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SURVEY AND MODELING: FROM THE PROCESS TO A METHODOLOGY

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Abstract

Documentation of architectural and archaeological heritage must be a multidisciplinary approach that enables analysis and interpretation from many fields of expertise. Nowadays, the representation of the architectural/archaeological survey represents a monumental change in capabilities thanks to the acquisition and alignment of massive survey data describing the geometry, appearance and context of the target environments. The construction of models is the point of departure for essential activities – from cataloguing to preservation, from design to restoration and valorization – linked to the knowledge of Cultural Heritage. The presented research focuses on the control over data quality from massive 3D acquisition, in terms of metric accuracy, by comparing 3D image-based acquisition methods with consolidated methods, in order to present the enormous potentialities inherent in models obtained through 3D surveys.

Keywords

Cultural Heritage, surveying, survey, 3D massive acquisition, 2D/3D models

1. *Introduction*

An enquiry into a work of architecture signifies investigating a physical space constructed and experienced by man ever since his appearance on earth as well as analyzing elements that vary from structures of great dimensions to the smallest objects. Corresponding to this dimensional variety is a series of problems connected with the instruments, which enable us to acquire knowledge about these objects; a knowledge conceived in terms of the synthesis of surveying and the survey. To the former belong all the operations indispensable to determine elements necessary to fashion the characteristics of the object under study; ascribed to the latter - through model construction – the representation of all the characteristic features identified in the preceding stage of surveying. Hence the operation of cognizing becomes a synapse (*σύναψις*) between the theoretical aspect and the operative one. Observing the process of knowledge of the work of architecture, we cannot disregard that instruments of massive data acquisition and digital representation have become almost the only intermediaries for the study and the communication of the cognitive process.

In the past the subject of the process of cognizing an artifact was strictly linked to the problems intrinsic in the traditional instruments applied as well as to the prolonged duration of data acquisition. Moreover, the quantity of information acquired often proved to be insufficient and inadequate for scientific purposes while the high subjectivity of representation yielded reinterpretations of little congruence with the object studied. The technological advancement of the last two to three decades has radically changed the process of knowledge due to the development of instruments that have transformed surveying operations into semi-automatic processes capable of gathering millions of data points at a very low uncertainty level (Bianchini, Ippolito, Senatore, Borgogni, Capiato, Capocefalo, & Cosentino, 2012). Thanks to these advancements we are able to construct detailed models that allow extensive cognition of the object by reducing the possibility of subjective interpretations. It is also now possible to share the raw data and 2D and 3D models faster than ever. Application and integration of instrumentation for massive data point acquisition has completely revolutionized a process in which the construction of a model was previously the fruit of a long process where the discontinuities of measuring had been selected before starting to gather data. Nowadays, the survey, understood in terms of a process aimed at constructing 2D and 3D models, has become a qualitative operation of profoundly cognizing the object of study and a result of the quantitative surveying process of massive data acquisition.

The presented study has been undertaken with the goal to better understand the future developments of this field of study within the domain of Cultural Heritage, which become more and more connected and dynamic (Addison & Gaiani, 2000). The methodologies and procedures applied in surveying open up an operative possibility to make the continuity of reality discrete by measuring a finite number of points – and that means to carry out a process of selection thanks to which one can expose an object of interest (Docci & Maestri, 2000). Such an operation results in reducing the geometric complexity of real objects to points, lines and surfaces including the act of selecting, extracting and interpreting some of the infinite information at one's disposal. What is more, is that it makes implementation of the survey difficult when the theoretical foundations at its base prove to be unknown. Hence, understanding the concepts of surveying and of the survey – especially in view of the extensive diffusion of massive acquisition technologies[1], must be considered fundamental for managing and controlling to our best ability the process[2] that includes heterogeneous instruments and data types. (Docci, 2013).

A variety of data acquisition modes are more accessible and increasingly used to document Cultural Heritage.

The Architectural /Archaeological representation process is now in the middle of a transformation due to the advancement of complex surveying technologies. The use of these new surveying tools allows us to recognize how the geometric survey process and the model concept are more and more consolidated. In the digital age, the model concept is based on digital techniques, now present in all architectural representation tools, techniques which have also invaded the field of architectural survey. In particular, with regard to the model, 2D and 3D representations have created a new kind of model no longer simply static, but also dynamic. The model concept must therefore be refined and updated. This model is able to represent, comprehend, elaborate and modify the survey; it allows one to move around it and travel from outside to inside the model using the 2D and 3D elaborations in an interactive manner; a complex and absolute interactivity has been created between the real object (point clouds and/or photographs) and virtual systems of 2D and 3D digital models.

