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DIGITAL ARCHAEOLOGIES, MATERIAL WORLDS (PAST AND PRESENT)

PROCEEDINGS OF THE 45TH ANNUAL CONFERENCE ON COMPUTER APPLICATIONS AND QUANTITATIVE METHODS IN ARCHAEOLOGY

GEORGIA STATE UNIVERSITY, ATLANTA, GA

EDITED BY
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Quality vs Quantity: Advantages and Disadvantages of Image-Based Modeling

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Abstract

In the last few years, survey has changed radically thanks to progress in the field of 3D, massive data acquisition methods. The scientific debate focuses on the control over data quality by comparing Structure from Motion acquisition methods with consolidated methods. Collecting and interpreting a large amount of information helps us deeply understand our cultural heritage. This system of knowledge that we create has to achieve a dual objective: to document heterogeneous data with guaranteed repeatability and to ensure data quality during data capture and model processing. This information includes cultural resource data: dimension, information on construction, material characteristics, color; etc. The case study, the Abbey of Santa Maria della Matina, focuses on the shift from quantitative data, acquired in a semi-automatic manner, to qualitative data, controlled under uncertainty. In this framework, all branches of the "Science of Representation" ensure metric, spatial, and formal control of the built models.

Keywords: integrated survey, models, color, scale

Introduction

Every organism of architectonic heritage is a complex system that embraces interlinked tangible (material) and intangible (non-material) values which equally contribute to its overall value. In order to grasp its "essence," it is necessary to study it properly, carry out enquiries that go beyond its exterior aspect and include its significant (constituent) elements. In other words: it is necessary to survey it. Indispensable in achieving this objective are all the surveying activities directed towards generating a deep knowledge[1] of the artifacts and features being studied. Taking into account the cultural significance of the object of study and having subjected it to observation and proper cognitive processes, the surveyor enters into a dialogue with the structure so that it becomes possible to preserve it correctly and communicate its value (Docci and Maestri 2009). Knowledge is propaedeutic for the evaluation and preservation of cultural heritage, both of which are intimately related with innovative technologies in all the stages of the preservation process: acquisition, management and sharing.

Nowadays, observing how this process is tackled, we can only conclude that the instruments of massive acquisition, digital representation, the use of systems of fast communication of raw data and 2D/3D models have become almost the only vectors for the study and communication of the architectonic and archaeological artifact. Technological developments of the last two to three decades has profoundly changed the process of knowledge generation. While the contri-

1 Whenever in the course of their evolution human beings confronted complex phenomena, they invariably sought to develop strategies which enabled them to overcome the limitations imposed by their senses. Descartes demonstrated clearly that this involves two different kinds of knowledge: the common-sense knowledge (which we acquire through experience) and the profound knowledge that can be reached solely by methods and techniques exclusively related to the mind and which are beyond the capabilities of our senses.

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bution of the scholars at each stage of cognition must be considered indispensable, it has become evident that the new instruments have transformed surveying operations into semi-automatic procedures capable of gathering millions of points at a low uncertainty level. The phrase "digital building recording technologies" leads us to a relevant gathering of data that are accurate and efficient, but until now the measurable aspect of a building cannot be considered exhaustive for its cognition. Hence, the necessity to study the dichotomy between quantity and quality of the data inherent in every survey carried out with instruments of massive acquisition. While the term "quantity" refers to physical parameters, coordinates, positioning and geometry, all of which define the artifact, "quality" describes its contingent or permanent properties, the formal aspect concretely determined. The control over data "quality" is connected with the set of parameters which define the measuring properties: precision, uncertainty, repeatability, accuracy (Yasutaka and Ponce 2009; Ippolito and Bartolomei 2014). Quality is also involved in the capacity to consider all the aspects of the artifact that make a better understanding of its intangible values (chromatic, material, those concerning its preservation and its context).

Acquired information considerably improves qualitatively when we integrate diverse methodologies, considering that each of them fills in the gaps left by others. While the research objectives are various, they rest on the profound knowledge of an architectonic complex, deeply stratified, whose complexity will be enhanced through a synthesis of digital models with a correct interpretation and management of information. Specifically, the enquiry will be oriented towards an analysis of the quality of the data acquired massively, ranging from the urban scale to that of the architectonic detail. The other fundamental aspect of the study, after years of consistent use of the laser scanner, which is a high cost surveying instrument, is to compare it with the results of using low cost acquisition instruments (with the use of open source software at the stage of elaboration rather than the paid variety) in order to test the level of detail that is possible to achieve in terms of metric accuracy as well as metric, chromatic, and surface information[2].

2 The comparison between high cost and low cost survey instruments is possible because they give analogous result in terms of models (numerical model) and edit operation to construct mesh models. In fact, for some years, SFM allows a user to get analogous results as 3D laser scanner for just the cost of a simple camera.

Reflections on the Surveying/Survey Operations

A few decades ago, any consideration of cognizing a cultural artifact had to take into account a series of limitations inherent in the traditional instruments applied as well as the long time it took to acquire information. The consistency of data gathered often proved to be insufficient and inadequate to obtain results that were scientifically valid. The construction of the model was the fruit of a series of attempts when the discontinuities to be measured were selected prior to starting the acquisition operations. Nowadays, the continuous advances of technologies and the development of ICT (Information and Communications Technology) offer innovative instruments, updated and improved in a short time span, that are more economic and faster, more easily applicable for scientific research for the acquisition and subsequent elaboration of models.

