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Geomatics for structural assessment and surface diagnostic of CH

Grazia Tucci*, Alessandro Conti, Lidia Fiorini

GeCO Lab, DICEA, Università di Firenze, Via S. Marta 3, 50139 Firenze, Italy

Abstract

The capacity to rapidly acquire large quantities of spatial data, to geo-reference information on them, to obtain detailed models that allow more and more accurate analyses and simulations, place Geoinformatics at the center of attention in many research areas. Among these, the use of these techniques for the study of existing structures is particularly interesting. Assessing the current stability of a building, monitoring the evolution over time of a failure, preventing the potential causes of damage, simulating the behavior of a building under seismic actions, are just some of the ways in which the geometric properties of a structure, acquired with the most up-to-date automated surveying systems, are used to help validate structural integrity analyses

Keywords: Survey methodologies; Geomatics; Cultural Heritage documentation; HBIM; FEM; Diagnostics;

1. Introduction

The only irrefutable evidence of an architectural structure is the edifice itself; a scientific approach that deciphers the text of a construction, therefore, must be based on systematic observation and measurement of the building. The complexity of the relations between its elements, determined by their position in space, can only be systematically approached by a model that takes into account the reciprocal spatial relations of the collected data. For this reason, well before its analytic and descriptive geometry was rigorously defined, the survey–and its subsequent architectural representation in two and three dimensions, both on paper and in physical models– has constituted the main instrument for the study of its design, whether in the didactic setting of the ancient academies or in the current context of understanding the history and the necessary operations required to guarantee the preservation of a construction (Tucci 2003, Migliari 2004, Musso 2017).

* Corresponding author. Tel.: +39 055 27586587.
E-mail address: grazia.tucci@unifi.it

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1.1. The survey in the Carte del Restauro

Even if the survey can therefore boast a long and solid tradition in the field of restoration, its role has only come to be truly appreciated in recent times. An examination of the so-called *Carte del Restauro*, both on an Italian and international level, reveals that references to the survey are both superficial and fragmentary. The Athens Charter (1931) recommends “precise surveys” only for archeological excavations at sites that will be reburied. The Venice Charter (1964) discusses "precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs", without specifying the metrological value of the drawings. The *Carta italiana del Restauro* (1972), finally, indicates the content of the restoration project, affirming that “it should be based on a complete graphic and photographic survey to be interpreted metrologically.” It was not until the *Carta del rilievo architettonico* of 1999-2000 (Almagro et al. 1999) that we were provided with a study explicitly dedicated to the survey. This document recommends that the regulatory criteria for a survey should incorporate a project as well as oversight of the operations and testing; it should additionally include a report indicating the implemented criteria, objectives and degree of precision, so as to make qualitative evaluation possible. The survey is further defined as “an open system of knowledge” that brings together all relevant data and whose creation involves multiple professional specializations. The study also alludes to the possibility of multimedia management and to the establishment of an information system that can be updated over time. This document, finally, emphasizes the structural survey among the themes for detailed study, pointing to the dual objective of “illustrating the structural model in its overall configuration” and “documenting the geometric characteristics and the materials necessary for the engineer to conduct the required assessments and tests,” in consideration of the need for further experimentation to integrate the survey methods with non-destructive analyses of structures covered by plaster. The *ICOMOS Charter–Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage* (ISCARSAH Principles 2003)– additionally devotes a section to structural surveys, beginning with the mapping of visible damage and cracks and of the materials and their state of decay, and moving on to a consideration of geometric and structural irregularities and the relations with the context. Although they highlight the importance of the survey in the restoration project, these documents lack precise specifications, regarding, for example, scale, level of detail, the instruments needed to carry out and verify results: such shortcomings are probably due to the great variability of situations in the survey of architectural structures. Typically, those most familiar with a monument were surveyors armed with tape measures and plumb lines who gauged spaces and noted shapes and dimensions in accordance with their training in the history of architecture; yet the badges of land surveyor or “measurer” have not generally been happily worn by architects or engineers, who consider themselves to be in possession of a different –higher– set of skills. Measurements were essentially limited to distances, related to planes whose spatial positioning was not simple to realize. The traditional survey, therefore, was often unsatisfactory above all for measuring buildings with complex floor plans or spaces of great height.