This research is a contribution to Survey, considered as a knowledge tool to understand material elements, i.e., the process that materially envisages the establishment of a suitable knowledge system to Acquire, Select, Interpret and Represent Quantitative but above all qualitative data. The former must be performed to the greatest extent possible within the boundaries of a strict scientific approach, while on the other hand, the latter (the result of critical observations) depends on the sensibilities and interpretative skills associated with the choices, selections and representations decided by a scholar. This consideration constituted both the scope of this study and also a pretext to analyze the state-of-the-art of the whole field of survey. Nobody can deny there is a clear-cut boundary between acquisition and representation procedures – all focused on 'maximum objectivity' - and interpretation, which is instead the phase during which the subject remains the protagonist. Having established this boundary, some segments of the process appear capable of overcoming the stringent requirements imposed by the Scientific Method that other disciplinary sectors normally use in their research activities. A well-structured knowledge system has several components: history, culture, quantity (from an integrated survey) and quality. If the first two can (and should) be gathered using a strictly scientific approach, the latter involve the sensitivity and interpretative ability of the scholar who, at times spontaneously and intuitively, is capable of reaching levels of understanding that go beyond the simple act of taking measurements.

The structure of a meticulous, complete and correctly organized knowledge system plays a key role in a complex knowledge process. The Data

[1] 3D capturing technologies (3D laser scanning, image-based, SfM) which make it possible to acquire millions of points off surface doing away with the necessity to preventively establish what distances to measure. The result is differentiated qualitatively and quantitatively from that obtained with traditional instruments which always required the operator to select salient points to measure on the object of study.

[2] Independent of the methodologies adopted for data acquisition and extraction the operative procedure of surveying is articulated into 3 different stages: the design of the survey, data acquisition and reading, and – finally – model elaboration and construction.

Acquisition phase obviously includes the concept of measurement, i.e., the operation that makes it possible to translate the quality of a phenomenon into a quantity expressed using numbers derived from the relationship between the quantity surveyed on the object and the chosen unit of measure. Nowadays the surveying is structured around massive data acquisition (3D laser scanning[3], Structure from Motion[4]). This raises the issue of how surveyors interact and manage these technologies and devices. All operations that envisage the gathering of knowledge need to have a reference framework both vis-à-vis the data acquisition method (surveying) and the selection, processing and restitution of the acquired data (survey). In this regard, the survey process is closely linked to the concept of model, considered as the outcome of the operation performed by an actor on an object to extract some of its endless data. As a result the model is always incomplete, abstract and above all subjective; only the effects and outcome of representation make it available to other actors so long as they are able to interpret the representation code. Choosing the right model (and hence the set of objective data to be selected) and representation code depends on the quantity of positively communicated data. The advent of digital systems has added new 3D models to traditional (intrinsically 2D) graphic models. These new 3D models are purely numerical representations, which, are capable of establishing a very precise correspondence between physical and virtual space[5]. To correctly establish an operational protocol (Bianchini, 2012; Siotto, Callieri, Pingi, Scopigno, Benassi, Parri, La Monica, & Ferrara, 2014) the survey concept has to be properly identified and this involves merging two separate kinds of survey: critical survey, which defines the object using its geometric and architectural characteristics, and objective survey which consists of providing unbiased data to allow for an in-depth interpretation by a specialist (Bianchini et al., 2012; Ippolito, 2015). The survey will therefore depend on two consequential but inevitable aspects: complex 3D surveying and complex 3D survey. The complex 3D surveying involves acquiring the data and collecting any useful information about the object, which can also be studied to acquire greater understanding and knowledge; an analytical phase focusing on collecting qualitative and quantitative data. A combination of methodologies and tools are used during the acquisition process including topography, photography and long and short range scanners. The second step, the complex 3D survey, involves turning the 3D surveying into a 3D survey by combining the models, turning objective data (surveying) into data containing all the information required to interpret and study the building (survey). Given the above, surveys are not only repositories used to gather in-depth knowledge[6] of the artifacts, but they also represent the method required to extract the most suitable, correct data from reality.

[3] 3D laser scanning is performed with instruments highly advanced technologically. These devices emit an electromagnetic impulse (the laser) and receive the signal reflected by the surface struck. This method enables a time-of-flight measurement of the interval between the emission of the ray and its return to the instrument, i.e. the distance between the instrument and the point surveyed. Acquisition of a high number of data in short intervals of time takes the form of an infinite set of points distributed on the object to be surveyed, with a variable pitch in function of detail degree one wishes to achieve. Each point is characterized by five data: three numerical ones corresponding to the x, y, z coordinates related to the scanner, the RGB datum which positions on the point the datum of the photography acquired by the device; reflectance data which correspond to the amount of energy emitted from the instrument a returns immediately after the surface to be surveyed has been struck. Thus we obtain a three dimensional numerical model perfectly congruent with the real object upon which it will be possible to carry out analyses and elaborations necessary to obtain survey data.

[4] Structure from Motion (SfM) has been derived from the theoretical assumptions of photogrammetry and ensures the construction of three dimensional graphic *models* by integrating the stages of the survey, modeling and representation extracting coordinates, distances, vertexes and profiles from photographs. What makes it innovative is the high level of automation in the process and the possibility to obtain a very large amount of information in a short span of time. Although it does not offer the possibility to manage a survey on any scale, its result is the model analogous to that obtained through laser scanning which makes it possible to acquire geometric and qualitative features of the object analyzed through photographs.

[5] Each material point P_r identified using its coordinates x_r, y_r, z_r in real space, immediately finds its virtual equivalent P_v, also identified by a univocal triplet of Cartesian coordinates x_v, y_v, z_v

[6] The approach to knowledge expressed by the philosopher René Descartes distinguishes between normal knowledge, achieved only by our senses, and profound knowledge, achieved by scholars using only study methods and techniques that can demonstrate to the mind, what is precluded to the senses.

