing typical solutions and original types in function of a "sustainable" conservation.

From a structural point of view, the application architecture is organized in three levels, interconnected and scalable, which are the database, the MIS component (Management Information System), the GIS (Geographic Information System) and finally the multi-user interface (system manager, private and institutional interested parties due in the matter).
MIS is an organized integration of hardware and software technologies, data, processes, and human elements. It focuses on the management of information technology to provide efficient and effective strategic decision making. It is a set of procedures which, when executed, provides information to support decision making. GIS is a tool that allows to analyze, represent, interrogate entities or events that occur on the territory. In the technology present within the geographic software are integrated to the common operations that can be carried out on the data base, such as research, statistical analysis, graphics, the functionalities of a G.I.S. as the storage of spatial data, their processing and especially their representation in the form of maps or tables cut out over more or less extensive portions of territory. Multi-user interface instead is the part that allow the user to query the system allowing the mutual interaction between user and system. The application thus articulated provides the necessary support both to the public, administrations, planners, designers and companies in the sector.
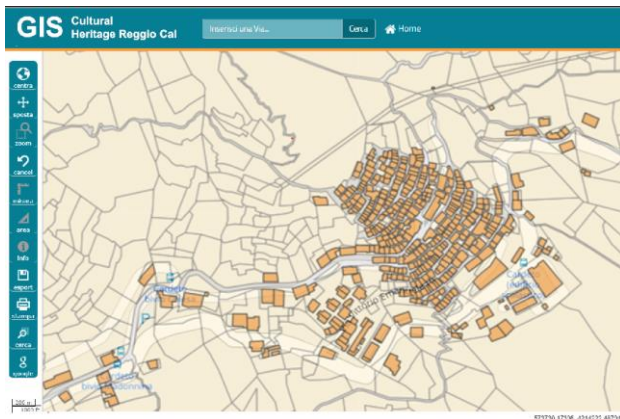
Figure 12 –Cultural Heritage small village rappresentated on Gis.

4   Conclusions

As widely recognized by several studies, the protection, preservation and enhancement of cultural heritage offer opportunities to improve the livability of a place, social integration and a sense of community belonging and, more broadly, the economic development of the territory of reference. It is therefore an important element in terms of regional development policies.

It is well established that culture is an essential resource in the pursuit of the objectives of economic and social cohesion. In particular, the potential of the cultural and creative industries within the growth process of local economies and in the creation of new activities and sustainable jobs is recognised. In addition, the cultural heritage sector has a positive impact on other sectors of the economy, contributing to the improvement of the image, attractiveness and social cohesion of a territory[15,16,].

However, the development and implementation of all the activities proposed for each area of study, necessary to obtain a complete and rigorous analysis, although it is desirable and in line with the latest European policies clashes with the real operational cost of studies. Performing a 360-degree analysis requires the use of a lot resources both in terms of cost, time and human personnel to be employed.

On top of this, there is a scarcity of resources and that Italy has a vast cultural heritage with a simultaneous increase in the number of goods that require restoration accordingly goes from whether it would be unthinkable to imagine that such activities could be repeated in all areas and for all the goods present in our territory [17].

However, it is essential to note that investments in cultural heritage are able to pursue more objectives

(general and specific) that strengthen and complement each other. General objectives include: the preservation of cultural heritage and the preservation of historical, artistic, architectural and/or archaeological assets of international/national/regional importance; the provision of recreational services such as cultural and artistic events or performances; providing education and research services [19,20,21]. These, in turn, can be translated into the following specific needs: to preserve a historical monument from its deterioration; Improve the conservation status of an archaeological site; Provide new resources for the preservation of paintings, sculptures, paintings, books, artifacts, etc. (e.g. museums, bookshops); equip existing facilities with the appropriate equipment to host events, exhibitions and presentations (e.g. theatres or art galleries); develop a path of educational growth in a particular discipline [22,23].

As a result, the objectives and defined the beneficiaries of the intervention are identified, it goes without saying that the research and activities proposed by the writers, although objectively onerous, come out of the cost schemes, "directing" in the sole view of the benefits and fallout on the territory. The final goal of this note is to provide guidelines to exploit all the potential of the best geomatics techniques applied to the Cultural Heritage sector. The system realization advantages are clearly visible if we consider the final result: the digitalization of the Cultural Heritage and consequently the possibility to don't lose it after for example a earthquake disaster, giving the possibility to the other generation to admire it.

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Example
John Smith, Donald Smith carried out the simulation and the optimization.
George Smith has implemented the Algorithm 1.1 and 1.2 in C++.
Maria Ivanova has organized and executed the experiments of Section 4.
George Nikolov was responsible for the Statistics.

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