1.2. Modelling built heritage and new surveying technologies

For this reason, researchers have for decades been experimenting with the use of technical instruments which have already been tested for land surveying and cartographical production, such as topography and photogrammetry; yet the use of such instruments was not widespread, due to the elevated costs and high level of expertise required. In the last decades, with the advances in computer science and the transformation to digital platforms, we have seen a dramatic change in documentation systems. Laser scanning and SfM digital photogrammetry have for several years now allowed us to survey complex geometries at lower costs; if we consider the geospatial market as applied to constructions, attention is no longer directed toward acquisition in itself but rather toward integration and automation of the various technologies:

- Autonomous Technologies – towards the adoption of autonomous vehicles in a wide variety of operations;
- Portable Scanners - handheld and portable systems for generating 3D models from tight, busy spaces;
- Immersive Data Visualization - moving beyond abstract data sets is enabling to fully interact with 3D data;
- All-digital Environments - be it BIM or VDC, AEC firms are moving to an all-digital design environment;
- Data Processing Automation - automating data processing to bypass the bottleneck of massive digital data sets.

All of these techniques aim to define the position of high-density points in space; their results can be integrated as long as they are expressed in a single reference system defined by a reference network created with GPS or total station. Moreover, the permanent materialization of the network and the preservation of all data and metadata allow us to verify the accuracy of the result and its successive integration as well as to monitor the evolution of conditions over time (Grussenmeyer et al. 2011, Voltolin et al. 2007, Guarnieri et al. 2006, Rodríguez-Gonzálvez, et al. 2017). The most interesting aspect of new digital techniques for reality acquisition is that they enable us to obtain models, not only in the architectural or computer-graphic sense as two- or three-dimensional images of a building, but from the broader perspective of a faithful and objective conceptual representation (apart from measurement uncertainty and inaccuracies in following the adopted procedures, which are in any case verifiable through quality statistical parameters), and thus useful for describing certain phenomena (Tucci et al. 2015). As in the past, proximity (Sanpaolesi 1973) to the object, both during acquisition and data processing, places the surveyor in a better position to identify aspects that are less easily detected from a more comprehensive perspective. Three-dimensional acquisition can also be employed as a diagnostic instrument to identify anomalies and investigate the deviation between the real geometry and ideal surfaces, to monitor the development of instability or of other phenomena, or to automatically characterize decay (Sidiropoulos et al 2017, Del Pozo et al 2015, Nespeca and De Luca 2016).

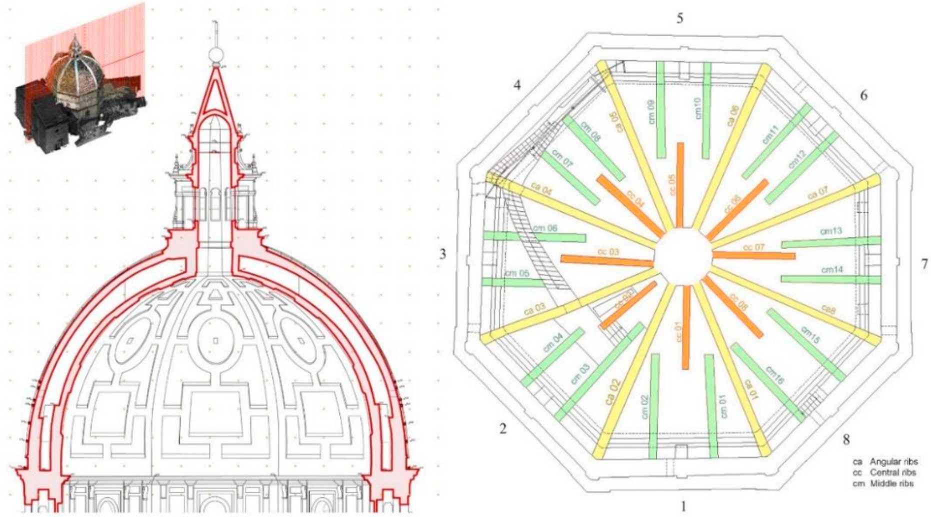

Fig. 1. Madonna dell'Umiltà in Pistoia: 3D model of the space between the two calottes.