Even though the density and accuracy of locational data acquired through 3D scanning or SfM reduces the danger of a subjective interpretation, it should be understood solely as a starting point for subsequent, in-depth analysis. The analytic phase of data acquisition and gathering of any information that can serve to increase the knowledge of the object under study adds to the complexity of 3D surveying (Chih-Heng et al. 2010). The "baggage" acquired, which at this point emerges solely in its quantitative aspect, should assume a qualitative value. In order that the final quality of the model is not compromised, one must adopt a critical standpoint at the stage of massive data acquisition and pose questions on fundamental aspects, like resolution, accuracy, precision, and evaluate all the parameters accurately, such as: the choice of the instruments, the characteristic features of the object surveyed, distance, sample spacing, etc.

The subsequent stage of the survey, understood as the process leading to the construction of models, constitutes a qualitative operation carried out with the view to deepen our knowledge of the artifact and is rooted in the quantitative component of the massive data acquisition (surveying). Nowadays, surveying methodologies and techniques enable us to capture millions of points on architectural surfaces and link those points to the scale of the models to be constructed (Wojtas 2010). Hence the survey is responsible – through the construction of 2D/3D models, for the representation of all the characteristics extracted in the process of surveying. Thus, the survey emerges as a cultural process, which identifies distinctive characteristic elements and initiates the process of selection; albeit with a great number of objective data at the point of departure and a through interpretation of the critical capacities of the operator.

The use and integration of the instruments for massive point acquisition has reversed the ways of selecting and measuring done traditionally: the significant points are now selected after having been acquired (Docci, Bianchini, & Ippolito 2011). The construction of the object obtained directed towards the profound knowledge, to use Descartes' terminology, of the edifice to which it corresponds, is by no means co-related only with the great quantity of points gathered but also to the quality and type of information and its correspondence with reality. The result of the process will depend on the equilibrium struck between the quantitative component, related to the abundance of data acquired in the course of surveying, and the qualitative one linked to the choices critically decided upon at the stage of elaboration and leading to the construction of the survey, in accordance with the principle of data irrefutability[3]. If the result obtained passes the falsifiability test, we can consider it to be scientific.

In this manner 2D/3D models contain more than metric data, namely other heterogeneous information of equal or even greater relevance to the purpose of protecting and preserving Cultural Heritage. Among them we can count the information on construction aspects, identification of possible modifications introduced in the past, characteristic features of the materials, the color, the state of preservation, etc. The principal objective is to establish a bijective correspondence between the real object and its model, reducing the complexity of numerous multidimensional data acquired and synthesizing them within the very model that will describe reality through geometric entities, like points, lines and surfaces. Apart from being suggestive of reality, the 3D model must be the fruit of an intelligent activity of selecting variables that are capable of communicating the artifact on the basis of predetermined goals (Bianchini, Inglese, & Ippolito 2016).

We can conclude, therefore, that constructing qualitative models is based on the principles of the method that can be considered practical and theoretical at the same time and which finds corroboration in the rules of René Descartes' "Discours de la méthode" (1637).

These rules, defined as evidence, analysis, synthesis, enumeration, and revision can be considered stages in the process directed towards the scientific construction of a model where the passage from objective to subjective data inevitably transforms quantity into quality. This set of procedures can be defined as the starting point for structuring out a critical operative method that will lead to the representation of the artifact, taking into account the objective component acquired preliminarily. Acquisition of data conceived as measures, and of metadata, conceived as information on the process, must be carried out in accordance with the uncertainty level adopted. The various data must then be archived accurately and shared so that they became easily accessible to all members of the scientific community.

Even though nowadays the surveying and survey operations are realized almost exclusively with digital means following a pre-established sequence, what is often missing from the operative practice is the complete and reasoned out standardization of processes. This would make it possible to fix quantitative and qualitative features of objects analyzed in relation to the methodology applied as well as to the scale of models. Hence, it is a correct approach to take into account the structure and quality of data in accordance with their limitations and potentialities but also with their ability to superimpose and complement each other in order to provide a digital database containing heterogeneous elements in an organized manner.

3 The principle of falsifiability is the criterion formulated by Karl Popper (Reale, Antiseri, & Laeng 1986) for differentiating controllable theories from the non-controllable ones. This particular interpretative model is based on the error in which the truth emerges as the fruit of scientific progress characterized not by accumulating certainties but by progressively eliminating errors. According to the falsifiability criterion, a theory – in order to qualify as scientific – must be proved to be falsifiable, i.e. there must exist conditions of at least one experiment which can demonstrate the theory to be completely false, incompatible with facts. Thus, un-falsifiability or irrefutability of a statement (theory) is not a virtue, as it is often claimed, but a vice. Each genuine test of a theory proves to be an attempt at falsifying or refuting it. Controllability coincides with falsifiability with some theories being controllable or exposed to confutation and others not so much. The latter ones, one might say, run considerable risks.

Figure 1. Location of the Abbey of Santa Maria della Matina, San Marco Argentano, Cosenza, Italy.

The Abbey of Santa Maria della Matina. Three Interpretations from the Large to the Small Scale

One of the nodal points in this research is the definition of model typologies we can construct with systems of massive data acquisition (high or low cost) in relation to the information that the very same models transmit in representation scale fixed at the point of departure. Another fundamental aspect seems to be the comprehension of the quality level of the models based on the diverse methodologies performed as well as their scalability (Alby et al. 2009).

