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The survey of cultural heritage: a long story

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Abstract The conservation and enhancement of our cultural heritage (CH) require an exhaustive study in terms of position, shape, colour, geometry and also of the historical and artistic features. Survey methods have polished data acquisition techniques in line with technological progress. Today's electronic and IT technologies, that are the tools of modern Geomatics, allow the effective survey and representation of 3D objects in different scales: from architectural structures to sculptures and also archaeological findings. All these respond perfectly to all the shades that our rich and versatile heritage present. This report does not really aim at explaining analytically the methods of Geomatics. Its main aim is to reflect on the relation between Geomatics and CH, not only highlighting their meaning but also and above all, their roots in the history of survey.

Keywords Geomatic · Cultural heritage · Survey's history

1 Introduction

The day on "Geodesy and Geomatics: the frontier today", organized by the Accademia dei Lincei in Rome last June, was an opportunity to explore the state of art of the Geomatics discipline, its structure and methodology as well as in its natural and essential vocation to the interdisciplinary applications.

Whilst the principles of discipline are clear and fully describable, it is equally clear how Geomatics can contribute to the growth of knowledge in many areas in which its methods and tools can be applied. This is strikingly evident in cultural heritage applications, in its various definitions and scales.

The paper wants to demonstrate how the relation between Geomatics and CH does not conclude rely just in the application of today Geomatics tools and methods on the "objects" belonging to the past, but it can be considered as a much older and deeper link, as witnessed in the history of the survey, where some important moments are explored.

2 Geomatics and cultural heritage today

Let us start by explaining the meaning of Geomatics and CH, using "official" definitions.

The MIUR (Ministry of Education, University and Research 2012) website defines Geomatics as follows: "… it studies the scientific and educational activity in the fields of physical, spatial and geometric geodesy, topography and aerial and terrestrial photogrammetry, cartography, telesurvey, navigation and geographic information system (GIS). The scientific and disciplinary contents concern the acquisition, elaboration, feedback, analysis and management of the data of a metric or thematic nature related to the Earth surface or to some of its parts. This includes the urban spaces, infrastructures and the architectural heritage, identified by their position and qualified by the precision of survey.

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The fields of application concern the global and local reference systems, the global and local field of gravity, the tools and methods of the survey, the control and monitoring of the territory, of the structures, of CH, the treatment of measurement data, production and updating of cartography and topographic database, the tracking of works and infrastructures, the mobile systems of surveying, the numerical models of the land and surfaces, the management and sharing of multidimensional and multi-temporal geographic information." (MIUR website).

About CH, the Unesco declares (Unesco 2009–2014): the term CH encompasses several main categories of heritage such as:

- Tangible CH:
  - Movable CH (such as paintings, sculptures, coins, manuscripts);
  - Immovable CH (monuments, archaeological sites, and so on);
  - Underwater CH (such as shipwrecks, underwater ruins and cities);
- Intangible CH: oral traditions, performing arts, rituals

Moreover in the same site, Unesco gives some additional definitions that can be read in its glossary.

Considering these definitions it is possible to analyse the applications of Geomatics in the field of CH, drawn upon from the experiences of the scientific international research that finds in the ISPRS (International Society for Photogrammetry and Remote Sensing), ICOMOS (International Council on Monuments and Sites) and in the CIPA (International Committee for Documentation of Cultural Heritage) its privileged channels (Bitelli 2002). These activities see a higher interest for the application of the techniques and technologies of Geomatics (Bitelli and Mannina 2010), in two main fields of application:

- Documentation for study, knowledge, conservation and renovation: thanks to today's digitalization, geomatic techniques allow a metric and qualitative description that can make use of different study and survey methods that can interface thanks to the availability of the methods and algorithms of data transformation and merging.
- Control and monitoring of the state of real and personal properties, actions that can be applied to the object and to its territory.

Today technologies and methodologies in this field of application allow to record the position, size and shape, as well as generate very accurate and realistic 3D models in terms both of geometry and of textures, that are required in any project related to the conservation of CH, forming an important element of the documentation and analysis process (Patias 2007; English Heritage 2011).