In summary, surveyors before the digital era, following a principle of economy, acquired data that was sufficient to produce the 2-D representations necessary for defining a conceptual model of 3-D reality, a model so abstract as to be fully comprehensible only by specialists. Today, digital transformation allows us not only to acquire 3-D geometric information but also to create 4-D models that also take the temporal dimension into account with continuous or repeated measurements. It is therefore evident that the idea of the survey, understood as a synthesis of an open system of knowledge which is always organized and articulated in a spatial form, today finds application in a 3-D digital model that is considered the framework for the geolocation of every type of data.

2. The survey in the Italian Technical Norms or Constructions

It may be interesting now to examine how technical norms in Italy accommodate these opportunities offered by the techniques of geomatics, with particular regard to CH buildings. On 2018, an updated version of the *Norme tecniche per le costruzioni* was issued, replacing those from 2008. The section regarding existing buildings (including historical ones) is found in Chapter 8 (*Costruzioni esistenti*): in particular, section 8.2– *criteri generali* states that in the definition of structural models, one should consider "that the geometry and construction details must be rendered knowable, at a level of detail that depends on the available documentation and on the quality and extension of the investigation to be carried out".

In section 8.5.2, the definition of the survey remains unchanged: "the geometric-structural survey must refer to the total geometry, both of the structure and of the constructive elements, including the relationships with any other bordering structures. The survey should represent the modifications made over time, as inferred from historical and critical analysis. The survey must identify the actual state of the structure, accounting for the state of preservation of materials and constituent elements. Any forms of damage must also be indicated, whether existing or repaired, paying particular attention to areas with cracks and damage mechanisms." We should note that in the case of existing buildings, these norms require that detailed geometric-structural surveys contain a higher level of analysis such that calculation coefficients can be adapted with respect to those used for new construction.

The *Riferimenti Tecnici* of the 2018 NTC cite among the validating documentation the *Guidelines for the assessment and reduction of seismic risk of cultural heritage buildings*, issued by the *Ministero per i Beni e le Attività Culturali* on 2008. These *Guidelines* are the "instructions" with regard to the indications of the 2008 NTC in reference to cultural heritage monuments, specifically to those built in masonry. It is interesting to note that the text indicates the intent to define a process of information acquisition, which, furthermore, is to be realized on a national scale through a program for monitoring the state of preservation of protected architectural monuments, aiming at the construction of a data bank.

In chapter 4, "*Knowledge of the structure*", the norm immediately highlights the uniqueness and fragility of cultural heritage structures, reminding us that carrying out a complete investigation of a monument, if this is required, may turn out to be too invasive. It is therefore necessary to fine-tune different instruments and techniques for different knowledge levels that can be "sustained" by the structure in question.

These different levels of inquiry, related to confidence factors, aim to obtain as objective an assessment as possible of the actual state of the structure as well as of the operations of restoration that may be necessary. The norms define the course of inquiry in terms of specific activities, which we summarize as follows:

- situating the structure with respect to its urban surroundings by means of an initial reconnaissance;
- conducting a geometric survey, described in this way: "The stereometric description of the building involves identifying the planimetric and altimetric characteristics of the constituent elements. At each level, therefore, the geometry of all masonry elements must be surveyed: vaults, flooring and roofing, stairs, identification of any recesses, cavities, openings that have been closed, chimneys, extraneous elements that have been incorporated, and the type of foundation. The survey must also include a description of the significant points for a mathematical model, such as the impost height for vaults and floors, as well as the dimension of their bearings on the walls. In addition, the survey must completely indicate the masses of the elements and the loads supported by each wall element. It should further include cracks and deformations. Given the difficulties involved in the survey, such as issues of accessibility and the large dimensions of some architectural elements, the norm reminds us of the existence of (unspecified) "instruments" that "allow for rapid surveying and accurate restitution, even in the case of complex elements";
- evolution of the building and its construction phases, including analysis of modifications made in the past;
- a material survey that describes the state of preservation and the mechanical properties of the materials that make up the building. We should point out that this section as well recommends the creation of digital archives and a data base accessible through a program that monitors the preservation state of protected architectural monuments;
- geotechnical information on aspects regarding the basement and foundations;
- monitoring: the norm recognizes as indispensable a monitoring program which includes the necessary maintenance operations for the preservation and above all for attaining the "nominal lifespan" of the structure. In addition to the topographic and photogrammetric survey, the methods indicated for the geometric assessment of the building include laser scanning, whose product, that point cloud, is inappropriately defined as an "innovative technique." The norm then for the first time expresses the need for a careful assessment of the chosen "methodologies" (and not the instruments) in relation to their respective "accuracy" levels.

Chapter 4 concludes with section 4.2, *Knowledge levels and confidence factors*: here the information-acquisition level is quantified by means of a confidence factor and hence of an assessment of the reliability of the model of the structural analysis attained. The norm defines the level of analysis of the investigations with regard to different aspects of information and data and the relative confidence factors, summarizing the results in a spreadsheet.

Fig. 2. Florence Baptistery: 3D model with a detail of the extrados of the dome.

The geometric survey, defined as the "stereometric description of the building", certainly alludes to the three-dimensionality of the datum. Although it recognizes the utility of three-dimensional representation and recommends a three-dimensional approach and the use of 3-D surveying techniques in the performance specifications, in practice the norm only requires data to be presented in orthogonal projections (plans, fronts and sections) to be integrated into charts in this case as well. Similarly, processed data to be inserted into the *"Informational System for the Assessment of Seismic Risk" - SIVARS* do not adopt a vector format but rather the typical one of raster images (GIF, JPG, etc.). On these latter formats, operators are asked to draw structural elements and define the thicknesses, number and dimensions of openings, as well as to supply other information defined as "not deducible from the survey" but which would be immediately available if a 3-D model had been used. A reading of the description of the various information-acquisition phases immediately reveals two factors: first of all, the norm requires that temporal and spatial properties be associated to all the analyses, in other words, that information is situated in relation to different scales. This includes the locations of both the entire building and the single crack, as well as the understanding of how over time the events occurred which led to the present state of the structure. Secondly, the norm requires connecting the model to content without geometric characteristics (history, maintenance efforts, etc.). The need therefore arises for an instrument that coherently correlates the geometric model to all the documentation relative to the building, one that is also capable of implementation. The norm, indeed, contains the concept of the "nominal lifespan" of the structure, understood "as the number of years in which the building should be used for the purpose for which it is destined, given that ordinary maintenance is carried out." This gives rise to the need of a maintenance plan as well as to that for a new evaluation of the vulnerability state of the structure once the nominal lifespan has been surpassed. In regard to the nominal lifespan, (Lagomarsino 2013) emphasizes that "it constitutes the basis for programming preventive maintenance and allows one to create an informed conservation plan, avoiding heavy-handed interventions in the name of safety."