The Abbey of Santa Maria della Matina at San Marco Argentano (Cosenza, Italy) is an ancient complex of buildings founded in AD 1065 as a Benedictine monastery. Later it became the property of the Cistercian order. The preset configuration of buildings corresponds only in part to the original plan. In AD 1652 part of the Abbey was abolished, and the whole was turned into a manor farm. Nowadays it belongs to the state. The particular structure and the

Figure 2. The Abbey of Santa Maria della Matina: a secret piece of Cultural Heritage.

material aspect of the edifice have been found to be amenable to an in-depth study of a series of problems, for example that of metric accuracy and the information that can be drawn from its chromatic data, both of which are fundamental for the cognition and documentation of architectonic heritage on various scales.

By establishing the adequate representation scale during the stage of survey planning, we can critically describe various characteristics of the object under study.

The decision was made to study various subjects in-depth, which were selected from the organization of the architectonic complex in order to evaluate the efficacy of integrated surveying. This included the main façade, which delimits the internal court on urban scale, the chapter hall on the architectonic scale, and a column capital on the detail scale. The research was conducted only on the external surfaces. The surveying operations have been carried out following the project of a unitary survey. However, one of the characteristic features of the artifact is its complex articulation related to the different construction stages in which the edifice was realized as well as to its transformations and the recent restoration of some of its features. Theses peculiarities, apart from

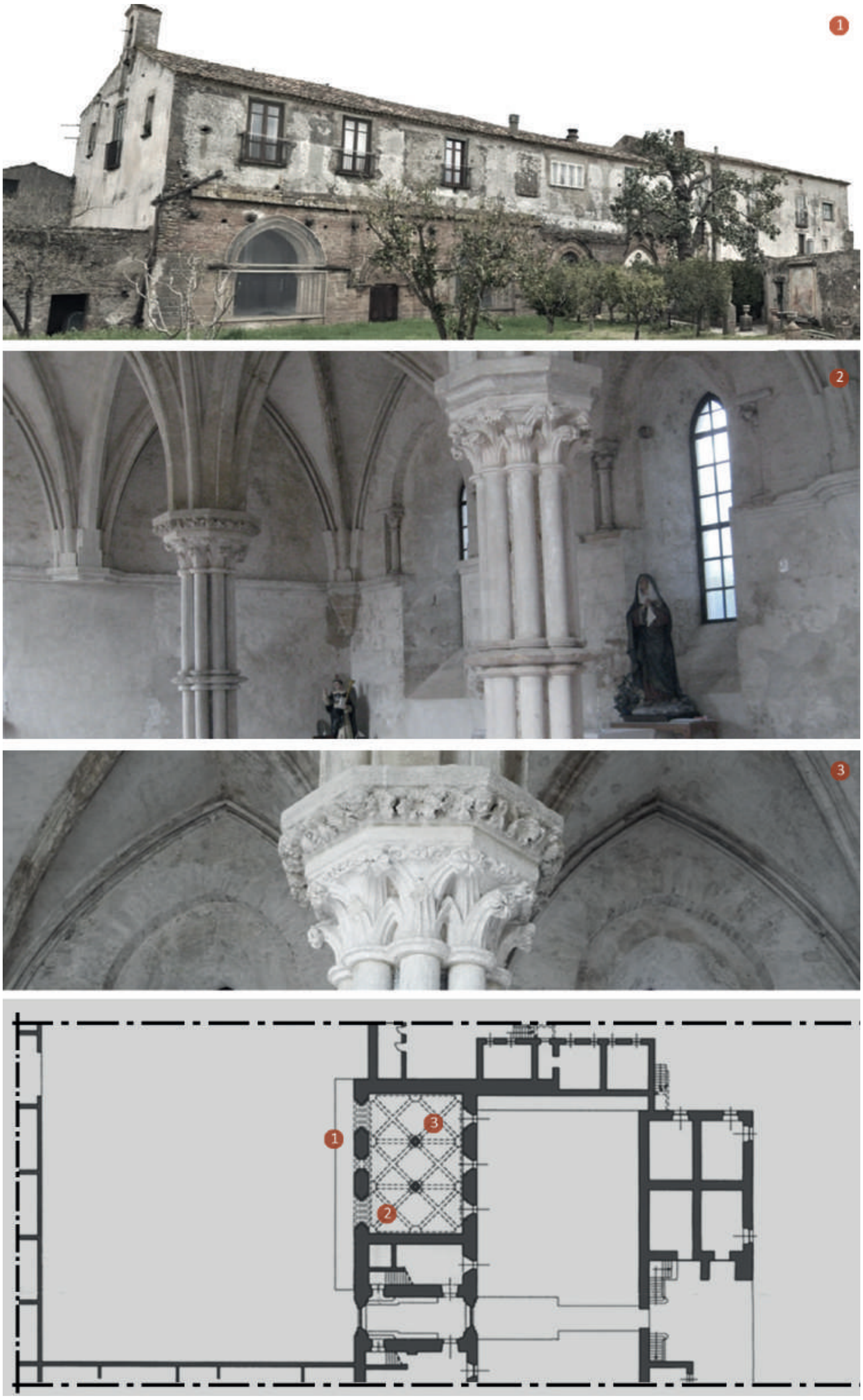

Figure 3. Three case studies on three different scales:
1) urban scale,
2) architectural scale,
3) detail scale.

the adopted aim to represent it on different scales, have yielded concrete premises on the basis of which to work out a project of the survey both general and detailed.