2. Technological developments in surveying and representing Cultural Heritage

Any study focusing on architectural and archaeological elements – whether at an urban, architectural or detailed object scale – is based on the creation of a knowledge system involving the collection, interpretation and filing of data. Archaeological Architecture (Bianchini, Borgogni, Ippolito, & Senatore, 2014) is constituted by a massive number of surfaces (planes, cones, cylinders, rotation surfaces, paraboloids, etc.) and hence the set of points extracted from a 3D survey must inevitably be transformed into continuous surfaces by the creation of meshes or nurbs surfaces so researchers must be certain to have surveyed all the characteristic points of the target structures. The potential offered by the use of new survey tools for massive data acquisition of geometry and appearance allows us to study aspects of artifacts with a level of detail and a huge variety of heterogeneous data that was unimaginable until a few years ago (El-Hakim, Beraldin, Picard, & Godin, 2004; Entwistle, Mccaffrey, & Abrahams, 2009; Bourke, 2012; Remondino, Spera, Nocerino, Menna, & Nex, 2014; Hess, Petrovic, Yeager, & Kuester, 2017). The phrase "digital building recording technologies" may infer the collection of accurate and efficient dimensional data, but in actuality a building's size is often not the only focus for the study, preservation, or conservation of a structure. Collecting, interpreting and disseminating a large amount of information helps to define a system we can use to understand our Cultural Heritage. The system has to be based on scientific process used to achieve a dual objective: to document the acquisition using a heterogeneous set of data and metadata to guarantee repeatability and to ensure data quality during data capture and processing of 2D and 3D models.

Data acquisition is an articulated operation aimed at extracting a series of information from the complexity of the real object. Even though it may seem to be an automatic process that applies existing methodologies, to perform it it is indispensable to have a knowledge of the theoretical concepts and practical operations that must be executed in order to work with the instruments and guarantee optimization of the results. The choice of one or more modalities for data acquisition means that some methodological questions have to be addressed: the specific criticalities of different instruments, the correct approach in their application, their influence on the timing and the quality of the surveying and representation processes (Ippolito, 2016). Integration of various surveying methodologies that allow one to acquire data from the general and the detailed point of view as well as their most exhaustive reconstruction is almost a well-established operation (Bianchini, 2012; Remondino & Campana, 2014). Technologies like 3D laser scanning and SfM enable surveying of complex objects as well as to gather a high number of points making it possible to survey contexts of extensive dimensions and to obtain results of great precision as concerns the metric aspect and surface characteristics (Bartolomei & Ippolito, 2014; Lambers, Eisenbeiss, Sauerbier, Kupferschmidt, Gaisecker, Sotoodeh, & Hanusch, 2007). The description of surfaces becomes particularly detailed in providing metric, geometric and chromatic information. Moreover, digital surveying technologies prove advantageous at the stage of reconstruction, opening up possibilities to integrate not only the surveying methodologies but also different model types. Geometric data allows measurement of damages, deformations, structural dimensions, and proportions. Appearance gives a more realistic view of the structure to characterize its state of conservation and the surface conditions of the construction materials. Context allows for interpretations and analyses to be performed based on the environmental, urban, and geographical contexts (Hess, Petrovic, Meyer, Rissolo, & Kuester, 2015). Each of these aspects have their own specifications and requirements in order to provide the appropriate accuracy and level of detail for the intended use of the data. Studying architectural and archaeological heritage from the digitized geometry requires an extremely high level of precision and accuracy to measure details down to the order of a millimeter. When considering appearance, the required resolution may be even finer than is even possible with laser based techniques; this is where photo based 3D reconstruction and Gigaphoto texturing becomes extremely useful. Contextual analyses often require less geometric precision and can performed from coarser datasets, but require a broader expanse of data collection (Gaiani, 2015). The transition from surveying to survey is defined by formalizing 2D and 3D models which express the relation of correspondence between the real and the virtual and make it possible to establish a continuous relation iconicity and the visualization of the object surveyed. Today models are the point of departure for all the activities aimed at a more profound knowledge and protection of the object. Different fields of operations connected with Cultural Heritage - from cataloguing to preservation, from design to restoration and valorization - begin to present the enormous potentials inherent in models obtained through 3D surveys. In some cases, to observe artifacts at various scales and from different viewpoints digitally is more productive than studying work itself. They make it possible to design and prepare reconstruction, reinforcement and restoration operations directly in three dimensions as well as to document different transformations the artifacts underwent over the course of centuries. Moreover, they open up various possibilities linked to their application through different representation scales (from 1:1 to 1:∞), different reading levels for purposes that lead from knowledge towards popularization and research. Thus, a system is structured out – rigid but dynamic and complete in its contents - based on the transitive application of different models. While at the stage of data acquisition we referred to integrated surveying (integration of methodologies), at the stage of elaborating we shall be concerned with integrated survey (model integration). Each model typology communicates something a little different in accordance with the peculiar features of the representation modality used and the characterization of 2D and 3D models through different attributes makes up a multi-level documentation system based on the definition of the geometry, typology and texture[7]. Multilevel analytical documentation, represented by unprocessed data, is an important aspect when defining 2D/3D models. It includes absolutely free documentation for all scholars; 3D models that can reach a 1:1 scale with the possibility to use texture mapping to characterise surfaces (Styliani, Doulamis, Athanasiou, Ioannidis, & Amditis, 2016).