The norm acknowledges that the information-acquisition approach for heritage buildings begins with an evaluation of the structure itself in terms of its material consistency; through different levels of analysis, it then arrives at numerical quantification and qualitative assessment of the structural functions, on the basis of which any necessary interventions are programmed. The indispensable tools for information acquisition include the survey, and, therefore, “measurement”. Paradoxically, though, the norm makes no references to and provides no indications for defining specifications or methods for planning, acquiring and processing data, in other words those elements which allow one to assess the quality of the procedures and the results. The strategy of ongoing analysis and the need for monitoring programs suggest, on the other hand, that the norm envisions taking advantage of the techniques of geomatics for their implementation potential and their perfection of information acquisition in different temporal phases. These techniques can be concretely realized with a system of permanent topographical networks for the one-time definition of a reference system and in the realization of a three-dimensional model understood not as a mere representation of the structure, but as an archive of reciprocally correlatable data structured according to uniform conventions: a flexible record that can be implemented, transmitted and shared. The quality of a specific datum and therefore of the model to which it belongs can be defined by means of metadata. These should therefore become an integral and qualifying part of the model and accompany it in all its successive applications. In the same way that surveys and historical representations are worthy of being preserved, so must we treat the models themselves of a heritage building and consider that they should be equally conserved and protected (Tucci et al. 2017).

3. Surveying structures: some case studies and conclusions

What has been affirmed above indicates a course of data acquisition that has already been traced with regard to its principle aspects. It must now be shown that in practice its stages are still often applied in a discontinuous way. It may therefore prove useful to investigate for which ends and in which ways the techniques of geomatics have been used in projects for structural evaluations of significant CH buildings which have involved the GeCO laboratory.

3.1. Domes

An example of the great potential residing in the adoption of the techniques of geomatics concerns the survey of the great domes (Balletti et al. 2013). This has always been a challenging work because it involves broad and tall structures which are difficult to measure with precision by traditional means. It is further difficult to measure their thicknesses because the extrados is only visible in cramped crawl spaces: if no direct openings are available, creating a topographic network to connect the internal and external surfaces becomes a daunting task.

The church of San Vitale in Ravenna is one of the masterpieces of late Roman architecture. Its dome is built of clay pipes closed at one end, placed in concentric rings of decreasing diameters from the impost to the keystone, where an opening of a diameter of approximately 15 cm is found. Important studies were conducted on the dome in the 1990s (Baronio et al 1997), when a tacheometric survey was carried out on the intrados and the haunches of the extrados: these studies showed that the surface was attributable to a spherical calotte. A new survey with a laser scanner allowed researchers to create a denser sampling of the intrados and also to completely survey the extrados in order to correctly determine the geometry and thickness of the structure. Results revealed that the geometry is less regular than believed and that the curvature of the dome is variable. It was seen that its thickness is greater at the keystone, such that bulging appears on the extrados (Tucci et al 2012).

A broader case for the application of the techniques of geomatics for the study of domes is that of the Basilica of the Madonna dell’Umiltà in Pistoia. The dome was built by Giorgio Vasari in the mid-16th century. The architect consolidated and inserted numerous tie-rods in the corners of the pre-existing structure, which was considered inadequate for supporting a large, double-calotte dome. Nonetheless, numerous cracks were already visible after only a few years, leading Vasari to add other tie-rods both on the exterior and the interior. The four additional tie-rods and the works of reinforcement carried out by Bartolomeo Ammannati were the first of a long series of interventions, which were, however, unable to prevent further damage (fig.1). Recent methodological developments in analyzing masonry structures has led to fresh interest in studying the basilica with geomatics technologies, beginning in 2008. The survey is not only the basis on which to create structural models, but especially in such complex cases represents the only tool which allows correlation of the overall geometry, the construction techniques, the characterization of the texture of the materials, the position of the tie-rods, the cracks detection and mapping, etc. Combining these data with historical and archival information enables researchers to gain access to the reasoning behind the initial project and to the modifications carried out over the centuries.

