# METHODOLOGY OF 3D DIGITAL SURVEY OPERATIONS AND DATA PROCESSING ACCORDING TO ARCHITECTONIC INVESTIGATIONS IN ARCHAEOLOGICAL AREA

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**KEY WORDS:** Cultural Heritage, LIDAR, Acquisition, Processing, Interpretation.

**ABSTRACT:**

Purpose: This is a presentation of same case studies conducted by our survey lab on some archaeological monuments. The main objective is to underline the general rules that guide 3D digital survey operations and data processing in order to obtain a point cloud model according to our investigations (metrological investigations, lectures of masonry structure, architectonical typology, ecc).

Methodology/Approach: The main subject of the presentation will be the digital surveys of some areas from Villa Adriana in *Tivoli* (*Grandi Terme*, *Grande Vestibolo*, *Cento Camerelle*). Starting from important general rules to lead the digital survey operations based on 3d Laser scanning of those monuments (conducted using Leica HDS systems) we will show our procedure to manage and archive the data of those survey together with some evolved solutions of data processing in order to obtain not only two-dimensional drawings for metrological investigations, but also three-dimensional stratigraphy solutions. Finally: some considerations about methodology to relate the digital survey data to the other information acquired during the direct survey of the monument.

Results: The digital survey cannot be considered just a simple massive data acquisition; the survey operations should be planned in order to produce optimized data for the following data processing operations. Point cloud model is just a digital measurable model of the real object (absolutely not sufficient to describe the features of an architectonic building, especially in archeological area), so is necessary to develop a methodology to relate all information acquired using the computer science applications.

## 1. GENERAL RULES TO LEAD A THREE DIMENSIONAL DIGITAL SURVEY

### 1.1 Introduction

Now a day it's clearly that the practices related to the digital survey have become consolidated solutions and that the operations of data acquisition are become standards procedures accepted from a large part of the Cultural Heritage operators (E-arcom, 2007).

During the last five years the Laboratory of Survey of the *Dipartimento di Progettazione dell'Architettura* of Florence (Laboratory coordinator: prof. Marco Bini; coordinator of the digital survey team: dott. Giorgio Verdiani; coordinator of the topographical survey team: arch Mauro Giannini) has lead a long series of digital survey, this massive activity was finalized to two main purposes, on one side the creation of a precious patrimony for the documentation of the architectures from Florence and Tuscany; on the other it supports the activity of research connected to graduate thesis or Ph. D thesis.

In this case the subject of our paper is the experiences of survey lead in archaeological area and is aimed to put in evidence, as clear is possible, the advantages deriving from the use of laser scanning technology and all the odds that can take place during the data acquisition phase and later, during the data processing.

First of all it seems appropriate to define a list of general rules to guide the work of the surveyor, in the next paragraphs these rules will be simplified through the analysis of specific case studies.

### 1.2 General rules to lead a three Dimensional digital survey and data processing phase

This directory of norms derive by the knowledge that "the quantitative" data produced by means of the operations of digital survey can be useless if the survey operations are not clearly finalized to the requirements from the contractor. The operations of data acquisition and processing are strongly tied each other and unavoidable; in this case we wish confute a rule, accepted by many professionals in the field who think that the data acquired from the operations of digital survey, visible as a point cloud three Dimensional model, is indifferently usable for any type of applications. So it is opportune during the acquiring process and the phase of data elaboration to take in mind those general rules:

1) Lead digital survey according to the main objectives.
2) It's important to choose the technical instruments to take a digital survey according to the main objectives and to the future of the site. So it is important to consider the level of accuracy, level of noise, max and min distance from the subject, possibility to work in the open air or just in enclosed space, machine controlled time (time in which the instrument complete one scan, during this period the machine must remain still in place).
3) Often it's necessary to integrate the digital survey using other different survey techniques (traditional survey, topographical survey, photogrammetric survey) in order to obtain a complete documentation and an high level of accuracy (High level of accuracy

means that the digital survey can describe all the metrical and morphological futures of architectonical complex, in this case is important to consider not only the survey objectives, but also the size of the searched measures. Complete documentation means that during the survey it's acquired enough data do produce two or three dimensional drawings). In this case is important to know the methods to relate this kind of information to the data acquired by means of laser scanner. Sometimes, during the digital survey, it's necessary to use different technical instruments (thermographical camera, georadar, or other three dimensional scan systems) in this case it's important to know the methods to connect this heterogeneous information during the survey operations or in a second step during the data processing.

