

# 3D AND 2D DOCUMENTATION AND VISUALIZATION OF ARCHITECTURAL HISTORIC HERITAGE

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## Abstract:

*The use of 3D models for a deeper study of historical buildings has significantly increased over the last years and indeed 3D visualizations and animations in architectural heritage preservation has been a big issue for the whole scientific community. The cooperation between different disciplines such as photogrammetry and computer science (computer graphics) provides the opportunity to develop new tools and techniques for filing buildings documentation. The present technologies and methodologies for classifying architectural allow the generation of very realistic 3D models (especially in terms of geometry and texture). This paper describes the generation of 2D and 3D models of Castel del Monte in Southern Italy. In particular, for the 2D model, directed to the realization of an automatic procedure in order to obtain 2D data from the real building. This because most of the applications for laser scanned data treatment that are commonly available on the market are not conceived to provide automatically such a representation (the great majority of them, in fact, can do it only after a very careful manual reconstruction of the original design of the building). At the end of the whole process, the result is an accurately texturized 3D model.*

## 1. INTRODUCTION

### 1.1 Castel del Monte

Castel del Monte is one of the architectural treasures of Puglia in Southern Italy and one of the main tourist destination in the region. This Swabian extraordinary monument, isolated in a high position and located at the foot of the Murgia mountain dominates from its 540 m above sea level, a wide area of Puglia and Basilicata regions. Its history is shrouded by the charm of mystery. In fact, it has been a study subject for several disciplines: mystery sciences, ufology and archaeo-astronomy, all in order to search imaginative esoteric, magical and/or ancestral references. This interest was generated from the difficulty to recognize a proper castle in the whole monumental complex that, effectively lacks in the traditional elements of defense, so, in the past, it has read as a temple, an astrolabe or even an astronomical clock [1]. “On January 28th, 1240, in Gubbio, the Emperor Frederick II of Hohenstaufen signed a decree ordering to arrange everything you needed in order to build a castle near the church (subsequently demolished) of Sancta Maria del Monte” [2]. This date can be considered as the actual beginning of the castle construction, a process that lasted enough to lead us to think that the emperor himself was never been able to stay there. Since 1700 it was abandoned becoming a shelter for shepherds and bandits. Only in 1876 the castle was bought by the Italian State in and since 1928 a series of restoration works had been carried out with continuity and scientific caution almost until the most recent interventions (figure 1) [2]. The castle is listed as a national monument in Italy since 1936 and in 1996 it was also enlisted as an UNESCO World Heritage Site.



**Figure 1** : Castel del Monte

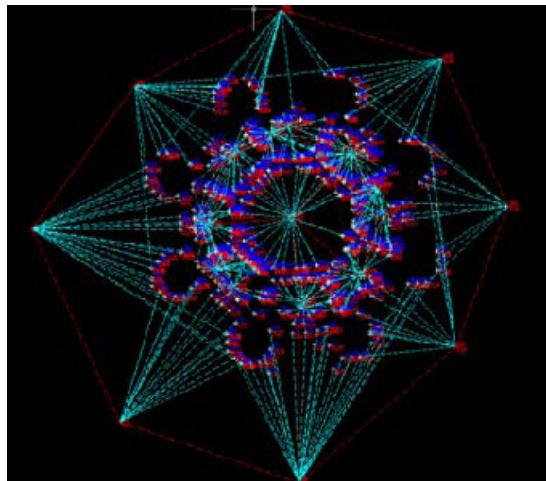
At a first glance the castle looks like a regular octagon, about 16.50 m square, an octagonal tower placed on a basement at each one of the eight vertexes. On the outside, a frame string course defines the division of the two internal plans, which in turn consist of eight rooms corresponding to the eight sided octagon. Each face of the castle between the towers, has two windows in axis: a lancet window at the lower floor and a double lancet window on the upper floor. Only on the north side there is a triple lancet. On the towers there are many narrow openings such as the splay slits giving light to the stairs and the rooms of the towers. The main entrance is located on the eastern side of the building, while on the west side, there is a secondary access. Much more doors and windows open on the inner courtyard with no symmetry but according to the needs of the rooms facing it [3].