The process used to define the general and detailed 3D models is divided into separate phases that follow the registration of the point clouds and allow accurate determination of the topology of the surfaces. These models, whether geometric, textured or thematic, were the basis for a series of considerations about the form of the surfaces, their regularity/irregularity, state of conservation and analysis of the materials. Furthermore, depending on the type of model and its characteristics it is possible to communicate different aspects of the objects in question. For example, even if the geometric model has no chromatic or material data it is still very useful to study the arrangement of masses, geometry and proportions as well as understand the reciprocal position and relationship between the elements in the architectural composition. Instead the textured model helps to define the formal aspects and state of conservation of the artifact by first using the RGB data obtained from the digital images acquired by the same instrument at the same time as the laser scan; the chromatic data in these images is accurately linked to the geometric position of the surveyed points. Finally, the thematic model exploits the symbolic nature of colour to provide information about several different aspects. By using colour to establish homogeneous areas in the model we can highlight forms, the heterogeneity of the materials, their state of conservation and sometimes even their degradation pathologies.

Creating 3D and 2D models makes it possible to shift from a real object to its representation by selecting some of the endless data describing the object. Obviously, the more the virtual data corresponds to the real object, the more accurate the analysis and interpretation. Two issues have to be tackled when it comes time to build models and execute drawings of complex artifacts. The first involves the need to understand and underscore the unique aspects of the contexts in question - large, sprawling areas and geometrically irregular architectural and archaeological artefacts - since the latter effectively stop the operator from identifying sharp edges or precise forms. The second issue involves the representation scale, in the case of 2D models, and the level of detail for 3D models.

[7] Geometry defines the position of objects with the *x, y, z* coordinates. They identify the points of objects in space in a system of reference. This can be – as necessary – absolute or relative. Topology describes the relations between geometric entities and analyzes the surfaces that define the object. Texture completes the description of the virtual object making in recognizable and attributable to the real object.

3. Building 2D/3D models from massive 3D data acquisition

The irregularity and distinctive traits of artifacts makes it necessary to document their morphology based on a plan which, during acquisition and restitution, ranges from general to detailed areas. It's important to understand the 'contact point' between products created by traditional survey activities and those generated by new massive data acquisition technologies. It involves not only the operational aspects associated with the representation, but the more general issue of how cognitive processes work in the world at large. With the continuous advancement of technology, data acquisition and elaboration operations are becoming ever more digitized (Brunetaud, De Luca, Janvier-Badosa, Beck, & Al-Mukhtar, 2012; Minto & Remondino, 2014). It is invariably the case that only by integrating different methodologies can we obtain results more complete and better in the perspective of cognition. However, it is indispensable that practical-operative procedures are critically and intellectually supported. This is the basis for a full and informed development that prompts future progress.

There are three principal fields of application concerned in model construction and development. The first can be identified in cataloguing and classifying models which allow one to construct a 'historical' memory snapshot, ever more unstable today due to unpredictable events whether natural or manmade; the second sphere of application is linked to the study of antique objects even if only partially preserved where integration of different methodologies allows one to reconstruct the object in its completeness; the third field concerns designing, restoration, and consolidation – where the designing stance can directly turn to the three dimensional object. Furthermore, the construction of models within the above-mentioned fields of enquiry, makes it possible to valorize objects of cultural heritage, offering at the same time a chance to get to know them more extensively thanks to the possibilities of popularizing knowledge so much increased by the use of the Internet.

The following case studies may fall under the first and second field. In both cases the two primary techniques utilized for digital documentation are laser scanning and photogrammetry. Laser scanning provides trusted accuracy and precision, but each instrument has its own limitations and fixed set of resolution capabilities. Photogrammetry techniques are extremely flexible to provide resolutions ranging from kilometers to micrometers (Micheletti, Chandler, & Lane, 2015). In addition to the relative geometry generated by photogrammetric techniques, the images themselves can be used to provide high-resolution photorealistic textures to the target being studied. Integration of imaging techniques can yield a superior end product if the integration methodology is well documented and optimized for accurate alignment of modalities. The high fidelity geometric data provided by laser scanning can be complemented by the high resolution images from photogrammetric reconstructions. The necessity of elaborating 3D models as a successive stage made it possible to apply high definition images to the surveyed object. The multimodal data together should not only serve as visual aids, but should be used to their fullest extent for collaborative analysis among a multidisciplinary team. Another fundamental aspect, strictly connected with the above, seems to be the comprehension of quality level that the models obtained with the diverse methodologies (laser scanner and SFM) achieve as well as their possibility to perform on larger or smaller scale. On precisely such models we can carry out initial analyses of the state of preservation of surfaces, map out the degree of their degradation and identify changes in the wall texture while in case of decorative coverings gaps can be discovered.