The three case studies were analyzed independently of one another, although a project of placement survey has been executed. During preliminary planning, indispensable for carrying out the survey scientifically as well as for speeding up field activities, problems of a methodological nature were addressed and following the almost well-established practice the decision was taken to integrate various methods and instruments (Baglioni and Inglese 2015; Bianchini 2012; Bianchini, Inglese, & Ippolito 2016). Data acquisition carried out through integrated instrument surveying[4] availed itself of various non-contact surveying methodologies (3D laser scanning, Structure from Motion and Image Matching, photo-rectification) with the goal of obtaining global representation, detail representation, or a specific analysis of material aspects of surfaces (Brown and Lowe 2005). The information acquired have then been organized in order to make sure that the cognitive picture of the object under analysis be as complete as possible. The approach adopted envisages a comparison of data for all case studies obtained in the familiar process of 3D laser scanning with the data provided by expeditious and low-cost methods, like Structure from Motion and Image Matching (SfM/IM). We then compared the metric accuracy and the information derivable from the color data and surfaces, all with the aim to construct models on the 1:50 scale[5]. In fact, we can now assess the metric accuracy of numerical models by managing two parameters: probe and sample spacing[6].

4 A 3D laser scanner Leica Geosystem C10, a Leica total station Geosystem TS02, a photo camera Reflex Nikon D90 with 35mm focal length, a photo camera Reflex Canon 450D with 50mm focal length were the instruments used.

5 Digital representation retrieves the three-dimensional character of the object surveyed. In the realm of the virtual, the graphic model can be represented without being reduced in scale in relation to reality. It can be said, therefore, that also with digital models it is possible to attribute reference to scale in order to identify its capacity to reproduce reality on the basis of the level of detail and the uncertainty possible to achieve (Bianchini 2012).

6 In the project the two main parameters of scanning, that is sample spacing (scanning pitch transformed into a sphere which covers ideally the part to be surveyed) and the probe (the radius of the very same sphere) have been defined in terms of the objective of the survey. Considering that the distance between two successive points has to be approximately compatible with the uncertainty level - controlled on the basis of the scale and the final elaborations to be realized – the sample spacing of 1cm x 1cm and the variable probe between 4.00-8.00 m for internal ambiences and between 8.00 and 20.00 m for external ones have been set up. For some details, like parts of the walling in case of the facade and elements of particular architectonic value as in the case of the chapter hall, scans with the sample spacing of 5 mm x 5 mm or 2 mm x 2 mm have been conducted.

Massive Data Acquistions: High Cost and Low Cost Technologies

A general survey of the whole architectonic complex was the first step in the research conducted. The survey project envisaged the adoption of the open polygonal topography formalized into six stations. It started at the entrance to the edifice and ended in the chapter hall. Topographic measurements enabled us to acquire 50 targets useful for adjusting the system of reference with that of the laser scans as well as for positioning significant points applied to support photographic rectifications. Laser scans were carried out by positioning the instrument at exactly the same points as those of the polygonal topography stations.

The project for the photographic survey of the façade was planned for a long time, the façade being the most complex part of the edifice considering its size, the material stratification, as well as vegetation, which partially covers the edifice, and differences in the altitude profile. All these elements considerably influenced the possibility of distributing the “takings” in a homogeneous way and so, the 64 photographic shots[7] were taken at various distances, in some cases from a point very close to the façade. The process of photographic acquisition was followed by photo elaborations done with Agisoft Photoscan[8]. The model of the façade was realised part by part, seeing that some photos taken from too short a distance from the object invalidated their overall construction.

The definition of the final model with SfM/IM was possible by comparing it with the point cloud obtained with laser scanning. This course of research allowed us to evaluate its precision level (El-Hakim 2006; Goesele et al. 2007). The first registration was carried out by following a manual procedure which imposes the necessity to recognize homologous points in two different clouds.

The model obtained through this procedure,

7 Effected with a Nikon D90 with the focal length of 35 mm and 50 mm.

8 In the course of the research, three other open source software packages, Arc3D, Photosynth, 123D Catch, were compared with Agisoft PhotoScan. Paid software was chosen because of a great number of vertexes/polygons with which it generates meshes in comparison with others, and because of the higher resolution of images that it can handle.