## 1.2 The survey of the castle

The measurements were taken with a total station Leica TCRP 1201. The inner and the outer surveying (ground floor, foreground and courtyard) required four days. The polygonal is composed by 28 vertexes (table 1). The natural points and the targets, as GCP for laser measurements, were collimated and a GCP description had been made. The elaboration of the acquired data has been done compensating the polygonal and, subsequently, determining the coordinates of the coincident vertexes (figure 2).

**Table 1** : Distribution of the topographical stations

Site	no. of stations
Outside	8
Rooms Ground Floor	8
Courtyard	1
Rooms Foreground	11
<b>TOTAL</b>	<b>28</b>

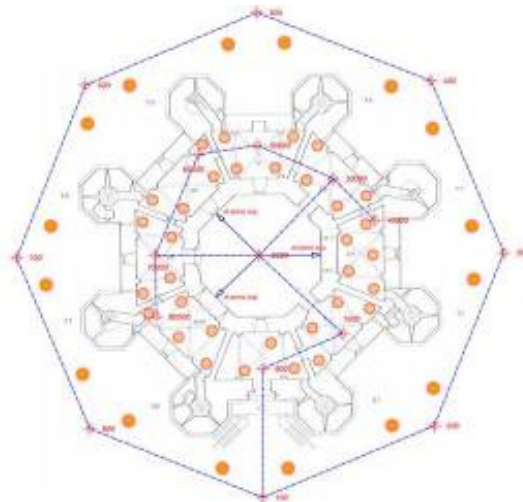


**Figure 2** : Plan of the topographical surveying

The laser scanning surveying was performed with a laser HDS 4500 by Leica Geosystems S.p.A., that is based on phase observation with maximum range of 52 m. For the castle 92 scanning acquisitions were done (table 2, figure 3).

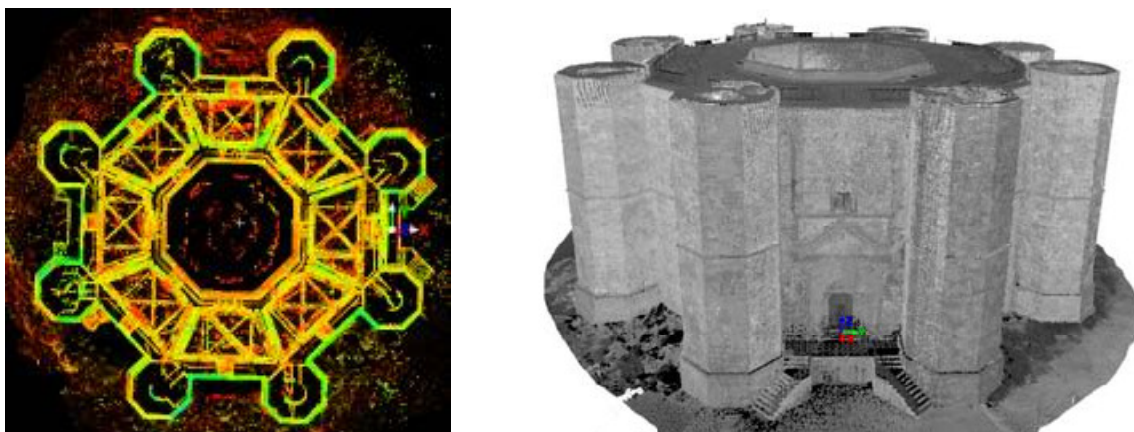
**Table 2** : Summary of the laser scanning acquisitions

Site	no. of stations
Outside	12
Plant Ground Floor	29
Courtyard	3
Foreground	40
Roof	8
<b>TOTAL</b>	<b>92</b>