4. Villa Borghese architectures

The first application, on Villa Borghese architectures[8] (Fig.1), has been undertaken with various objectives in view. It rests on the

[8] The Villa Borghese park in Rome covers the area of approximately 80 ha and is situated in the very center of Rome. The construction of the villa as a suburban residence started around the year 1606 but then, in consequence of historical events and urban transformations concerning Rome and the whole of Italy, the park was to have been parceled out and the whole site could have been dismembered. For this reason in 1901, the State of Italy bought the whole monumental complex and in 1903 the park was handed over to the Commune of Rome and opened to the public. Today it is an open-air museum containing buildings, architectural complexes, monuments and fountains, all works of outstanding baroque, neoclassical and eclectic artists.

Fig. 1: Villa Borghese in Rome

profound knowledge of an important complex, dotted with elements representing various architectural typologies of huge, medium and small scale (Fig.2). The majority of buildings erected for the purpose of representation function today as venues of cultural events and intellectual activity: art galleries, museum and academies. Others, conceived as forms of embellishing the gardens, have not changed their original function and are used for identifying important places in the park like, for example, entrances or intersections between main alleys.

The complexity of the architecture in the whole park will be enhanced in the process of synthesization through digital models and in 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 detail. The other fundamental aspect of the study is to analyze the results of using low cost acquisition instruments (with the use of open source or low cost software at the stage of elaboration rather than the paid variety, or those whose price is much more reasonable than that of other usable programs) in order to test the detail level possible to achieve in terms of metric accuracy as well as metric, chromatic and surface information. Even though nowadays the surveying and survey operations are carried out 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 which would make impossible to fix quantitative and qualitative features of objects analyzed in relation to the methodology applied as well as to the scale of models.

The study of the architecture of Villa Borghese started with a careful and detailed cataloguing of existing structures. The present research concerns only objects of the medium scale, like entrances or architectural decor, and on the small scale, like fountains featuring various sculptures. The choice is related to the experimental aspect of the surveying methodology adopted, considered especially suitable for artifacts of this type.

Fig. 2: Cataloging of Villa Borghese Architecture: huge, medium and small scale

The study enabled analysis of the potentialities as well as the limitations of an approach that uses low-cost methodologies for acquiring and constructing models worked out for the purpose of documentation and cataloging. Case studies analyzed, heterogeneous stylistically and formally, have common features linked to the recognizability and repeatability of architectural and decorative elements as well as of the dimensions. The latter feature has been found to determine the choice of surveying methodologies applied and the analysis of the results obtained. In fact the SFM technique, tested on various cases of medium and small scale, seems to be effective in describing of geometric, dimensional, material and chromatic features. Constructing such a system has to overcome certain fundamental problem: how to obtain 3D reality based models of objects which are different but homogeneous as to their scale, uncertainty level and visualization typology. The definition and managing of the 3D model become the crucial point of the problem for the solution of which it is fundamental to define an operative methodology that could be referred to in a standardized manner.

The surveying operations have been carried out following the project of a unitary survey. One of the nodal points in this research is the definition of model typologies we can construct with the systems of massive data acquisition in relation to the information, which the very same models transmit in representation scale fixed at the point of departure. The concepts of data quality and scientificity alongside that of uncertainty control turn out to be fundamental in the processes of acquisition and elaboration. Therefore, different case studies were analyzed, in order to execute a project of placement survey, independently of one another. During preliminary planning – indispensable for carrying out the survey scientifically as well as for speeding up field activities, problems of methodological nature have been addressed and - following the almost well-established practice - the decision was taken to integrate various methods and instruments (Bianchini, Inglese, & Ippolito 2016). Data acquisition carried out through integrated instrument surveying[9] availed itself of various non-contact surveying methodologies, the photo rectification with the view to obtaining global representation, detail representation or a specific analysis of material aspects of surfaces. The information acquired have then been organized into a system in order to make sure that the cognitive picture of the object under analysis be as complete and multi-level as possible so that it can be studied in-depth in its different aspects and interpretation keys (metric, chromatic, historical and that of preservation) which can the be compared to one another.

The experiment seeks to integrate the process of surveying with that of cataloging by structuring models obtained through digital photographic images with the aim to create a documentary archive. Acquisition operations are linked to the correctness of the processes followed and to the concept of metric accuracy (Cipriani & Fantini, 2015).

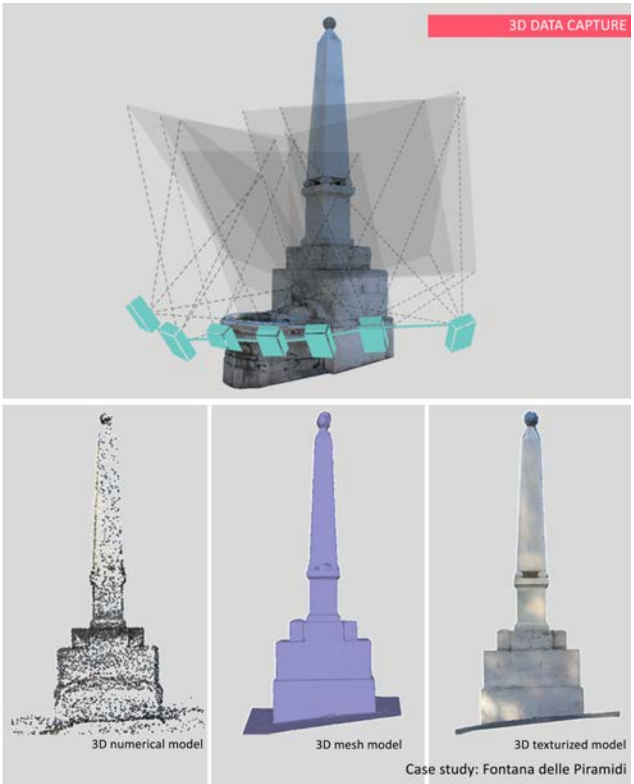

Fig. 3: Repeatable methodology for 3D data capture and 3D data. Case study: Fontana delle piramidi

