Survey and Virtual Restoration

The Castle of Magacela (Spain)

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***Abstract*— This paper present an application of the latest sensing technologies in the field of restoration is presented. The object of study is a Castle built in different historical periods by different hands so it has undergone changes, deformation and partial replacements. The aim of the survey is to study this issues looking for a common denominator that makes them more understandable. The results of the research are constantly compared with the hypotheses, avoiding in this way the typical contradictions of isolated analysis.**

The different phases of data acquisition were characterized by the implementation, analysis and comparison of different survey methods: GPS, total station and laser scanner. The results were used to design an appropriate restoration.

The use of 3D modeling for attempting the conservation and the revaluation of cultural heritage is having an increasing role. For this reason, it is important to have a high level of detail, and at the same time obtain a model of easy interactive visualization. Therefore, this study is the first attempt to enhance and promote the archaeological heritage through three-dimensional virtual reality. This will allow the visitor the opportunity to transform his role from a simple viewer to an active subject, to virtually 'live' the ancient site, its forms and spaces with a more dynamic participation.

Keywords-laser scanning; 3D modeling; reverse engineering

I. INTRODUCTION

An important strategy to revitalize the cultural, economic and social development of a city is the promotion of its architectural heritage. The case study attempts to give a solution to Magacela's municipality policy of architectural and environmental enhancement. This project was made possible thanks to the financial help from the regional government of Extremadura destined to preserve and categorize the local resources and traditions. The restoration of the Castle of Magacela is one of the crucial points of this proposal because the local community recognizes in its historical and cultural identity. This study analyzes the problems of formal reading and geometric-proportional of the building, and material-technological investigation up to the dimensional-physical data. All this information are important to generate a philological understanding of the whole architecture and to find a solution for its future.

II. THE PLACE AND HIS HISTORY

Magacela is a town of the Province of Badajoz located in the autonomous Spanish Region of Extremadura. The origins of the name probably come from the name *Umm Gazala* ("mother" or "big house") attributed to the Castle that dominated the place in the Moslem age [1].

The Castle is situated in the highest part of the hill of Magacela (Fig. 1), at a height of 563.35 m (according to the reference system ETRS 89) and it extends for about 230 m, with an average width of 56 m.

During the Moslem occupation, literary references of Bakri in the eleventh century, and Yaqut in the thirteenth century, confirm the existence of barbarian at the Castle *Umm Gazala*. These authors described how the Arabs armed the fortress and defended every inch of their territory building a structure impregnable to the enemy [2].

The complex is completely adapted to the topography of the ground. The fortress consists of three enclosures: the first, located in the eastern side was used originally to accommodate a large part of the population; the second, contiguous to the first but more to the west, is smaller and the third one, in the western part, constitutes the main part of the Castle, the functional and administrative center.

Figure 1. View of the Castle of Magacela

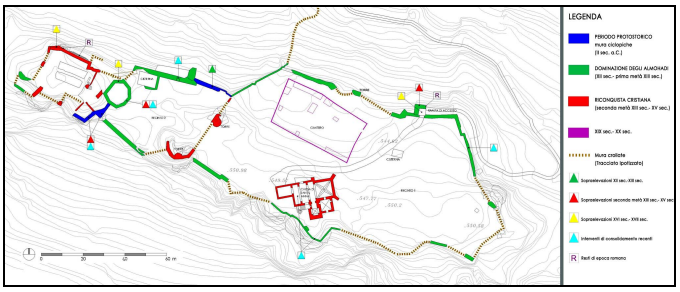

Figure 2. Plan of the Castle and chronology of the walls.

Despite of the high degree of deterioration, it is possible to reconstruct its primitive structure thanks to different descriptions and references of a period from late sixteenth to early seventeenth century [3]. From this data the site was used for defensive purposes, in fact, it is still possible to observe one of the curtains on the north side built with huge blocks of quartzite regularly arranged, typical of the Cyclopean walls of pre-Roman times. In the Arab period significant reforms have substantially changed the original shape (Fig. 2). After Christian occupation, new structures were built and, in the Middle Ages, the fortress was adapted to new functions. Due to reasons not yet clear, around 1615 the works in the fortress ceased [4] therefore, now the Castle is in ruin mainly due to extreme climatic conditions of the place (the name of the region in which the Castle of Magacela is situated *Extremadura* expresses clearly the presence of hot summers and cold winters).