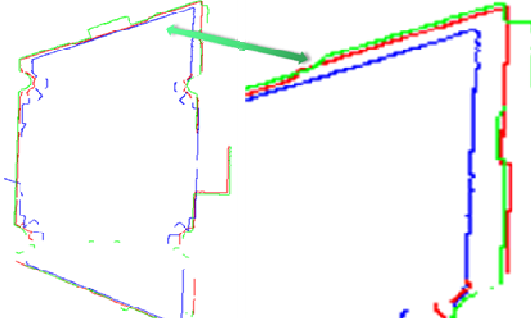


**Figure 3** : Plan of the laser scanning and topographic surveying

The scans were processed with Cyclone through a first alignment based on the recognition of the control points materialized from the reflecting targets and of the natural GCP. This was done separately for each room of the ground floor and of the first floor. The same, then, for the courtyard, the outside and finally for the covering. On the model that was obtained it has been reconstructed a surface composed by a triangular grid beginning from the cloud points. The meshing on every single scanning with an appropriate software used different layers and produced a more intuitive visual representation (figure 4). Starting from the surface, the contours parallel to the XY plane in the local reference system at different levels were obtained by a Cyclone automatic procedure [4]. All was subsequently exported in dxf format (figure 5). Looking to figure 5 is immediately clear the high degree of fragmentation of the vector information obtained. A tough manual rework was needed in order to obtain technical drawings [5].



**Figure 4** : Total Point Cloud registered (left) and Mesh (right) in Cyclone



**Figure 5 : Contours in Cyclone**

## 2. THE DEVELOPMENT OF THE EXPERIMENTAL ALGORITHM

### 2.1 Introduction algorithm

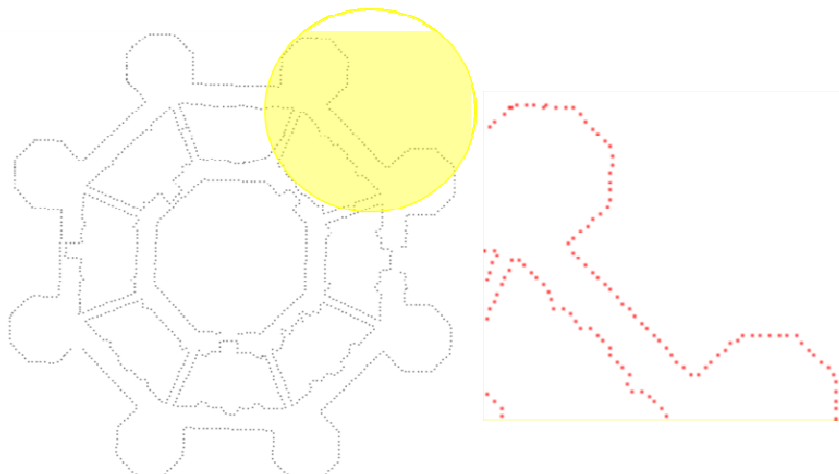
Our first aim was to define a method to transform the laser scanner data into continuous information in order to extract discrete data for the construction of maps suitable for technical reference. The main need of the processing activity is a total manual manipulation and this requests a huge computational complexity. In order to face this problem a computational algorithm in Matlab® has been implemented. The principle adopted has been the one of the interpolation that in general refers to the process of estimating an intermediate value from two known values. In the linear interpolation, and in general though, if the values of  $x_i$  and  $x_{i+1}$  are known, the value of  $y(x)$  can be approximated by

$$y(x) = y(x_i) + \frac{y(x_{i+1}) - y(x_i)}{x_{i+1} - x_i} (x - x_i) \quad (1)$$

It is possible adopt the higher order methods, because, the drawback to linear interpolation is that straight line is supposed to be the function between two known points. Some methods suggests to try to fit data with a polynomial or another known curve in order obtain a slightly better approximation. Due to the uncertainty inherent in any data, this is considered extremely risky without the absolute certainty that the functional form taken on is correct and that the data used have a very high signal to noise ratio. So, when in doubt, it is more appropriate to use the linear interpolation.