Thus, a metrological setting is qualitatively described by an aggregate of parameters that define the characteristic of measure: uncertainty, repeatability and accuracy). The stage of data acquisition should always be considered as an application of a scientific method based on a collection of empirically observable and measurable data, which can be archived and subjected to external verification to be validated. The applied procedure (Fig.3) should be replicable in order to acquire a new aggregate of data comparable to the preceding one.

The data capturing stage (Fig.4) has been conducted with the aim to test the validity of a

[9] A camera Reflex Nikon D90 and a photo camera Reflex Canon 450D were the instruments used.

procedure that assumed that only low-cost instruments will be used for surveying and building 3D models, contrasting diverse systems. The experimented procedure was aimed at constructing qualitatively controllable 3D and 2D models where it is essential to define the uncertainty level of the models linking it to the model scale[10]. An attempt to define a priori the scale of the model requires the knowledge of the maximum detail level such models can reach. In order to verify the accuracy of the survey data as well as to control the level of uncertainty of the model scale, it is fundamental to confront the data obtained by making photo images with those obtained by direct surveying. The reflex NIKON D90 camera with CMOS sensor of 12 Megapixels with automatic focusing and manual zoom procedures is used in the surveying campaign. The surveying project[11] had defined in order to guarantee cover of the whole object and each photograph overlapped with the successive one in at least 30-40 %.

The final representation scale of the data was fixed in advance at 1:50 while – in order to get all the elements of the object precisely in the selected scale, the distance was calculated based on the lens focus and the characteristics of the camera used. Considering that in any surveying operation it is necessary to determine the level of uncertainty also in relation to the representation scale preventively fixed, the difference would amount to 3 millimeters, a value perfectly acceptable because it falls within the graphics error. Extra confirmation has been obtained by calculating the deviance value with Cloud Compare, an open source software used for elaborating and comparing 3D cloud points: also in this case the value obtained from the section of the surfaces that make up the model in the two dimensional plane, proves to fall within millimeters.

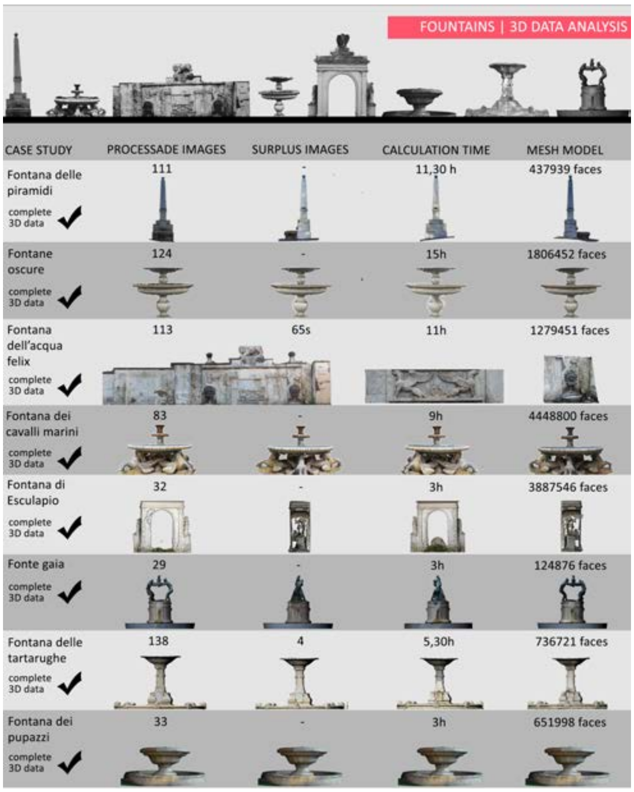

Fig. 4: Repeatable methodology for 3D data capture and 3D data. Case study: Villa Borghese fountains

The level of uncertainty has been managed by correcting the optical aberrations of individual photograms and this stage directly preceded the creation of the 3D model (Fig.5) and using some markers on the obtained point cloud found the correspondence of the salient points measured with the methodologies for direct surveying. The model obtained through this procedure, compared by means of open source Cloud Compare software with the data extracted from direct surveying, revealed an average deviation of 3 millimeters[12].

[10] 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.

[11]Since each architectural object has its peculiarities, is impossible to establish an absolute rule regarding the way a survey should be performed. Nevertheless, all the methodological options are analyzed and developed during the survey project in order to optimize the operations vis-à-vis the objective. The survey project is a key stage in the whole process. It establish the instruments, the 2D model scale, and the number and position of the various stations. A correct survey project (partly) guarantees the quality of the data later used to produce the survey drawings; it also ensures the accurate gathering of numerical data obtained only from the measurement operations and still not processed. The operative phase comes after the survey project; this is the moment when all the planned operations, and any unforeseen operations, are formalized in situ.