4) The survey cannot prescind from a clear vision of a workflow in order to finalize acquired data to the production of elaborates demanded by the contractor or necessary to lead a research.
5) The work of data processing must always be carried out being aware that any type of operation executed on the raw point cloud model - in absolute the closet metric model to the physical object (Verdiani, 2001; Verdiani, Di Tondo, 2006) - will remove important metrical information.

The point number five show clearly the problematic connected to the digital survey based on the relationship between the fast access to the data and quality of the measure. Before we have said that "the quantitative" point cloud model is the closest "metrical copy" to the physical object, so in this way it's clearly that the main point cloud's future is the fidelity of the measure; the attention of the operators must necessarily refers to this characteristic especially in metrological and morphological studies of the architectonic structures. Now a day often the panorama of the three dimensional digital survey applications, especially in archaeological studies, optimized (now a day commercial software used to elaborate the data produced by means of three dimensional digital survey allow to link to the metric data (single point) the chromatic data from digital image acquired by means laser scanner or digital photo camera) point cloud model (using the point cloud applications tools, or converting the point cloud model directly in a three dimensional polygonal surface model), in order to produce a simple model suitable to represent the conservation of the architectonic structure. As a consequence of this is not necessary to consider the metric use as the main point cloud feature. On the other side, especially when the size of the acquired data covers completely the architectonic object, the conservation of high quality of measure became an heavy load for the hardware performance; moreover it's necessary to add to the demands for an adequate hardware system, the demands for software performance, in fact often software applications are not able to manage huge size projects, so sometimes those software limitations affect the operating choices done by the researcher more then hardware in itself. For sure, working on the point cloud model favours the management of the information, but limits the elaboration functions and the quality of those data representation, in any case is not only advised, but most times necessary the conversion of the point cloud model into a polygonal surface model (this consideration can't be not accepted by the large number of operators that prefer to maintain the information as point cloud data, but studying the structure of the main commercial software used to elaborate point cloud model, is possible to understand that the polygonal surface model allow more operative applications than point cloud and open new space of research).
The software (in the large panorama of commercial software used to elaborate point cloud model it's necessary remember: *Inus Rapidform* and *Raindrop Geomagic*) dedicated to the management of the data acquired by means of laser scanner have an clear workflow (the tools used to elaborate point cloud model allow to reduce the noise level, to convert point cloud model into polygonal surface model and to trace the main boundaries to construct a mathematical surfaces) that often guide, using automatic solutions, the operators during the model optimization; however these procedures, are mainly classified for industrial design applications, are not suitable for huge size point cloud models, which often is the resulting product of an architectonic survey.
Which are the modalities to process the points cloud data, which are acquired by a survey of an architectonic complex, in order to produce a model that is easy to manage by common commercial hardware and software applications and at the same time not afflicted by alterations of the measure? The solution could be in the theory that always guides the work of the surveyor, that is in the quality of searched measure; so the quality of the measure that we expect to find is the rule that guide all of the processing operations and that modify the quality of acquired raw data. In this way the point cloud model can be converted in polygonal surface model, but before it's necessary to decomposed point cloud model in portions characterized by homogeneous characteristics of searched measure, after this process it is possible apply to these portion the right decimation level and reduction of the noise level (during the data processing operations the software used to elaborate point cloud model allow to control the position and to quantify the metric deviation between the new polygonal surface model and the point cloud model). In order to comprise, in more exhaustive way, the operations we deal a case studies applied to the monumental complex of *Grandi Terme* in *Villa Adriana*, *Tivoli*, *Rome*.

### 1.3 Analysis of measure applied to the *Grandi Terme* in *Villa Adriana*

This research, now a day, is still under development, it has the main purpose in the deep acquaintance of the architectonic and compositive rules that guide the design of a monumental complex as the Villa of Emperor Adrian at Tivoli. During the last three years the Dipartimento *di Progettazione dell'Architettura* of Florence took place the digital survey (The survey was conducted during the *Premio Piranesi*, seminar that face museography themes in the archaeological area of *Villa Adriana*. Director prof Luca Basso Peressut, coordinator prof Pier Federico Caliari. During September 2004 was lead the survey of the monumental complex of *Grandi Terme*, *Grande Vestibolo* and some portion of the building called "*Pretorio*"; during September 2005 was lead the survey of the *Palestra* and the portion of *Cento Camerelle* in front of *Antinoheion* and the roman that lead to the entrance of *Criptoportico* located under the *Grande Vestibolo*) regarding some buildings inside the Villa; this data, linked to the previous published searches and to the large number of literary sources, become an important cultural patrimony to understand the urban and natural environment in which, just in twenty years, was erected the Adrian's monumental complex. The data acquired from the digital survey is very useful for this type of considerations, because not only document in detail the building's structures now a day unavoidably conserved as ruins , but also document with an high precision the conformation of the landscape,