### 2.2 Dataset definition

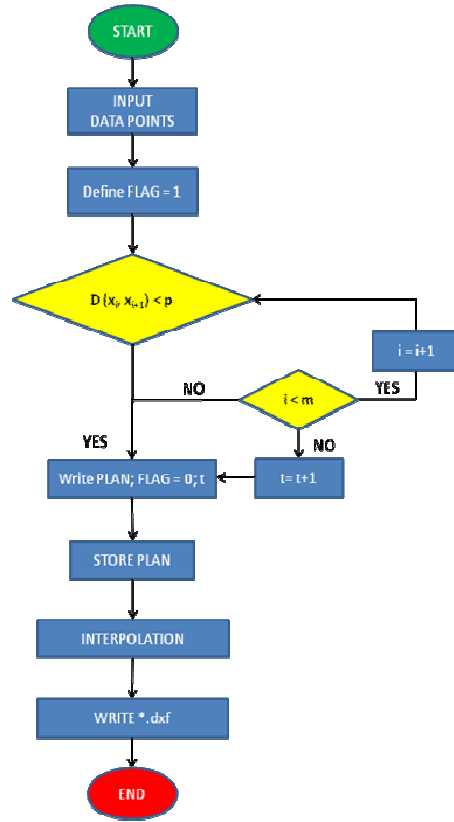
The overall numerical model was exported in ASCII format to be processed with Geomagic software. This generated a surface model on which the typical procedures of Cleaning, Reducing noise, Filling holes, Repairing normals and intersections were applied. Also in this case the sections parallel to the plane XY at different levels were obtained and thereafter been convert into points at constant step (figure 6); then all was exported in DXF format. Finally, the vector file has been converted into an ASCII one.



**Figure 6 : Curves extracted by Geomagic as points**

### 2.3 Developed Algorithm

In figure 7 the flow chart of the implemented algorithm is shown. For the implementation of the algorithm a matrix of input was structured as a first step.



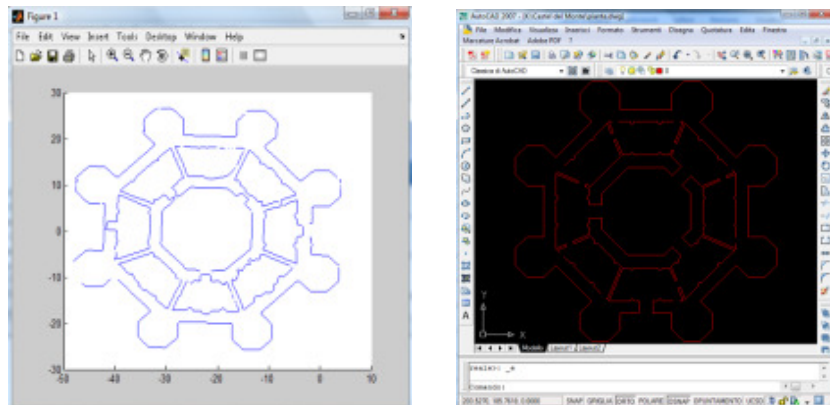
**Figure 7** : Flow chart of the implemented algorithm

$$LIV = \mathfrak{R}^{m,4} \quad (2)$$

Subsequently was defined a procedure for putting in order of the data considering the criterion of mutual distance and the sequence space, and defining the different domains that constitutes the two-dimensional representation, discretized by the control variable t. This can take values between 1 and n, where n is the maximum number of domains identified:

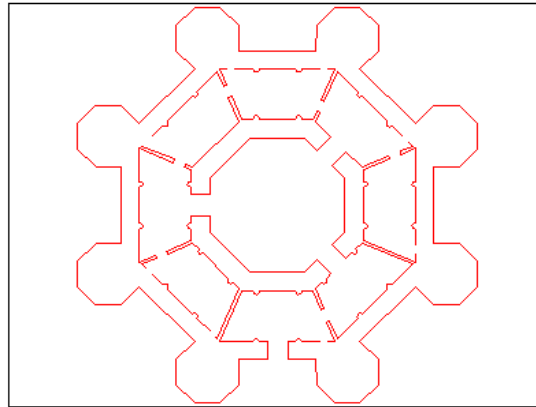
$$PLAN = \mathfrak{R}^{m,4} = \{\mathfrak{R}^{m,3}, t\} \quad (3)$$

The matrix so defined is the input of in the interpolation procedure [6]. In particular, the linear interpolation on a set of data points  $(x_0, y_0), (x_1, y_1), \dots, (x_n, y_n)$  can be recognized as the concatenation of linear interpolants between each pair of data points [7]. The result is a continuous curve, with a discontinuous derivative, thus of differentiability class  $C^0$ .