The methods and tools used in the survey of CH cover a wide range according to the characteristics of the studied object and of the required precisions. The survey becomes a very complex operation both from the methodological and operational point of view. It requires critical interpretation abilities for a correct comprehension of the surveyed object from which the correct strategies can be derived to obtain the best result from the survey operations (Guidi et al. 2004; Cignoni and Scopigno 2008; Remondino and Rizzi 2010; Brunetaud et al. 2012; Chiabrando et al. 2014; Balletti et al. 2014a).

In CH surveying, many applications and several scenarios could appear, each one requiring an adequate planning to obtain the best results from the survey operations.

Particularly, the actual spectrum of methodologies and instruments is extremely wide: it goes from the direct survey, a simpler but fine and useful method, to the more sophisticated one known as indirect measurement. Often, the multi-resolution approach and the application of different techniques and methodologies (such as photogrammetry, laser scanning and topographic survey) provide better results in terms of accuracy and optimisation of the final product (2d or 3d).

In the last few years, in the field of CH, laser scanners (triangulation or time-of-flight) and structured-light systems were very successful, making easier the acquisition process of data related to the geometry and shape of both simple and more complex structures (Balletti et al. 2014b; Tucci et al. 2013; Bonfanti et al. 2013). This can be applied to both documentation and monitoring. In fact building structural control can be performed in combination with other traditional topographic techniques such as geometric levelling and topographic network: the geometry of the structure can be described by analysing point clouds (Fig. 1); specific measurements have to be focused on constituent elements with the aim of detecting anomalies of the geometric configuration. Geometric anomalies might be read as the result of deformations occurred in the past or as future deformations due to an abnormal geometric configuration (Capra et al. 2012; Fregonese et al. 2013).

In general, active sensors can provide directly and in very short time a huge amount of 3D data that are normally returned as a dense point cloud to which can also be added the radiometric value for each single point. The relative ease of point clouds acquisition influenced the quick spreading of this technology. At the same time, the high morphological complexity of the objects made it essential for the treatment of data, the development of original and new software different from those used in the territorial applications

Fig. 1 The laser scanning survey of the archeological site of Sepinum (Italy) done during the Summer School organized by the Laboratorio di Fotogrammetria of the Università Iuav di Venezia in July 2014

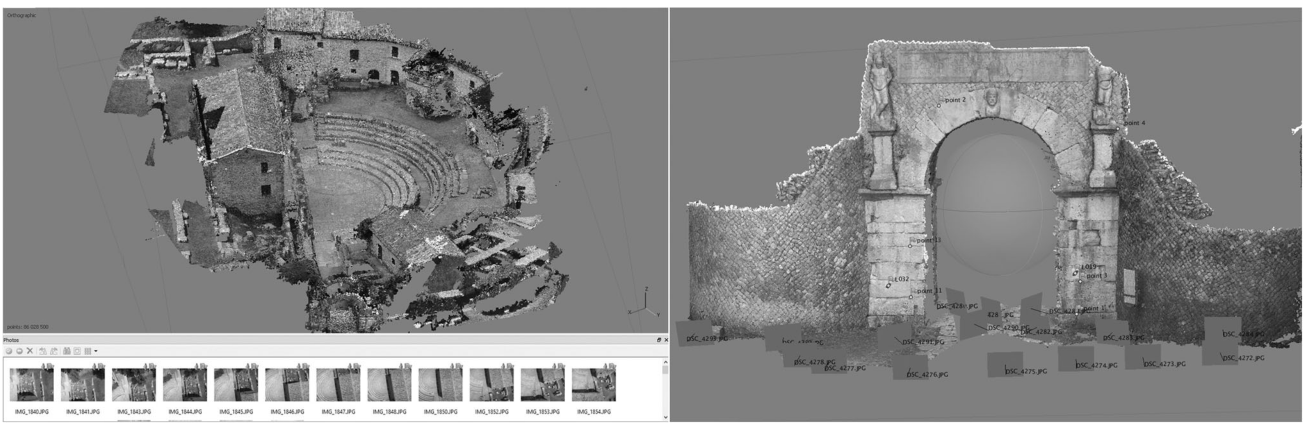

Fig. 2 Sepinum: the point clouds obtain by UAV and terrestrial phogrammetry

(Rinaudo 2011). The amount of data requires long periods of processing (registration, classification, segmentation) and editing to extract the most relevant geometrical elements, or to create continuous geometrical models.