III. State of the Art

From a long time the laser scanner has been used in relation with the cultural heritage as a tool for rapid and effective survey. On the other hand, regarding the restoration of ancient architecture, there are some applications carried out by only centers of excellence. To this day, in fact, some technicians of restoration are doubtful about the real potential of these methods and are still too tied to traditional standards. By the way, it is true that it is already from a decade that the topics related to the integration between photogrammetry and laser scanning are matter of study by several research groups of national and international scientific community [5]. In this context, the Bruno Kessler Foundation has obtained interesting results. The most recent publications of ISPRS were the background of this case study.

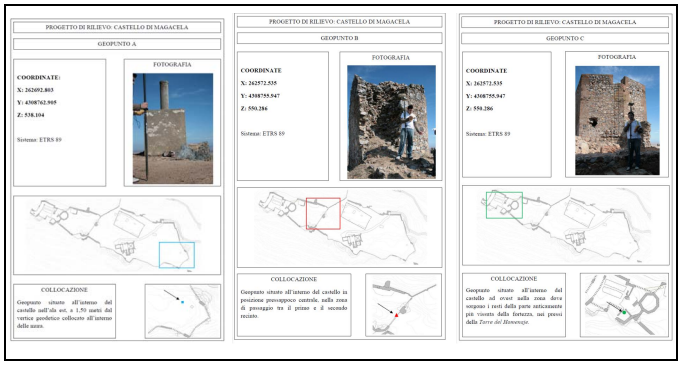

Figure 3. Examples of data sheets.

IV. The Survey

In this work an out-and-out "project of survey" was defined as a preliminary step to the restoration project. Technologies and operating methodologies used for the survey were different: differential GPS, reflectorless total station, surveying instruments, laser scanners and digital photogrammetry. To assign coordinates ETRS 89 was used the system GPS Topcon Hiper Pro. The georeferenced points were placed in strategic locations so that are visible to each other and were individualized on the ground by topographic nails; and all this georeferenced points were catalogued through data sheets (Fig. 3).

The survey of all internal and external surfaces of the Castle was made using the time-of-flight 3D laser scanner Leica HDS 3000. The orography of the place, in fact, did not allow the possibility to locate the laser closer to the walls, therefore we opted for a high-range instrument. Eighteen scans were made using the laser scanner: 9 on the inside of the wall and 9 outside with a final resolution of 9 mm and an estimated accuracy of 6 mm (the accuracy, or more appropriately, the measurement uncertainty is represented by the dispersion of measurements around their mean and therefore allows to assess the random component of the error). Each scan lasted about 11 minutes, with a number of points acquired approximately of 2.5 million: the final model is characterized by 11,258,000 points (Table I). We also used a Canon EOS 400D with a resolution of 10 megapixel to obtain a photo-realistic 3D model, applying static shots to the points clouds.

V. Data Processing

Several reverse engineering software allow to use raster images. In this specific application, the software used is Geomagic Studio (Fig. 4), for its superior capabilities in handling the texture mapping [6]. This result was obtained projecting, on the model, the images of the texture. The correspondence between the point clouds and the digital images was realized by hand. Once we have individuated homologous points we proceed with tools like generate texture, project image and manage texture in spreading the texture on the model. Homologous points were situated mostly near the holes or particular sections in relief or micro-fractures, avoiding image deformation when applying the texture, trying to obtain a model as much as possible photo-realistic and metrically correct [7]. In particular, the creation of digital orthophotos allows to bypass the complicated and long phase of manual vectorization of the structures and state of degradation. Moreover, compared with traditional process, it allows to obtain a more detailed understanding, because the new project drawings have 2+1 D and it provides information not only metrics but also textural.