**Figure 8** : Algorithm output: Matlab (left) and CAD (right)

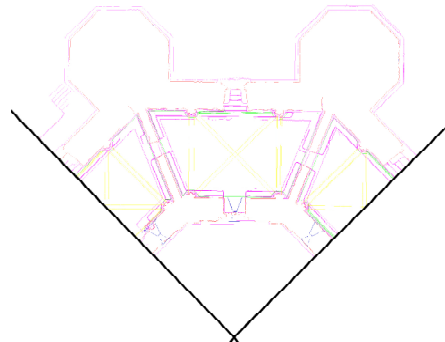
The interpolation error is proportional to the distance between data points, raised to the power  $n$ -th. In order to manage all the digital information defined by the algorithm and in CAD environment it was introduced a further procedure to save results in dxf format. Given a filename and a 3D polyline where each line element is specified by X,Y and Z coordinates it writes a dxf file with the corresponding polyline and N vertices [8]. The results are shown in figures 8 and 9.



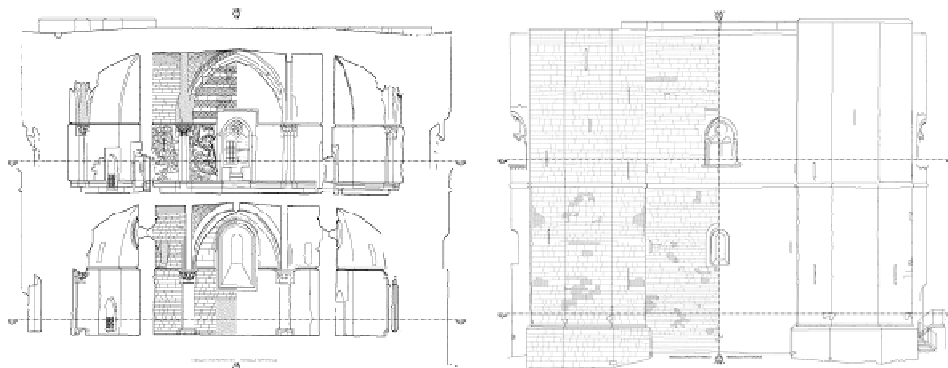
**Figure 9** : Example of extracted plan

### 3. THE 3D MODEL

The continuous 2D information extracted from the data of the laser scanner surveying of Castel del Monte were later used to identify a method for the 3D modeling. Starting from the vector data corresponding to planes placed at different levels and some sections and integrating them with appropriate information a set of drawings suitable for technical consultation reference, as aforementioned, was produced. These are the plans of the ground floor and first floor, intended as horizontal sections of the building, made at a significant level, and then projected at right angles to a horizontal reference plane which coincides with the floor. In particular, at Level 0 (ground floor), the section plane is placed at a height of 1m from the ground floor, at Level 1, the section plane is at a level of 2.3 m from the floor of Room IV of the first storey and 11.50 m from the floor Level 0. Figure 10 shows a detail of this.