In this case as well, the greatest challenges in performing the survey regarded the difficulty in carrying out topographical measurements and laser scans both in the tight crawlspace between the domes and in surveying the exterior, given that the building is high and located in a network of narrow roads, and the need to conduct a detailed survey of small elements, such as decorative features and cracks, in spite of these limitations. The survey allowed researchers to more clearly understand the morphology of the work, in particular of elements which are not directly visible. Vasari himself, when the first cracks appeared, modified the system of vertical connections and the crawlspace structures of the dome, adding eight ribs to sustain the weight of the lantern (Tucci et al. 2012). The survey highlighted and made it possible to quantify the number of ribs and their placing, form and dimension, the exact placing and dimension of the internal and external tie-rods, the thickness of the calottes; the building materials and techniques, the consolidation of the interventions, the horizontal and vertical connections, the cracks present on both calottes, highlighting the most damaged awnings, the links among the geometry, structure and deformations shown over time.

The Florence Baptistery is one the most important cases in the history of architecture: even in the past, researchers used progressively more advanced technologies to more exactly determine its geometry and to clarify doubts about its origins. From a structural point of view, the new survey enabled investigators to more closely study the construction technique of the buttresses that transfer the weight of the roof to the dome and the texture of the brick masonry of the dome extrados, which confirmed that Roman bricks were reused (fig.2). Deformations in the masonry were also studied. A comparison of the walls of the octagonal hall with vertical reference planes reveals a slight bulge precisely below the area lacking marble covering, inside of which is found an iron tie rod that was placed in 1514. In addition, the walls are slightly out of plumb toward the exterior (Tucci et al. 2017, Ottoni et al.2016, Bartoli et al. 2017). The survey also allowed researchers to tune the numerical model to the available experimental results and to interpret the detected cracking pattern.

3.2. Towers

In every culture, a significant portion of CH buildings consists of slender structures. The behavior of these structures depends on many factors, including their degree of slimness, the presence of adjacent buildings of lower height, the quality of the joints between the walls and the connections with the flooring slabs. An accurate survey of their geometry is particularly difficult, even with the techniques of geomatics (Sammartano and Spanò, 2009). Indeed, they usually contain walls of notable thickness, few openings and limited internal spaces. For these reasons, it is difficult to create a topographic network that links interior and exterior. In addition, if it is not possible to take measurements at heights, it is difficult to survey the top of a structure (where the most vulnerable elements are often found), given that resolution is inversely proportional to the range distance.

Most structures of this type show an inclination that is more or less apparent. The Torre del Mangia in Siena, which has a square base of roughly 7 meters on each side and is 88 meters tall, is one of the highest medieval towers in Italy. Two sides border on other structures, such that it is possible to collect data only from positions that are quite close and foreshortened; on the other hand, the sides facing the Piazza del Campo are more visible, yet at the time of the survey the available instruments produced results of inferior resolution at such a distance. To determine the degree of inclination, ten horizontal sections were traced in the area between 25 m (where the part of the tower isolated from other buildings begins) and 61 m (below the crownwork), and the displacement of their centers was measured. In this case, the inclination turned out to be negligible, equal to roughly 18 cm. Beginning with a point model, a numerical Finite Element model was constructed.

Subsequently, the numerical model was identified according to the results of the experimental investigation performed by means of an interferometric radar, which is able to remotely detect the dynamic behavior of the tower, subject to compliance with certain geometric and environmental constraints. The tuned FE model was used to reproduce the dynamic behavior of the tower and to evaluate the physical evidence of the experimental results. After tuning, the model is a good candidate to be used in subsequent investigations to assess the tower's structural behavior under severe loading or, in case of dynamic investigations repeated over time, to be used for structural health monitoring (Pieraccini et al. 2014).

More significant inclinations were investigated during studies on the towers of San Gimignano in the RiSEM project. The project evaluated these structures both by using existing data and by performing new scans on the exteriors of the thirteen towers. To measure the inclination, the displacement of the center of gravity of tower sections at various levels was analyzed, as were the deviations with respect to the vertical reference planes. In this case, the deviations were quite significant, although the absence of previous surveys unfortunately prevented comparative assessments from being made. In the case of the Ardinghelli towers, for example, the northern tower contains a portion that was rebuilt in the 20th century which leans in the direction opposite to that of the older part. Deviation analyses were then made with respect to the planes interposed in the façades; these showed quite irregular surfaces with alternating bowing and bulging. Another area in which numerical data were used concerns identification of cracking. The laser scanner samples the surface of the object at a predefined resolution, which is usually not fine enough to provide an overall systematic description of the geometry of the cracks. The ability to record small details is related to accuracy and beam diameter, both of which are distance related. If it is possible to scan the surfaces closely enough, rendering the intensity data can be helpful at least for crack recognition, even for cracks that are smaller than the sampling step (Tucci and Bonora 2017).