TABLE I. Data of the Points Cloud Modeling

N° points acquired	45,000,000 ca.
Relative error	6 mm
Absolute error	18.9 mm
Estimated RSM error	11 mm
Georeferencing error	< 2.5 mm
N° points of the final model	11,258,000

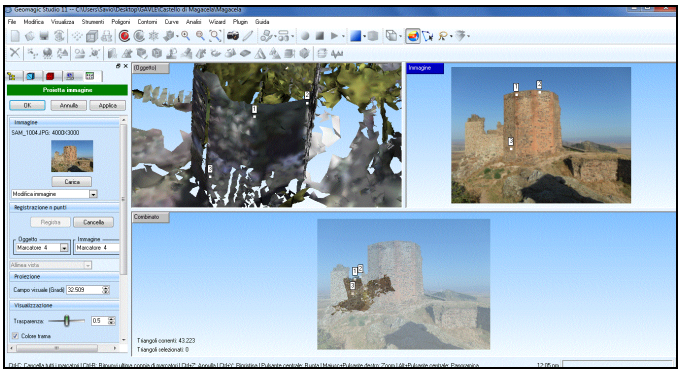

Figure 4. Texture mapping in Geomagic Studio.

The digital techniques used, therefore, were more efficient and effective than traditional survey or hand-drawing methods. The Castle and its history were uncovered as a result of either digital approach and modeling methods. What was learned via survey and modeling could not have been learned via traditional research methods. For this reason were chosen those specific methods of range-based modeling.

To obtain good texture to be treated as less as possible during data editing - using Photoshop for example - it is necessary to plan of the photographic survey.

From this scientific information and starting from the preliminary data acquisition with different methods used, it was possible to estimate and define the following framework of statistical errors (Table I): relative error of the points cloud of 6 mm; absolute error of the points cloud influenced by the registration phase of 18.9 mm; georeferencing error less than 2.5 cm.

The 3D georeferenced model answers to the questions and objectives of the work but also to a wide series of applications: it is possible to analyze the crack patterns and deformations with greater precision, the conservation state of matter, the loads of structural elements, the geometry of the buildings, the color changes of the surfaces, etc.

VI. THE RESTORATION PROJECT

The main objective was to focus on strictly indispensable additions for the renovation of the Castle. It is preferred, therefore, to act critically through the use of modern materials and according to the principles of minimizing invasiveness, of compatibility with the figural context, of distinguishability and reversibility [8].

In the project the new functions created were: two new spaces used as aggregation points for cultural purposes, both located in key points to form a balanced system of organization, a small reception center for pilgrims who walk the “way of Silver”, one of the ways leading to Santiago de Compostela, whose Magacela is a milestone.

This project is not out of context and interacts with the spatial organization of full and empty spaces of the ancient structure of the Alcazar.

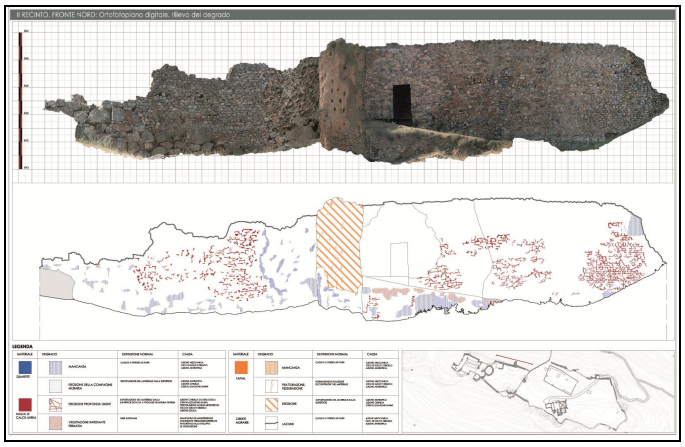

Figure 5. Analysis of deterioration.