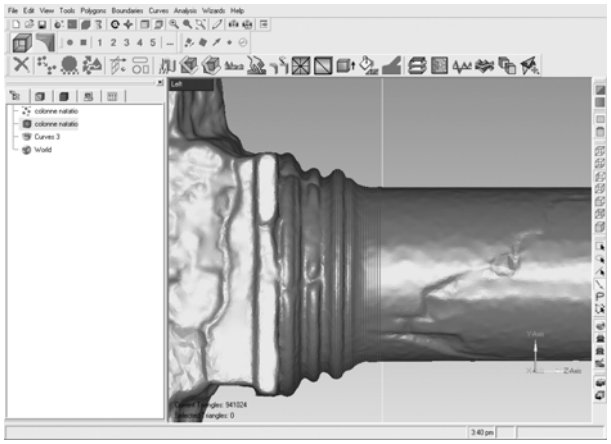

Figure 1. The three dimensional polygonal model obtained from the point cloud model of the column of *natatio*.

fundamental information in a complex inspired by Hellenistic theories, which is characterized by a sequence of different levels used as foundations for buildings. Moreover, it is important to specify that, when integrated by small excavations, the digital survey of landscape is useful to understand the connecting structures between the pavilions of the villa, that now a day, is really invisible, especially in the area between the *Terme con Heliocaminus*, *Palazzo d'Inverno* and building called "*Caserma dei Vigili*".

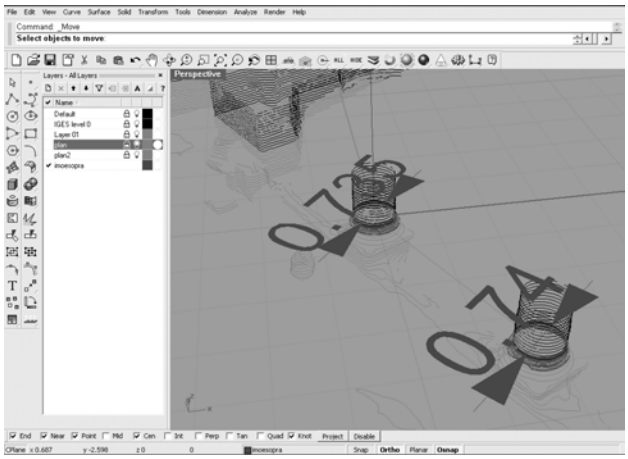

Figure 2. The analysis of measures of the *imoscapo* of the tow columns of *natatio*.

In this case the experimentation has been lead on the complex of *Grandi Terme*; since the beginning the search has tried to trace the base module employed in the architectonic scale for the construction of the building. Measure is a fundamental component in the architectural design; measure regulate the proportions of the *manufatto*, the "*dispositio vituviana*", so the correct lecture of measure related to the other information acquired during the operations of direct survey (lectures of masonry structures, architectonical typology, ecc…) is the main tool used by the researcher to understand the rules of architectural design. So it's important to define a rigorous methodology of surveying and data processing, that allow to create a digital model able to easily ménage the whole information, which are chosen according to the objectives of research. The experimentation is lead, as the literary sources advise (Vitruvio, Morolli, 1988), studying the diameter size of *imoscapo* and *soprascapo* of the columns of "*natatio*"(fig. 1). The model of the two columns is extracted from the complete point cloud model, the modest size (inferior to the meter) of the searched measure force to maintain completely the adhesion to the point cloud model and in this way to the real object; in fact in this case the data processing operations could introduce some minimal variations in measure which are sufficient to defect measure interpretation.

On the other side, the small portion of data processed, related to the two columns, allows to convert point cloud model into polygonal surface, maintaining an high quality of measure. The polygonal surface model put in evidence that the base module employed "m" is equal to 73,5 cm = 2,5 roman feet (fig.2) (Di Tondo, 2006). The traced base module is verified all the plant of the thermal complex, in this case the quality of the measure, the morphologic features of the architectonic building and the size of the three dimensional digital model allow to apply on the model data decimation level and noise reduction level in order to produce a polygonal surface easily used for metrological investigations. Measures verified using the plant of "*Grandi Terme*" (fig.3) has given a right confirmation about the base module chosen; the same analysis, executed at the urban planning scale (the whole Adrian's Villa complex), allows to characterize macro base module related to the composition of the entire Villa; macro module is a square "*actus*" side length equal at 120 Roman feet, divided in twelve same portions. The unit of measure used to design the buildings at the architectonic scale is the "*pertica decempeda*" (10 Roman feet) equal to four base modules of 2,5 feet; metrical condition admitted by the literary sources. The previous sequence of operations will lead to the creation of a three-dimensional polygonal surface digital model, in which the single portions respect the same level of detail in order to obtain the necessary quality of measures to lead correctly metrological investigations; moreover polygonal surface model can be elaborated by a large number of digital three dimensional applications, in this way it's possible not only to share model with other operators easily, but also integrated by external sources (two dimensional and three-dimensional drawings, bitmap, etc.). (fig. 4)