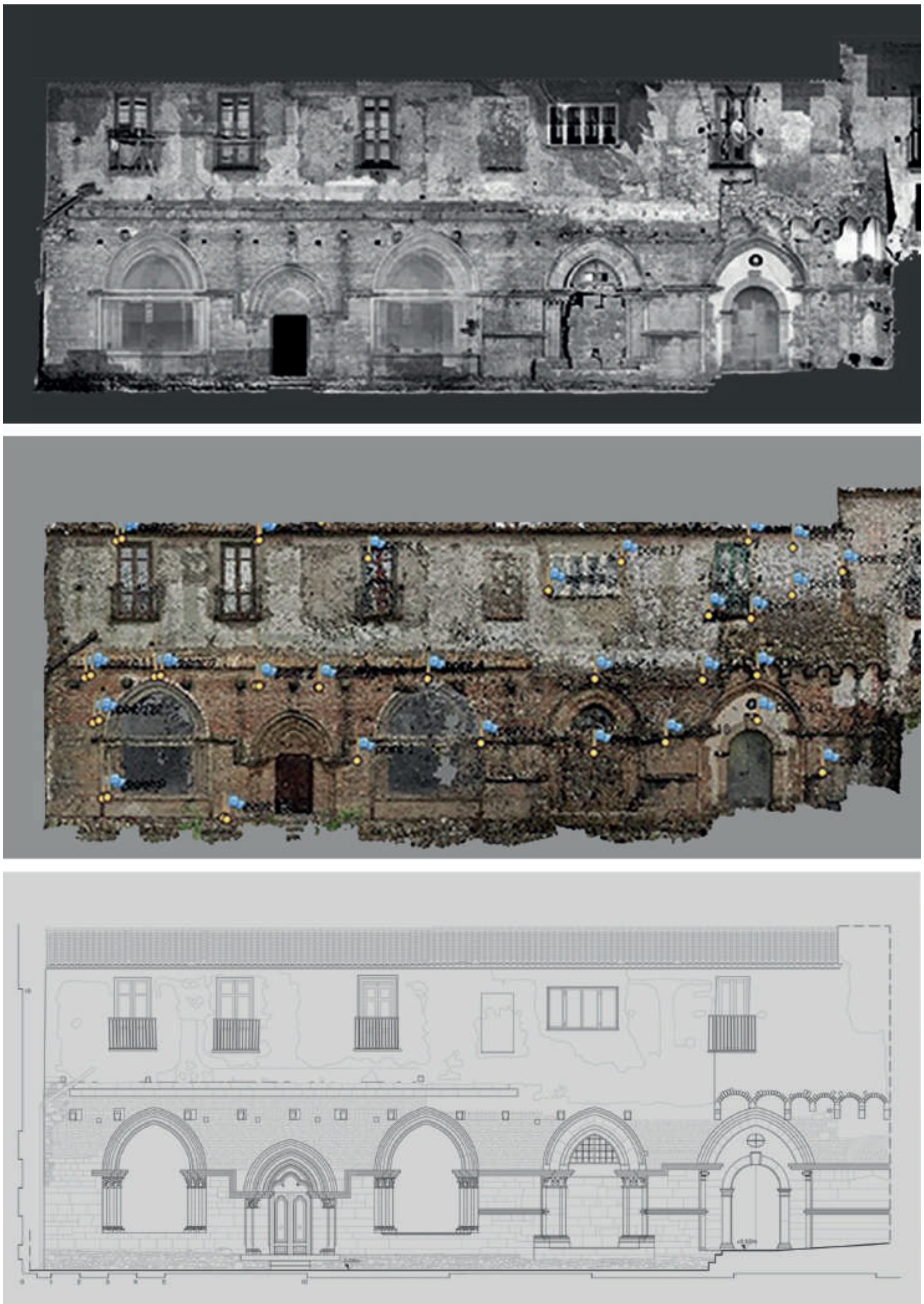

Figure 4. Urban scale, the Façade: numerical model derived from laser scanning, numerical model derived from Structure from Motion and Image Matching, architectural 2D model.

compared by means of open source CloudCompare software with the cloud point acquired by 3D laser scanning, revealed an average deviation of 3.7 cm[9]. Considering the metric quality of acquired points paramount and the uncertainty level linked to their identification in the photographs, we decided to make another registration attempt using 30 targets topographically measured and some points on the façade. The new registration was more accurate that the first one. It yielded 10 million points and was again compared with the numeric model derived from laser scanning. This time the average deviation was 1.6 cm. This was found to be compatible with the results we expected, as far as the metric aspect was concerned, and suitable to 1:50 restitution scale, whereas the first registration could only support the 1:200 scale.

9 The measurement is a set of three data: number, measure unit and uncertainty. The latter can be assessed with proper mathematical procedures. The standard deviation or average error can be referred to as the uncertainty of the measurement. Standard deviation is an index of statistic dispersion, that is, the estimation of datum variation. This is what is often referred to as the measurement error.