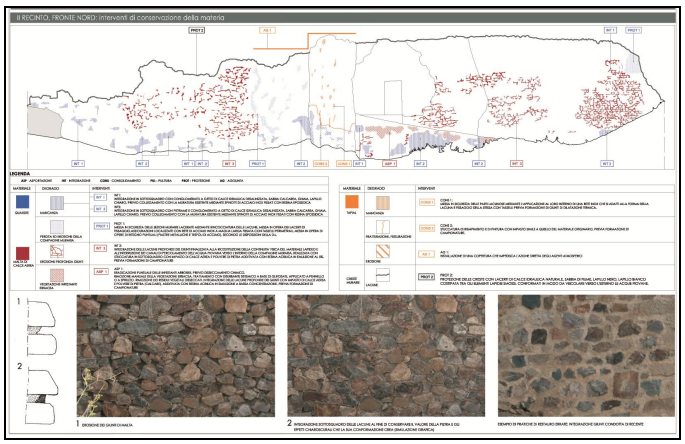

Figure 6. Virtual actions of preservation of matter.

These are the graphics that were produced for the research: 3D textured model of the Castle; orthophotos; analysis of deterioration (Fig. 5); actions of preservation of matter (Fig. 6); plans, sections and facades.

VII. SOLID MODELING AND RENDERING

The virtual restoration of the Castle is based not only on the two-dimensional graphic works produced with CAD software (in this case, of Autodesk), but especially on the creation of photorealistic rendering, using Rhinoceros and its tools for rendering, Flamingo (both McNeel).

During this operation it was important to choose the correct texture to apply to the 3D model: for example, the texture representing the masonry systems was obtained from orthophotos produced for the analysis of degradation.

For several years the rendering of the project has assumed great importance in the architectural design and restoration, becoming ‘obligatory’ when working in restricted natural landscapes or with protected buildings. In fact, the possibility to have a realistic view of the project allows to control the impact that the transformation produces on the environment or construction.

VIII. METHODOLOGY

The steps of the methodology used were (the approach adopted with the lessons learned could be useful, as starting point, for other research):

- inspection of the area to survey;
- definition if a survey project, with the choice of instruments according to site conditions and to financial resources;
- survey of the building using GPS, total station, laser scanner and digital photogrammetry;
- editing of data acquired;
- production of graphic drawings;
- definition of the structures chronology, by the examination of the stratigraphic relationships with the hypothetical reconstruction of the destroyed parts of walls;
- analysis of deterioration of the matter of one pattern wall according to normalized indications (Fig. 5);
- precise definition of actions of conservation, with tools of computer graphics and techniques of restoration discipline (Fig. 6);
- identification of new functions compatible with the figural aspect of the ruins, to permit the re-use for public interest and, at the same time, the constant maintenance [9];
- the necessary additions for the refunctionalization follows the minimizing of invasiveness, the compatibility with the context, the distinguishability and reversibility.

In particular the virtual restoration project was based on the following principles:

- preserving the spatial and structural organization of the existing ruins;
- thinking new spaces to create meeting places to be used for cultural purposes;
- using building systems based on light technology, trying with the 'new' intervention, in this context, to establish a relationship of little contrast between tradition and new materials;
- exalt the environment planning the landscape outside the walls and providing new streets to the Castle;
- adopt intervention strategies that provide the future reversibility of the transformation;
- use of exotic wood and steel corten for additions, coherently with the pre-existing figurative contexts and according to a critical-conservative approach (Fig. 7).

IX. CONCLUSIONS

We have worked from the cognitive phase to the decision phase analyzing the potential capabilities that architecture in ruins, neglected for a long time, can still give if we make a careful reading of the building, of its context and of the new needs that can be compatible with the instances of conservation. A better care of the ancient buildings, preserving the historical-artistic-cultural heritage, also means a constant maintenance and not only intervening in emergency situations. We always have the risk of losing something irreversibly when destructive events occur, and that reminds us that nothing is eternal, it exists an upper end to all earthly life, even the "books written in stone" (V. Hugo), when is written on the history of our civilization.

Figure 7. Virtual restitution and restoration (P. Ortiz Coder and E. De Feo).

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