Photogrammetry, that has always been the most used methodology since the first applications of Geomatics to CH, is today a widely used technique that can be applied to object survey, architecture and land survey for documentation, control and restoration.

Especially in the last few years, thanks to IT development and the spread of digital images, interesting software and hardware solutions were proposed to reduce the costs of instruments and to expand the pool of users that today include also non-experts without a specific training. The image-based techniques, using algorithms derived from computer vision, such as the well-known structure from motion, (Remondino and El-Hakim 2006), are able to automatically perform the whole pipeline reducing time both for images orientation and 3D reconstruction (Fig. 2).

Nowadays, we can work with software applications (such as Photomodeler, Agisoft Lens, iWitness, MicMac and 3DF Zephir) that can automatically perform camera self-calibration and offer the possibility use several cameras and sensors to obtain dense point clouds or 3D models suitable for different fields of application.

These instruments are widely used for 3D reconstructions of architectural parts, for the rigorous modelling of lands and cities or monuments and statues, by creating complex models. This complexity comes from both the high number of acquired and processed data and the description of the documented shapes. A common feature of the systems used today is that they can be easily carried, which means that costs can also be reduced. The development of electronics provides Geomatics with new survey methods: the UAV (unmanned aerial vehicles) are the most well known and present an integrated system of navigation/positioning and of digital images acquisition (these are acquired from sensors that operate in the visible field or in

Fig. 3 Sepinum: the UAV acquisition

Fig. 4 The topographical survey of the site

other bands such as near or thermal infrared, according to the needs). These systems are particularly useful in the case of wider areas (Fig. 3) for which a higher definition is required, such as for archaeological sites (Chiabrando et al. 2012) or emergency surveys (i.e. in case of earthquakes). The application of UAV allows the documentation of damaged buildings without compromising the safety and security of the operator: it acquires data in areas that would otherwise be hard to reach (Ballarin et al. 2013; Baiocchi et al. 2013).

Laser scanning and photogrammetry give a very similar generic product also in terms of accuracy, the point cloud, which can be complementary to the others. Their integration shows a great potential, balancing the downsides of both techniques in specific fields of application. They can be used in special applications (such as with triangulation laser tools): an example can be on one side the survey of very tiny objects and on the other the creation of 3D models that can be used in the new representation methods, such as virtual exploration and navigation paths in museums or libraries or in virtually reconstructed environments.

During the surveying process, there is always a phase which aims at the recognition of the reference system–global or local. In the case of the survey of architectures, big monumental complexes or archaeological sites, it is always necessary to create a topographic survey not only to contextualize the object but also in the possibility of activities that can continue in the future. It is possible to operate with the traditional topographic methods, with total stations or with GNSS systems, or integrating the different methods (Biasion et al. 2005; Spano' and Costamagna 2010; Bitelli et al. 2005).

Often the framework networks necessary to geo-reference in the same coordinates system the photogrammetric blocks and laser scans are made with the tools and the method of land topography, whereas the inclusion of such networks in a larger system (e.g. the national system) is made with satellite topography (Fig. 4).

The instruments of terrestrial topography can measure angles and distances without the use of a prism up to 500 m ensuring an accuracy of 3 mm + 2 ppm for the distance and 1 mgon for the angles. The GNSS receivers, in the real-time acquisition mode or in post-processing, can get an accuracy of few centimetres. This ensures final accuracies on the final survey, delivered to the CH operators (restorers, architects, engineers, etc.), that are entirely relevant to their scale of representation. Although it is not completely internal to Geomatics, but more to the documentation of CH, it is necessary to consider the mode of representation of the digital data obtained from the surveying process. In a society in which visual communication now has a fundamental role in disseminating information, the 3D model—appropriately adjusted through today's technological possibilities—can provide a message that is easily perceived and extremely incisive in communicating information about cultural heritage.

The overlapping and the integration of Geomatics with computer graphics is clear: alongside the more traditional Monge projections, where vectorial restitutions are integrated with orthophotos and rectifications, three-dimensional models, also texturized, are more often proposed and can be visualized through animation or applications of virtual reality. Finally, attention needs to be paid to BIM (Building Information Modelling): born in industrial building field, today it starts to be applied as a new tool in the documentation and management of CH field (Achille et al. 2012). Geomatics gives BIM the essential metric and geometric references.