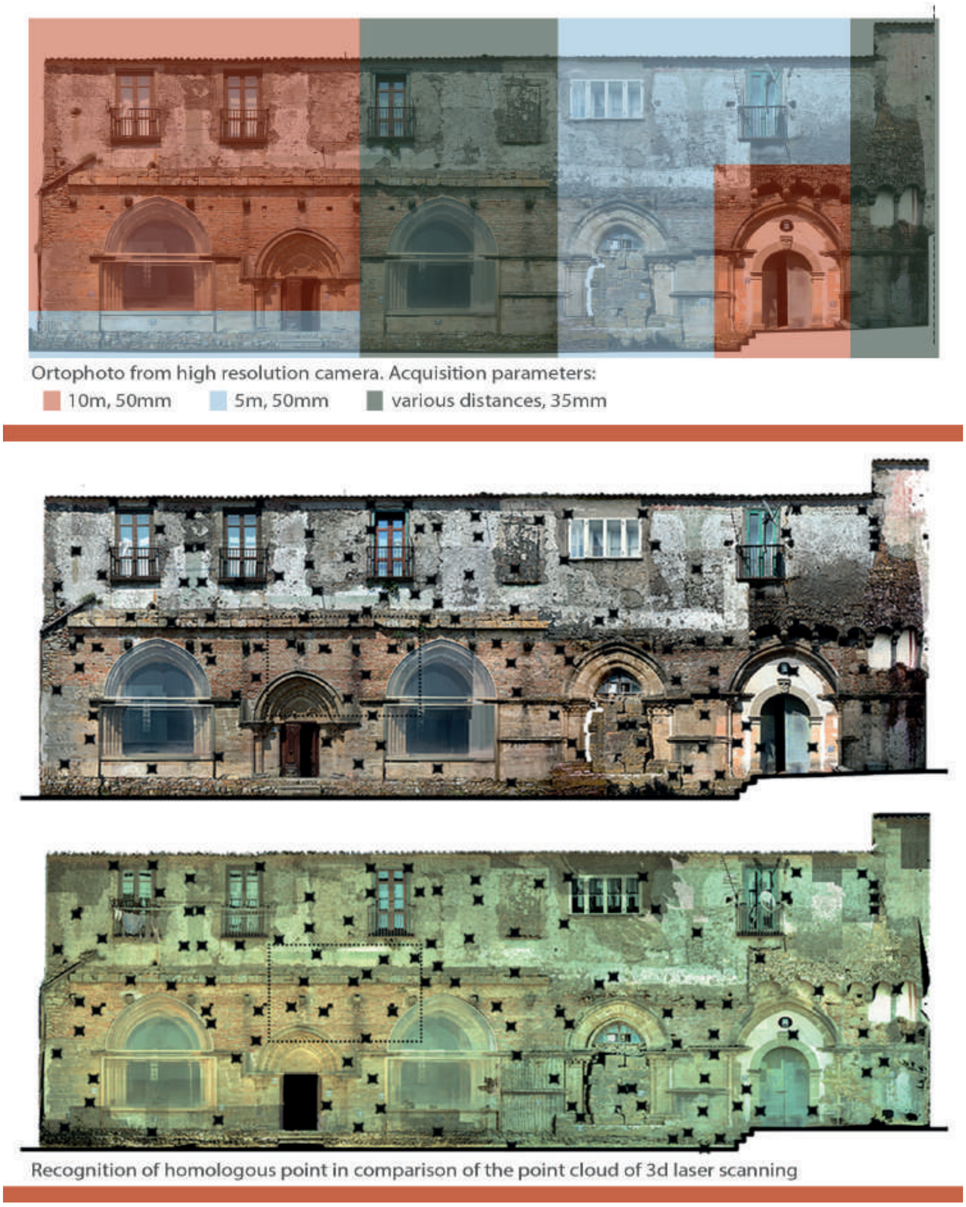

Figure 5. The construction of the orthophoto of the façade derived from high resolution camera.

Also, a photographic campaign had been carried out for the façade[10], photographs having been taken at different distances from the object, in order to obtain images to be rectified by the RDF opensource software, and then, by postproduction operations to construct photo plans. The average scale of the photogram[11] made it possible to construct a 1:100 scale model.

Having obtained the information necessary for representation at a large scale, we applied the same procedure for surveying and representing at an architectonic scale. The procedures adopted for the Chapter Hall confirmed the results obtained earlier, so the optimization of the numeric model obtained after 118 shots[12] and with 32 targets, allowed us to reach the average deviation around 1.7 cm, which made it possible to construct a 1:50 scale model. Also, in this case, the deviation was calculated by comparing the cloud obtained with SfM/IM with the cloud of the laser scanner.

The last case study was at the architectonic scale. It concerned specifically the capital in the Chapter

10 Realized with a Nikon D90 with the focal distance of 35 mm.

11 Mean scale of the photogram: the relation between the dimension of the photogram and the real object dimension represented in it, obtained with the formula $1/s = f/D$, in which s = photogram scale, f = focal distance, D = average distance between the object and the camera.

12 Carried out with A Nikon D90 with the focal distance of 35 mm.

Figure 6. Architectural scale, the Chapter House: numerical model derived from laser scanning, numerical model derived from Structure from Motion and Image Matching, architectural 2D model.

Hall. Its model has been constructed on the basis of 26 images[13]. In this context the SfM/IM technique, thanks to the effortless handling of the camera in comparison with the laser scanner, proves to be able to resolve all the limitations generated by shadow zones and undercuts that then produce considerable gaps in the data. Because the average deviation achieved in the last case was 0.14 cm, it was possible to edit the elaborations to the 1:10 scale.

13 Obtained with a Nikon D90 with the focal distance of 50 mm.

Figure 7. Detail scale, the Capital: numerical model derived from laser scanning, numerical model derived from Structure from Motion and Image Matching, architectural 2D model.

The best results, therefore, can be obtained at the medium and small scale, whereas for the large-scale models, integration with other methodologies provided the indispensable control parameter. Hence, clearly, the data extracted with integrated surveying methodologies prove to be not solely comparable, but – considering the error deviation achieved – help structure out a heterogeneous database of information that can describe the object analyzed more completely..

Datum Color: Instrument of Knowledge

Having demonstrated that cognition of architecture at any scale does not end with identifying its geometric and morphological characteristics but has to be based on a selective and specialized reading of various aspects, we proceeded with an analysis of the object taking advantage of additional data acquired earlier. Another type of comparison we wanted to experiment with was that obtained from the interpretation of the RGB datum acquired with different surveying methods (laser scanning, SfM/IM, and digital photograph accurately rectified), which help towards the chromatic and material cognition and reading of surfaces and of the state of their preservation.

The case studies demonstrate that the resolution of the texture of the mesh model obtained with SfM/IM is superior to that acquired from images provided by a laser scanner for visualizing the point cloud with the RGB mode. This feature makes the model derived from SfM/IM more adequate, with respect to the scale initially adopted as the objective to be attained, to document with more reliability and coherence the state of the object as well as the changes it was subject to.

However, acquisition with the laser scanner also makes it possible to visualize the RGB data in reflectance mode[14].

A comparison of the data acquired with various techniques of massive acquisition show that this very datum inspires interesting considerations on the preservation state of surfaces. Reflectance constitutes a parameter which operates on the extension of the scale of chromatic values and thus enables us to better assess material discontinuities, degradation phenomena, traces of old coloring and information not easily deducible. Therefore, visualizing views in parallel projection of the numeric model in the RGB mode of reflectance at a specific interval of values, it is possible to glean, on the basis of various visible colors, information that is not immediately perceptible to the naked eye on the texture and layers of the artifact under study. Relocation of chromatic values in various ranges (in this concrete study the interval of values that made for a better visualization of phenomena was identified to be between 0.18 and 0.48, dividing continuously the field into four bands of further limited values) made it possible to read specialist aspects like the plastering, mortars, mural parameters and their coloring as well as the state of degradation, identifying old and recent parts, like, for example, doors installed at different time periods.