An additional example of the use of geomatics in support of structural investigations of a slender building concerns the “Oblique Minaret” in Aksaray, Turkey. The building is 30 m tall and inclines noticeably, so much so that in the past guy-wires were placed. Beginning with the geometric model acquired by laser scans, in this case again deviation analysis was performed to accurately identify the direction of and changes in the inclination.

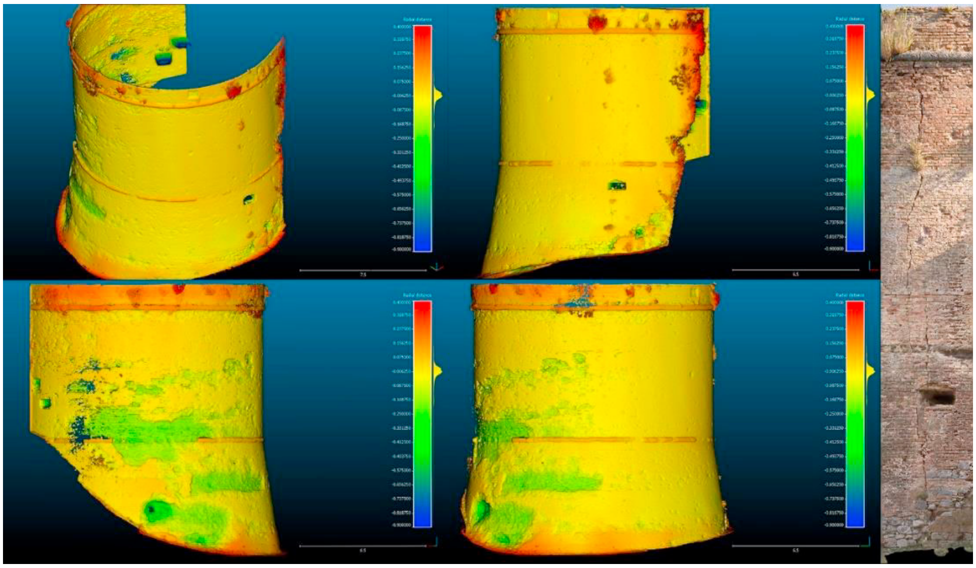

Fig. 3. Torrione di San Agostino: views of the 3D deformation map of the structure compared with an ideal shape and orthophoto of a crack.

Moreover, the benefits of 3-D model generation based on point cloud data for FE analysis were investigated and 3-D models of the historic minaret were obtained with different approaches. Creating a mesh model and converting it to solid model resulted in this case in the fastest and most accurate method, being able to preserve the original geometry with good accuracy. This approach turned out to be effective for FE modelling of historic structures despite some difficulties related to transforming TLS data to mesh/solid models and simplification of these models to computational models for FE analysis. The usefulness of an accurate model was apparent during the evaluation of the seismic vulnerability of the minaret through the pushover approach (Korumaz et al. 2017).