3 Geomatics and CH: an old relationship

We have seen how in the survey of CH, Geomatics is responsible for identifying the instruments and methods of the survey, the instruments and methods of the acquired data elaboration, the shapes of representation and their transmission and storage methods. All these can be easily understood if we think about the survey with laser scanning of a church façade. The tools are the laser scanner and the total station. The method is the survey with polar coordinates. The representation is the 3D model of the architecture using the point cloud from which it is possible to easily obtain the plan view orthographic projections. The storage method is the numeric which uses IT technologies that allow the transmission of data without loosing information. All these seem to be relevant to contemporary times, but the connection between Geomatics and CH is much older. Geomatics was part of CH before it was even defined and even before CH was named as such.

We could start a discussion about the fact that the same survey methods are part of those intangible CH that were mentioned above; the history of survey is part of the heritage of the scientific culture also because of those technical aspects that are essential in the scientific development. Leaving this aspect that could deviate our attention from the main topic proposed here, to testify the old connection between Geomatics and CH we want to focus our attention on two well-known humanists that marked the development of the western world and thought: Leon Battista Alberti (1404–1472) and Raffaello Sanzio (1483–1520). Both offer and use tools and methods for the understanding and management of the objects to which they recognize values.

The tools and methods are those of survey and representation that are now handled by Geomatics. The objects to which Alberti and Sanzio recognize values are all those ancient and contemporary monuments that require attention and valorisation: CH.

Both of them, 50 years apart from one another, speak about the need and importance of survey. The need of the survey does not come so much from a desire for documentation, as we understand it today, but from the need of intervention on the architectures themselves, with a sense of belonging that perhaps today is far away. The way in which to conduct the survey is described in detail, emphasizing and giving much space to the description of the instruments. This proves the innovation of the instrumental survey for the intervention of what we now call CH.

Raffaello, in the letter to Pope Leone X (Di Teodoro 1994; Bruschi et al. 1978; Frommel et al. 1984), underlines the importance of drawing with an orthogonal projection: map, prospect, sections which is to say the 3D model broken into essential bi-dimensional views (build to be recomposed) that will then be classified by Gaspard Monge (Cardone 1996) at the end of the XVIII century and that will then become the strict and universally recognized method of representation for the world objects.

> "El disegno adunque degli edifici si divide in tre parti, delle quali la prima è la pianta, o vogliamo dire disegno piano, la seconda è la parte di fuori con li suoi ornamenti, la terza è la parete di dentro pur con li suoi ornamenti."[1]

Raffaello proposes this method[2] because this is the way in which to represent to properly convey the contents. In his letter Raphael describes how a survey should be conducted, a survey that today we would call instrumental and that we would interpret as the realization of a polygon that describes the dynamics of the walls. In this survey, the angles were measured referring to magnetic north, using a compass.[3]

[1] Di Teodoro 1994, p. 152.
[2] ibidem.
[3] Di Teodoro 1994, pp.150–151.