14 Reflectance indicates the proportion of light striking a surface which is reflected off it. This value has a physical significance linked to the characteristics of the material of which the surface struck by a laser is made.

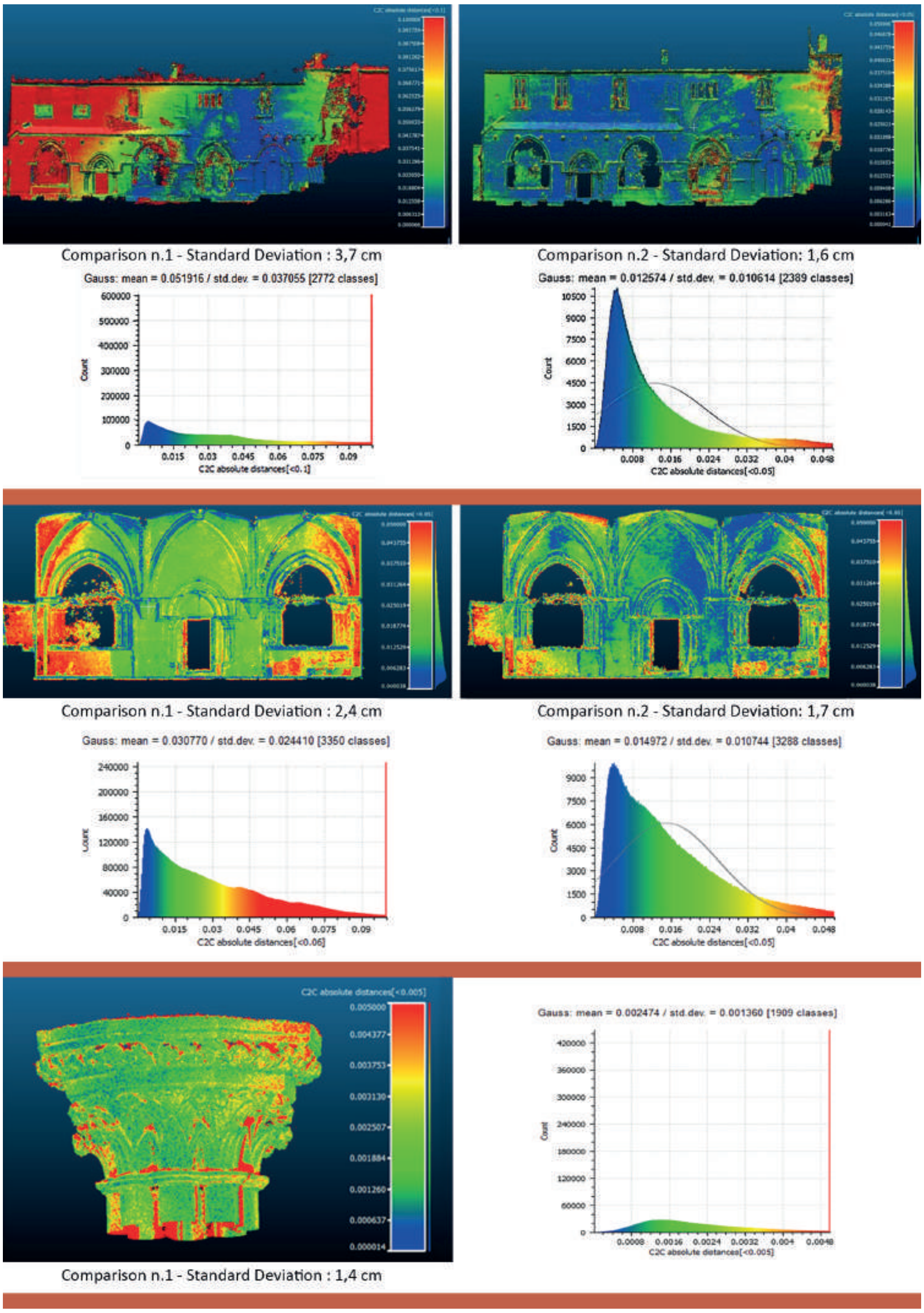

Figure 8. Comparison between numerical models derived from laser scanning and Structure from Motion and Image Matching, with software CloudCompare, for the three cases studies, and evidence of their deviation graphics.

Conclusions: Beyond the Digital

The integration of massive acquisition instruments, re-formulating the traditional process of defining classical 2D elaborations, integration of digital representation techniques, the possibility to communicate through innovative output, they all have provided the basis for investigating all the material and non-material aspects fundamental for understanding the architectonic complex analyzed. The present study made it possible to clarify certain problems connected with the possibilities to compare and superimpose a series of information on reality by applying multiple surveying methodologies. It has again demonstrated the efficiency of the integrated approach. Availing ourselves of a series of thematic models and the analysis of constitutive elements of the objects under study derived from various reading modes, we were able to arrive at a clear understanding of the significations that the attentive surveyor has to be able to grasp and communicate, all the time having in mind the critical stance towards the whole process.

Figure 9. Orthophoto of the façade obtained through three different methodologies: High Resolution camera, Structure from Motion and Image Matching, Laser scanning-RGB mode. Comparison about RGB data.