3.3. Other structures

The case study of the towers in the wall system in San Gimignano differs from those of the above-mentioned towers in the same town, as it regards extremely massive structures. These defensive towers were built at the end of the 15th century and represent examples of the transition from medieval to modern fortresses. They are, therefore, structures with very thick walls, made of a concrete core covered by stone or brick; they are as high as the adjacent city walls and are cylindrical in shape with a scarp base. The study in particular looked at the Torrione di Sant'Agostino, which showed quite evident cracks: the investigation therefore focused on interpreting the statics and the extent of the fractures (fig.3). Laser scanning was used to survey the overall geometry, while photogrammetry was employed to study the external walls in particular. In this case as well, the surveyed geometry was compared to a reference surface so as to assess any irregularities (out of plumb, bulging, etc.), which could provide possible clues for anomalies in the original construction or later damages. As the structure in question has a curved surface, the axis and the generator of a surface of revolution were identified, beginning with a series of horizontal sections. The survey showed that the real surface of the tower can be very accurately approximated with a cylinder and a segment of a cone with vertical axes, with the exception of the areas in which a loss of material was evident, due to decay of the external wall. This geometric model also allowed researches to perform stratigraphic and other related analyses. The survey of the identified geometry and of the cracked areas permitted investigators to create a structural model for which the damage may have been caused by structural failure at the base.

In 2010, the *Direzione Regionale dei Beni Culturali e Paesaggistici* of Tuscany decided to use the Galleria dell'Accademia in Florence as a pilot case regarding the application of the above-mentioned *Guidelines*. The Galleria dell' Accademia occupies several buildings, either completely or in part. Its spatial and distributive organization is quite complex, the result of transformations that occurred over the centuries without a unified project. The buildings used by the museum and its services border on–and sometimes share space with–other public offices and private properties; application of the *Guidelines* thus presented a suitable "stress test" to assess their effectiveness in a complex, real-life case. The investigations required by the norm involve the collection of spatial data, conducted by laser scanning. In this case, this part of the study was planned so as to meet the requirements of the norm with regard to the geometrical definition of all the spaces (from the basement rooms to the crawlspaces) as well as their relationship to the bordering buildings, choosing a resolution that could also describe cracked and deformed areas. In addition, acquisition process was used to realize a structural model and to locate spatial information relating to historical investigations and to the characterization of the construction materials and mechanics of the structures. Each survey attests not only to the state of a structure but also to the level of knowledge at a specific time; therefore, it will inevitably be improved on as new information is obtained with ever more sophisticated methods. For this reason, it is important to assure the preservation of data over the long term: above all in the case of digital data, this requirement represents a problem that is well known today in every application area. Awareness of this problem, though, is not enough: the scientific reliability of collected data is compromised if they are not conserved together with the metadata needed to reconstruct an investigation and to validate their quality over time, especially in light of new information and new survey techniques. In light of this need to assure the reliability of the survey over the long term, the topographical network, which represents the backbone of the survey, has been materially established. This has created a permanent reference system which allows for testing, for successive integrations–even when using different surveying methods–and for determining absolute or relative displacements in monitoring structures. Nonetheless, even if a very detailed survey was produced, from which seven plans and fifteen sections were created, the experience also highlighted the limits of a methodology that was not devised to take full advantage of the potential of three-dimensional geometric models, which are more readily available thanks to the spread of the techniques of geomatics: in light of these considerations, the survey therefore runs the risk of rapidly becoming obsolete. Even if all the research groups used the new survey for both the geometrical evaluation of the structures and for situating the single investigations in a comprehensive reference framework, a three-dimensional analysis would allow for a more immediate reading of the information and the results. On the other hand, this requires the recognition that the geometric model derived from a survey operation is not a mere gathering of data passively performed by a naïve "measurement specialist." The creation of an effective geometric model rather necessitates an interpretation of the architectural and constructive significance of the various elements; it is therefore to be hoped that specialists in different fields contribute to its realization (Castellazzi et al. 2017). This is, after all, the underlying approach of the Building Information Modelling that is steadily gaining ground in the design of new construction. The HBIM (Heritage-BIM), the specific application for cultural heritage buildings, is still only used sporadically and experimentally (Oreni et al. 2017): nonetheless, it is evident that the possibility of gathering all the information about a structure in a single database, organized spatially and capable of progressive integration in light of later investigations, would be particular advantageous for those great complexes, about which knowledge is usually divided among many different specialized fields.

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