[12] 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

Fig. 5: Definition of 3D model: 3D numerical model, 3D mesh model and 3D texturized model. Case study: Fontana dell'acqua felix and Fontana delle tartarughe

Fig. 6: 2D texturized and architectural model from 3D model. Case study: Edicola della Musa

MeshLab visualizer was used to clean the data gained from the survey. Then the numerical model obtained by processing photographs was first positioned and properly scaled in CAD environment on the basis of the measurements acquired during the campaign of direct surveying. The 3D textured models were then taken as the point of departure for constructing 2D models. Such an operation is all but automatic: a high level of knowledge of the subject and the rules of the science of representation are indispensable in order to build 2D models able to effectively describe the object analyzed (Fig. 6, Fig. 7).

5. Oxkintok Archaeological Site: Satunsat Labyrinth

Three-dimensional documentation is becoming increasingly popular in the architecture and engineering communities as well as other application domains including archaeology.
Given the challenging conditions typically associated with the practice of digital documentation of cultural heritage - tourist interference, access permissions, limited time, geometric complexity - establishing a reliable methodology for massive data acquisition is essential for performing efficient surveys (Hess et. al., 2017).

Fig. 7: 2D texturized and architectural model from 3D model. Case study: Portale Flaminio Ponzio

To ensure that the final products generated from 3D surveys are appropriate for use by varying domain experts, the digital documentation strategy must be built for repeatable comprehensive model creation.
With this in mind, a surveyor must be armed with enough knowledge of the surveying technology to be able to overcome the limitations of each technique as well as leverage their strengths.

The focus of this case study is on implementing Terrestrial Laser Scanning (TLS) for comprehensive documentation of a complex archaeological structure.

The Labyrinth of Oxkintok, also known at Satunsat (Fig.8), is an extremely fascinating ancient structure in the northern Maya lowlands.

dispersion, that is, the estimation of datum variation. This is what is often referred to as the measurement error.

Fig. 8: Contextual view of the TLS data of Satunsat

What appears from the outside as an unmemorable terraced building platform is, on the interior of the structure, a complex series of interconnected vaulted passageways spanning three levels.

These passageways utilize irregular, corbelled vaults and relatively narrow spine walls to support the above structure, which differs significantly from the veneer and concrete core technique characteristic of later Puuc vaulted architecture.

The relationship between the plaza, the structure's masonry components, and its bedrock foundation is another aspect that can be documented, visualized and studied from digital documentation records.

The goal of this section is to outline a practical, field-ready approach that ensures the generation of quality data from which detailed analyses can be made by different domain experts. The integrative methodology (Fig.9) concentrates on establishing repeatable acquisition workflows in order to guarantee reliability and usability of the data generated.

As the goal is to conduct these cultural heritage surveys given the constraints of real world practice, there are informed decisions that must be made in the field. A major focus of these acquisition workflows is on the surveyor or equipment operator be informed of the strengths and weaknesses of the technology in order to realistically plan t he surveying efforts under the given constraints.

The case study presented here is an excellent example of how this acquisition methodology can be implemented in the field to yield comprehensive surveys to be used by a wide range of experts. The 3D documentation of Satunsat enables researchers to better examine

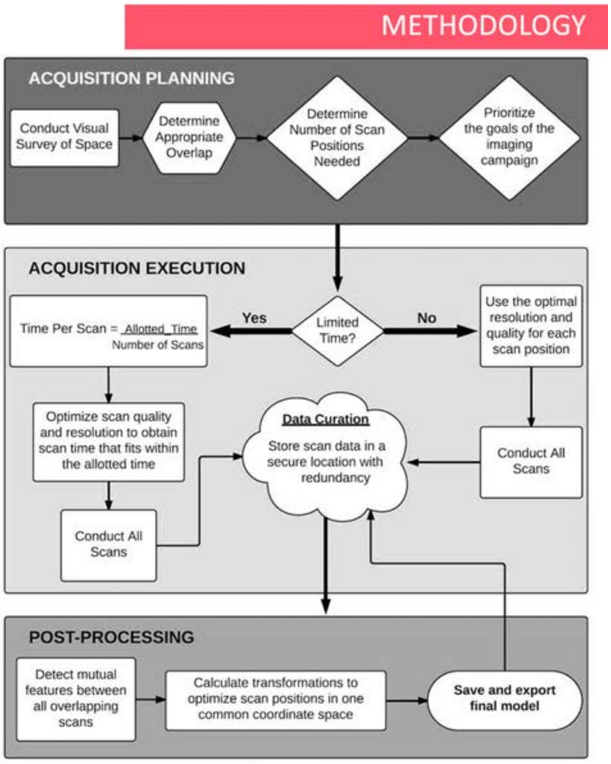

Fig. 9: Repeatable methodology for the comprehensive acquisition of TLS data

the complex morphology of the ancient labyrinth while also making it possible to conduct a more accurate structural health assessment of the structure as a whole. The structure is within a larger complex that is open to the public, but the inside of the labyrinth is not accessible to visitors. The inside passageways are humid, hot and in near total darkness with bats flying around every corner. One goal of the survey was to identify the layout of the interconnected passageways, and without the layout defined ahead of time, an accurate laser scanning campaign could not be crafted. This is a demonstration of why the methodology begins with a visual inspection of the spaces to be surveyed. During this initial walkthrough of the space, the surveyor will make informed estimates of instrument positioning in order to achieve overlapping regions that are appropriate for accurate registration and combination of individual scans with each other. Through these estimates, the overall number of scans will be determined and a decision of where to start will be made in terms of prioritization.