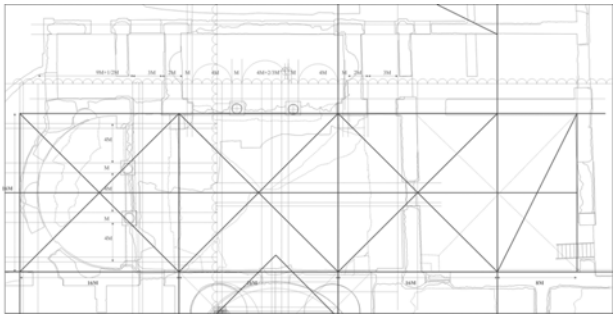

Figure 3. The analysis of measures of the plant of the Thermal Complex main hall

**1.4 The survey of unexpected aspects in architectural buildings**

As we said before the methodology of survey and treatment of the data processing are guided by a clear work structure which is possible through a good knowledge of the architectonic buildings or a clear vision of the constructive practices that has generated it; in this way it's not difficult trace the quality of measurers. This work structure wouldn't seem to consider one of the features of the survey executed by means of laser

scanner; the survey of the unexpected metric and morphologic aspects. During direct and topographical survey operations the surveyor chooses the measures just in order to his purposes. On the contrary the "quantitative" data acquired by means of laser scanner acquired during the survey operations, even finalized to purpose, is a good solution to describe completely the architectonic subject in all its parts with an elevated level of precision; this model could put in evidence some unexpected features. Many operators and researchers think that this property is the real innovation, especially in architectonic search, introduced by three dimensional laser scanner survey. This knowledge is made by the perceptive aspects of the point cloud model; in fact using three dimensional application tools it's possible to observe the model from different points of view and to characterize eventual morphologic anomalies present in the building, which are not visible from usual point of view. This application is useful especially studying vault systems or under ground systems related to the other structures over ground (Di Tondo, 2007). On the other side it's necessary to document metric and metrological aspects, which are recognized as anomalies, with an high level of precision in the three dimensional polygon surface model. In this case it's necessary to maintain the high quality of measures. The possibility to study these anomalies using three dimensional polygonal model and the possibility to associate to the polygonal model other external reference could help researchers for the interpretation of architecture complex.

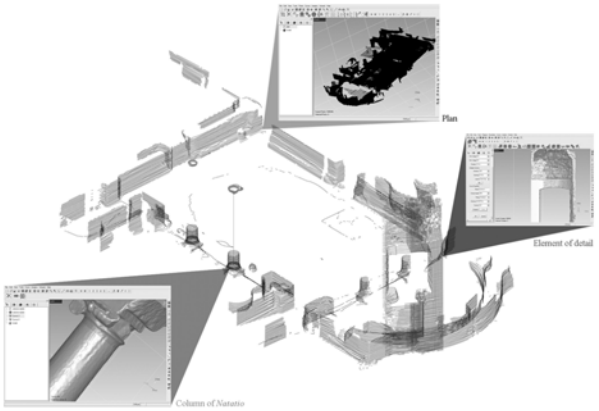


Figure 4. The three dimensional model (wire frame mode) in which the single portions respect the same level of detail in order to obtain the necessary quality of measures.

**1.5 Conclusion**

Now it's necessary to put in evidence the main concepts in order to produce a short list of the indications to respect in during the digital survey operations or, later, during data processing.

The survey operations and the data processing are closely connected and they are guided under the purposes for which we decide to take the survey.
The digital survey cannot be considered just a simple massive data acquisition; the survey operations should be planned in order to produce optimized data for the following data processing operations.
The point cloud is just a digital measurable model of the real object, so it is absolutely not sufficient to describe the features of an architectonic building.

A correct use of the computer science applications at our disposal allow us to relate data acquired from the digital survey with other external information obtained from the traditional survey or through advance technologies about the architectonic building. This operation is possible just to convert the point cloud model into a polygonal surface model respecting the indications which are illustrated before.

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