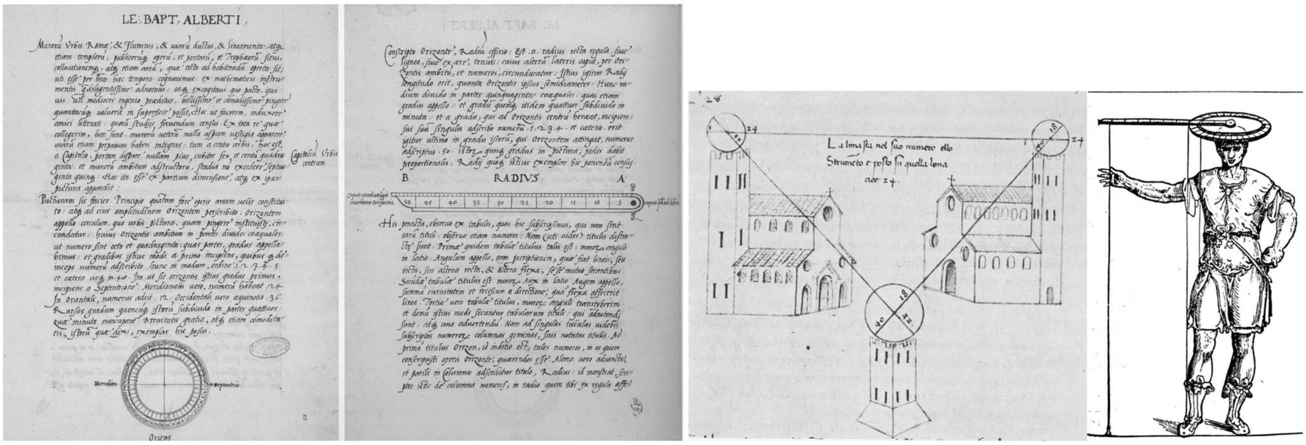

Fig. 5 The description of the surveing instruments (*oriens*, *radius*, *finitorium*) of Alberti in the *Ludi Matematici* and in the *De Statua*

Raffaello's willingness to have an operational rigour, necessary to the achievement of his goals is clear. His clear instructions to carry out a survey in the field, which must support a "scientific" representation, testify a maturity of thought with regard to the survey technologies and techniques, that come from a settled, though poorly testified, trial and reflection on the instrumental survey.

In this context, it is necessary and of absolute interest the work of Leon Battista Alberti (Borsi 1980) with regard to the instrumental survey and the representation that results from it.

In the "Ludi matematici" he describes the survey (at the urban scale in this case, but it is not important whilst dealing with survey and representation methods) with the method that today we call "intersections". In the first printed edition of Bartoli in 1568 (Vagnetti 1972), he divided into chapters the different problems faced by Alberti to help the reader. In chapter 16, we find the description of an instrument used to measure the angles and the way in which to use it (Fig. 5).

"… Fate un circulo su una tavola larga almeno un braccio, e segnate questo circulo in parte tutto atorno equali quanto voi volete, e quante più sieno, meglio sarà, purché sieno distinte e nulla confuse….Fatto questo, andrete altrove in luogo pur simile e veduto da questo primo, e porrete il vostro instrumento, e statuiretelo che proprio stia sulla linea medesima di quel numero per quale voi prima lo vedesti al diritto sul vostro instrumento, cioè che se da quella torre prima sino a qui una nave avesse a navicare, verrebbe per quel medesimo vento segnato."[4]

After the survey, Alberti suggests using a tool, which is very similar to the one used for the appropriately scaled survey.

"E in su questo punto ponete un piccolo instrumento di carta largo mezzo palmo, partito e fatto simile a quello grande col quale voi notasti le cose e assettatelo che 'l suo centro stia proprio in su questo punto, e di qui dirizzate tutte le vostre linee secondo che trovate scritto nella vostra memoria. Simile fate un secondo punto dove vi pare nella linea testé da voi notata alla tavola, … e in su questo punto secondo ponete pure un simile instrumento piccolo di carta, e assettatelo …. S'egli accadrà che queste due linee dette non si taglino bene insieme in modo che molto sia chiaro il suo angulo, ponete un altro simile piccolo instrumento sul terzo punto donde voi notasti le cose, e questo assettate simile agli altri che fra loro rispondano le loro linee, e questo tutti vi manifesterà a pieno."[5]

In the phase of restitution, Alberti clearly expresses the reason why a third point was used in the survey on the field: in the case of points aligned with the base of intersection, it becomes almost impossible to accurately determine the position of the collimated point. This fact, clear for all those who practice surveys on the field, has theoretical explanations that come from the error propagation law. In a certain way, Alberti is aware of the problem and tackles it by finding an efficient and methodologically sound solution. It is possible to say that there are old foundations also when considering the accuracy of the points as a fact not only linked to instrumental precision but also to the geometry of the measurement scheme.

The reading of the *Ludi* cannot be separated from the reading of *Descriptio Urbis Romae* where Leon Battista describes a tool to be used not in the survey but in the representation phase (Vagnetti 1974): the *Oriens* with the *Radius*. This tool is used for tracing on paper the points that model the plan of the city in a specific scale chosen by the

[4] Vagnetti 1972, pp. 235–236.

[5] Ibidem.

reader/user. The polar coordinates of these points are given.