The execution of the TLS survey will then depend on the given operating constraints such as access, time, physical placement of the tripod, etc. For this campaign, the total allotted time was 3 days on site with multiple equipment operators in the space simultaneously. Do to the multiple occupants in the space, there was not only coordination for the TLS operator alone, but also communication with the rest of the parties involved on site for the survey. In the end, it required a total of 103 scans to document the interior and exterior of the structure (74 and 29 respectively) and a total of over five billion data points captured. The level of detail captured was on the order of a millimeter on the interior and 3-5 millimeters on the exterior of the structure. This dense documentation record now provides an excellent departure point for all future analysis and interpretation by domain experts.

With the 3D point cloud accessible from the fruits of this surveying campaign, the labyrinth and its passageways can now be studied in a way that was not possible before. Five billion point dataset can be manipulated in a way to extract thin slices of points that render what amounts to section cuts of the structure.

With these section cuts, experts can finally study the relationships of the winding passageways and visualize through the data how each level of the structure is situated atop the floors below. The plan view of the first floor of the labyrinth that was extracted from the point cloud in order to capture and measure the layout of this ancient maze. The grid pattern (Fig.10) visible demonstrates that the pattern of the passageways is not only visualized through the data, but can also be measured down to millimeter accuracy given the level of detail of TLS technology (Fig.11).

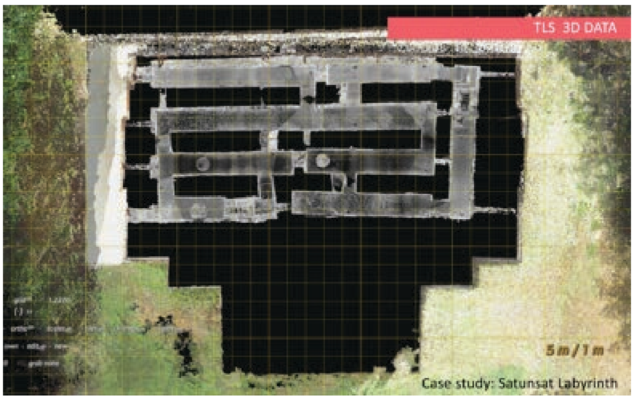

Fig. 10: Plan view of the TLS data showing the layout of the labyrinth's first floor

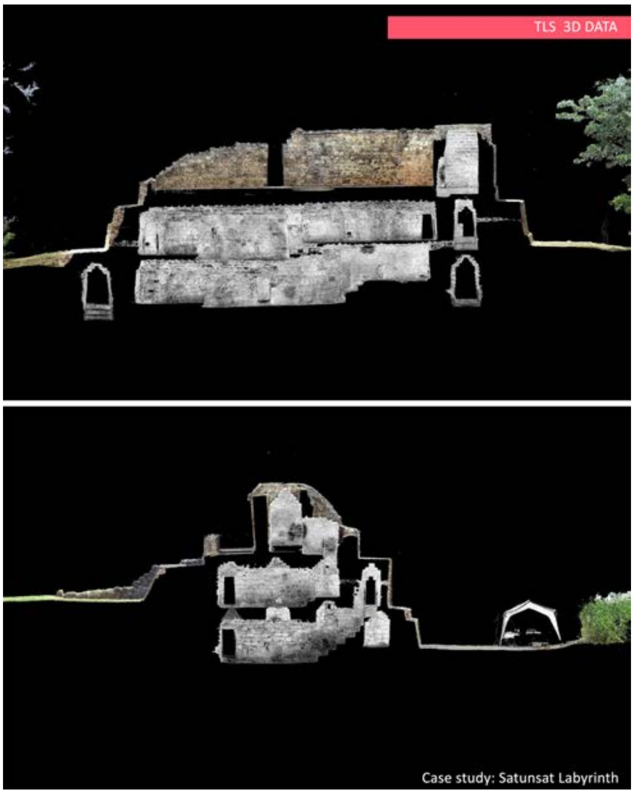

Fig. 11: Section cut of the TLS data from the plaza looking towards the back of the structure and section cut of the TLS data looking from the side of the structure

6. Conclusion

Integration of massive acquisition instruments, reformulating 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.

The comparison of models reveals that the two methodologies, mainly used nowadays – the laser scanner (high cost) and the Structure from Motion (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 they are easy to use and to transport, economic and that they ensure 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 in term of metric accuracy have been obtained in the case study at architectonic scale and that of the detail.

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 unconventional 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 reached prove to be fundamental. Equally indispensable in the digital epoch is the correct administration of 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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