The comparison of models reveals that the two methodologies, mainly used nowadays, the laser scanner (high cost) and the SfM/IM (low cost), yield results different for the urban, architectonic and detailed scales. In general terms, the advantage of the low-cost methodology is the speed of acquisition together with the fact that it is easy to use and to transport, economic, and that it ensures the repeatability of the whole process. However, the acquisition procedures are still strictly dependent on the nature of the object analyzed and the context in which it is set. The best results have been obtained in the case study at architectonic scale and that of the detail. As concerns the large scale, we have not been able to liberate the process from other integrated methodologies to guarantee proper metric accuracy.

It is almost obvious now that the massive acquisition technologies have to be integrated according to the potentialities inherent in each of them, the objective being to construct heterogeneous models exhaustive in all their aspects. Moreover, it becomes indispensable at the historical period when the use of massive acquisition instruments and digital representation are already a language spoken and accepted, that the researcher be able to grasp not only the canonical applications, but also the potentialities of the means at his disposal to use them to his advantage in a critical and alternative manner in order to reach the highest level of cognition of the artifact. The importance of two fundamental aspects which open and close the whole process seem to become apparent: the survey design and data archiving. Hence planning activities to be carried out and choosing instruments adjusted to the scale of models to be studied prove to be fundamental. Equally indispensable in the digital epoch is the correct administration of

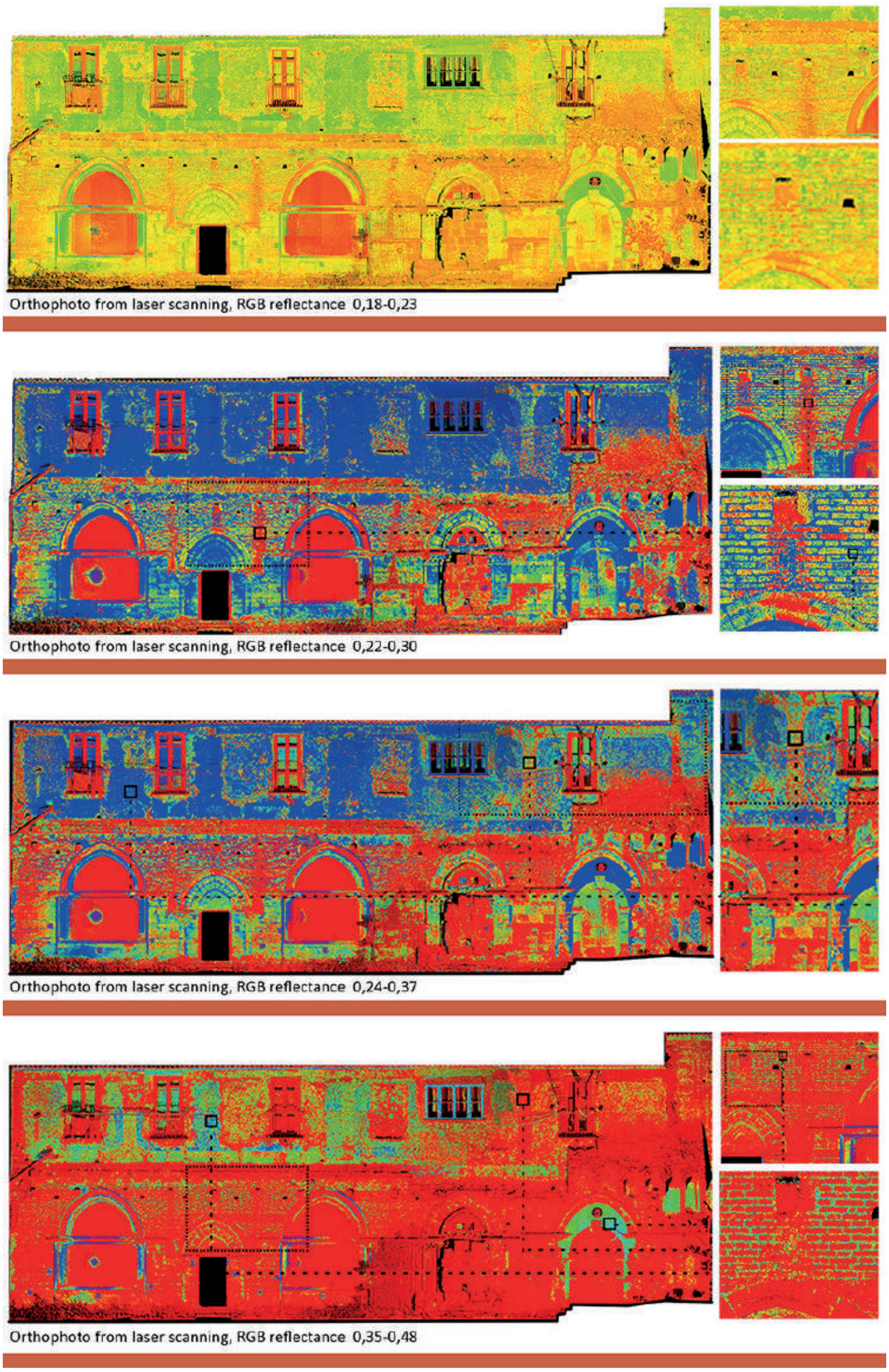

Figure 10. Orthophoto of the Façade obtained through laser scanning-reflectance mode, into 4 different extensions of the chromatic scale of values.

the data obtained both before their acquisition and after their elaboration, including the factors of sharing and implementation. Models constructed on the basis of various assumed objectives will become an integral part of the database which will allow us to achieve what we aspire to: a really profound knowledge of the artifacts we wish to preserve and communicate.

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