> "Ho rilevato quanto più diligentemente possibile, con l'ausilio di mezzi matematici,…Ho inoltre escogitato un metodo per cui chiunque sia dotato anche soltanto di una normale intelligenza possa con precisione e con facilità disegnarli su di una superficie grande quanto si voglia. Mi hanno spinto a fare ciò amici eruditi, i cui desideri ho ritenuto ragionevole assecondare." (Alberti, trad. Colombo Alberti 2005).

The above text clearly indicates that the instrument for representation is used as a result of a survey carefully carried out with the aid of mathematical means such as the one described in the *Ludi*. The product of the survey is a "file" of polar coordinates of the city's significant points, that through the *Oriens* and the *Radius* can be transferred on paper, and going from the numeric format (digital) to the analogue format.

Alberti actually defines numerical cartography, which is different from the one we have adopted today (remembering that cartography is part of Geomatics) for the adoption of a polar system rather than the Cartesian one. However, it is possible to go further and interpret the lack of information about the unit of measure that the user can choose, as the introduction of the idea of a multiscale map. This way of thinking may, however, seem forced as there is not a consideration about the semantic content (the quantity and the quality of the signs) and the problem of measures' accuracy related to the scale of reduction has been neglected.

Also, the *De Statua* (Spinetti 1999) seems to be surprisingly close to our Geomatics: here, the problem of survey and reproduction of an object of a very different scale is discussed. Here, Leon Battista Alberti suggests a tool and a method of numeric survey (Balletti and Guerra 2002): the *Finitorium* (or *definitor*) which allows the phase of the *Finitio*, which follows *dimensio*.[6]

This tool is an extension to the three-dimensional case of the tool proposed in *Descriptio Urbis Roma* for the tracking of numerical cartography, going through the use of polar coordinates to cylindrical coordinates. The *Finitorium* is a digital tool that allows recording and then transmitting and reproducing alphanumeric data relating to the form, in such an efficient way that leads Alberti to say:

> "La cosa più sorprendente è che, se ti fa piacere, potresti fare metà statua nell'isola di Paro e l'altra metà nella Lunigiana, in modo che unendo e collegando i punti di tutte le parti otterresti la figura completa, corrispondente ai modelli usati."[7]

[6] Spinetti 1999, p 35.

[7] Spinetti 1999, p 29.

In these words, it is surprising to note the proximity with some of the concepts that today are familiar to rapid prototyping. A digital model of an object, obtained through tridimensional survey with a 3D scanner, can be transmitted at a distance without loosing information and can be printed in different places, obtaining the same physical model.

Many researchers in the Geomatics field are working exactly on this: they are studying the digital recording of the shape, its transmission and the tools used for its physical representation (Adami et al. 2012).

In light of what has been said until now, we do not have to be surprised by the lack of graphic representations (Iconography) in the works of Alberti because these are substituted by numeric representations that are tables of polar or cylindrical coordinates that he proposes methodologically and includes in his papers.

Because of this, Alberti becomes part of an ancient tradition that is against the presence of images in scientific texts (let us remember Plinio il Vecchio, who is adamant about this: only names and properties for a purely verbal description) because of the fear that scribes would wrongly copy them. Alberti finds the solution to the problem by introducing the numeric design and recognizing the possibility of an error-free data transmission. Should we want to find a precedent, we should name the list of geographic coordinates (latitude and longitude of the *oikoumene* of the second part of Ptolemy's Geography) but it would deviate from the field of CH.

From what has been said, we can find a complete continuity between Geomatics and Survey in ancient times that could be explained by thinking that today we simply gave a new name to this branch of knowledge (Geomatics) and to the objects that it studies (CH). But may be it is not like this.

If we re-read the declaration of the disciplinary area, we find a hidden term that has certainly a core role in the figure of the surveyor: "precision". In fact, if we consider fundamental in Geomatics the data acquisition process and the creation of interpretative models, accuracy is the essential category that characterizes them. The precision in the data acquisition, in the data elaboration and in their presentation, together with the ability of finding models is what distinguishes Geomatics from other sectors that focus on the study and the documentation of CH.

A clear example of this, which in the past brought up some useless controversies, is the drawing sector where qualitative and figurative aspects prevail on the metric ones.