**Figure 10** : Detail of the horizontal sections



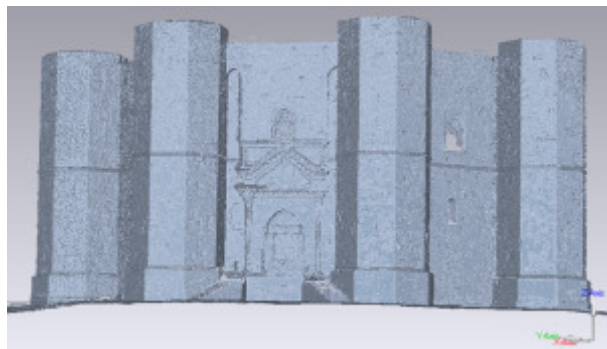
**Figure 11** : Example of vertical section and prospectuses



The vertical sections have been obtained using planes of projection passing through the keystone at the center of the room and along the highest point of the perimetrical arches. For a proper architectural representation the information given by the 2D model was not enough. What was needed was a more accurate presentation of the examined area: a further integration was essential to deepen the description of details and textures of the elevations (figure 11).

#### 4. THE TEXTURED 3D MODEL FROM POINT CLOUDS

After the registration the resulting point cloud was sub-sampled with data reduction at 10 cm as the last of three tests: at 1, 5, 10 cm. Such a strategy was adopted in order to find a good compromise between a good level of detail and a high computational complexity. Indeed the 3D model of the Castle should have to be used as primary dataset to conduct a textured analysis on the structure. As softwares currently available on the market for this application are not optimized to manage large amounts of points, such as those typically obtained from TLS surveys, a data reduction was a necessary step. The 3D model was triangulated with Geomagic software, getting a mesh of about 7.661.811 triangles (figure 12). Doing this it would have been easier to import the whole dataset in a CAD or an open source software for a further model texturing.



**Figure 12** : 3D model triangulated with Geomagic software

In the most of the published works the concept of “integration” or “combination” of 3D models derived from photogrammetry and laser scanning is considered basically in two different, alternative ways: as a texture mapping of the meshed TLS model or, on the other hand, as a production of orthophotos using aligned and triangulated point clouds as a DEM. Here the melting of data is aimed to create a unique 3D virtual representation where photogrammetric and laser scanning data are merged together so that the final product can be seamlessly explored. This utilization of 3D modeling applied to Cultural Heritage can benefit of the use of both the techniques of surveying. For example, in the case of historical buildings, such as Castel del Monte, 3D information about pretty regular portions of the structure can be derived from photogrammetry, while more interesting architectural details and areas with higher surface curvature can be reconstructed from laser scanning data. The whole TLS 3D triangulated model has been then imported in Autocad 3D software as dxf file, what allowed to keep the texture information provided by the high-resolution digital images. 3D model has been subdivided in four principal layers (courtyard, exterior, principal portal, balcony) and fourteen secondary (windows). Most of the time has been spent in images rectification using an photo editor software (figure 13), with the intention to obtain the maximum detailed texturing of 3D model.



**Figure 13** : Example of images rectification

Rectification work needed about two weeks of work, in order to combine 6÷8 photo in one, playing also with brightness and contrast, to define an homogeneous texture [9]. The results of the texture process is showed in figure 14.



**Figure 14** : 3D model texturized with Autocad 3D software

## 5. CONCLUSIONS AND FUTURE PERSPECTIVES

The work has addressed at first the study of various stages of conversion of point cloud and the determination of contours. It must be pointed out that all the softwares available for data processing LST are not conceived to provide significant 2D representations, unless with a complex intervention of manual digitizing. The need to have a two-dimensional representation arises both from requirement of operational techniques and from the technical requirements of the customer demand. Only through a good two-dimensional model it can be switched a three-dimensional one of the same high quality. An algorithm capable of joining the above mentioned kinds of representations was developed, as detailed, with the functions of both the survey methods (linked to the precision) on successive stages of data processing in proprietary software. The work, therefore, has required a exiguous manual intervention in order to achieve the vector model to provide a harmonious integration of all the elements characterizing the architectural heritage. The final results that have been obtained, therefore, the technical drawings of Mongian representation (orthogonal projections, sections) will be easily used for basic studies of engineering, architecture, history and tourism. The spatial vision of the model was then created by a mix of data aimed to create a unique 3D virtual representation where photogrammetric and laser scanning data are merged together so the final product can be seamlessly explored. In conclusion this approach to 3D modeling applied to the filing of Architectural Heritage is going to make the best of the use of both the most important surveying techniques.

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