Focusing the attention of Geomatics on precision, it is imperative to consider a fundamental figure: Friedrich Gauss.

The work of the *Princeps Mathematicorum* does not break the continuity of the surveying of CH (the inadequacy of the term is evident from a temporal point of view) as we have described it, but introduces error handling as a key component of the measurement operations. With Gauss the error is no longer a quality but a quantity: error handling leads to quantify quality. Gauss defines, classifies errors and invents the tools to deal with them.

Even though he starts from practical problems linked to the execution of measurement campaigns, he says that (Tazzioli 2002): "tutte le misurazioni del mondo non hanno maggiore importanza di un solo teorema mediante il quale la scienza delle verità eterne viene davvero riportata alla luce". This is to say that the measure for which he build an evaluation system is not an end in itself, but has to reduce the distance from the truth, through the construction of appropriate models.

What is added is therefore the knowledge that the product of Geomatics (let us think about traditional drawings) has a quantifiable content of truth and looks to being rather than appearing. To explain it in a simpler way, we can argue that representations of CH coming from the field of Geomatics have a higher content of truth. This means that when these representations become active in the intervention on CH (e.g. restoration), they certainly have greater utility and are more efficient and therefore more effective.

4 The theory of errors applied to Alberti: a simulation on accuracies

Clearly, Alberti did not focus on the error transmission and estimate of the accuracy of the points noted. However, if we consider Gauss's lesson and apply it to the survey he carried out in Rome, conducted as described in *Ludi* and *Descriptio*, we open new perspectives to the studies conducted by eminent scholars on the work of Alberti regarding surveying. It should be stressed that the operation is exactly the one declared: Geomatics, perfectly aligned with the tradition of surveying, brings within the tradition itself an amazing tool known as the theory of errors. The operations of Alberti have been analysed to speculate on possible explanations of some phenomena and behaviours.

The meaningful points of Rome localized in polar coordinates have been analysed and in this way it was possible to re-create a map as Vagnetti did a few years ago (Vagnetti 1974). If you overlap the map of Alberti with the more recent one, it is possible to identify some incongruence that had been already discovered. Two types of phenomena can cause these incongruences:

- A different surveying system
- Surveying errors

As far as the first point is concerned, observing the path of the Aurelian walls, it is possible to observe a rotation of 6°–8° with respect to the current situation (Fig. 6). By eliminating this rotation, the map of Alberti and the current map overlap better. From the reading of texts and the subsequent interpretation of the measurement operations of Alberti, the rotation does not seem to be connected to the surveying phase. Contrary to what has been often suggested (Camerota 1996), in the survey Alberti does not use a compass for the orientation of the instrument for the angular observations that do not have the zero to magnetic north. On the contrary, from *The Ludi matematici,* in the explanation about "Modo di misurare il circuito o ambito d'una terra", it is reasonable to think about a reference to a relative resetting between two stations, since the compass is never mentioned.

Therefore, the rotation could be introduced in numerical design phase, explained in the *Descriptio*, where the orientation is towards the north but does not indicate the instrument or method to locate it.

In the modern versions of Alberti's data, the direction of Tramontana, the north or the zero of the instrument of Alberti, coincides with the geographic north whilst it makes more sense to use (for reasons of operational simplicity in the past) the magnetic north. This, however, had an eastern declination of 6–8°. This variation is demonstrated by the first measurements of magnetic declination made and recorded in 1510 by Georg Hartmann and confirmed by current models of interpretation of the phenomenon in the past centuries.

If it is then possible to explain the reason for the rotation, once the same rotation with opposite sign has been applied, it is still possible to find small errors between the two paths of the walls.

To verify whether these are due to measurement errors, we tried to make a simulation of the topographic network of Alberti following his instructions.

This is necessary and possible because from Alberti's work we know the coordinates of the points, the scheme of the measures (intersections) and the instrumental accuracy. Alberti did not report the observations but the polar coordinates of the points. If we want to define some hypotheses on the accuracy of Alberti's survey, the method to be applied is therefore the simulation of the network, as it is commonly done before starting a topographic surveying campaign. In this case, the estimate of the accuracy by simulation (in the absence of observations) helps to explain the errors' presence after the application of the reference system transformation (the abovementioned rotation).

In this case, the estimation of the accuracy by simulation (without observations) helps explaining the presence of errors after the application of the reference system transformation (the above-mentioned rotation), Therefore as written in the Ludi, we have identified a basis of intersection—according to the scholars who have preceded us (Fiore 2005; Vagnetti 1974)—and a precision suitable for

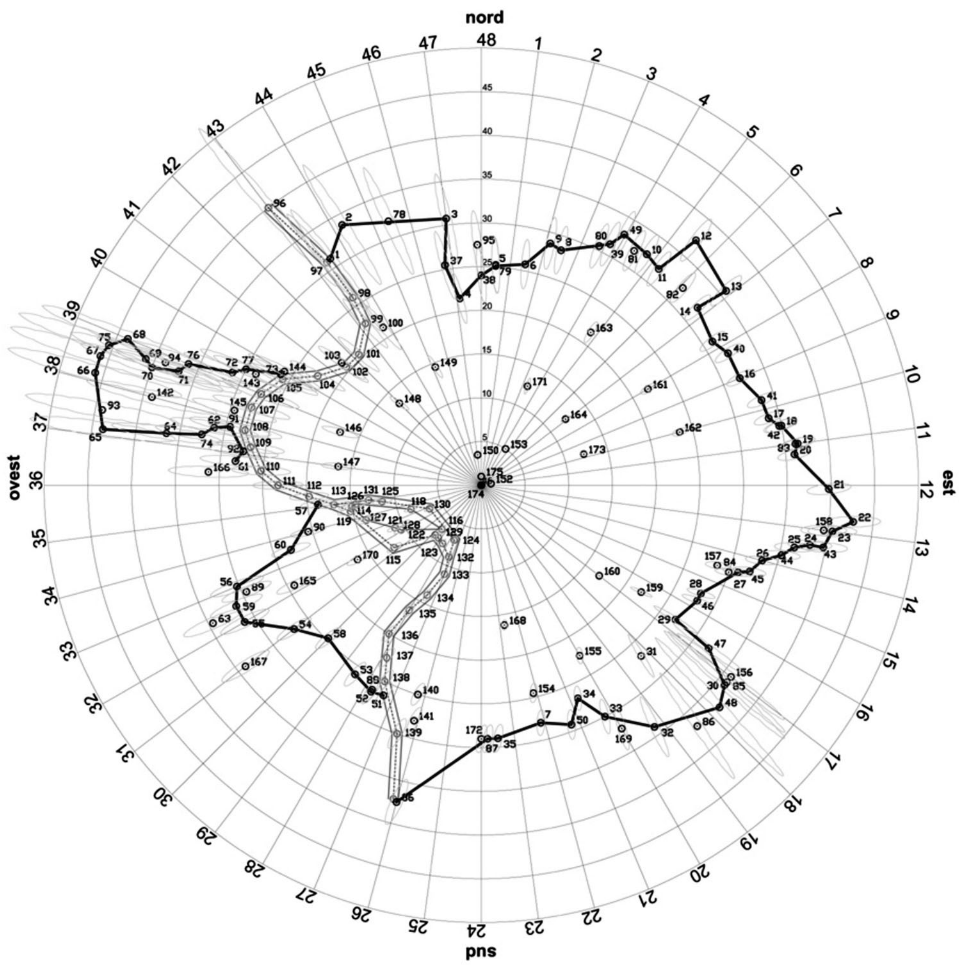

Fig. 6 The simulation of the Alberti' survey of the Aurelian walls

the tool has been assigned to the observations (the Albertian *Orizzonte*). Considering that the graduated of Alberti is divided into 48 parts, that are then divided into 4, and these are again divided into 3; an uncertainty equal to the minimum measurable quantity has been chosen, that is to say 1/576 of a round angle equal to 0.6944 gon. For the basis of intersection, about 450-m long, an accuracy of ±2 m has been assumed.

Having at hands the scheme of observations and their uncertainty, we carried out the simulation, obtaining the SQM of the coordinates and the error ellipses for each point.

Simulations have been carried out both using the scheme of the simple intersections and that of the triple intersections, suggested by Alberti himself for the determination of the position of points aligned with the base. The main problem encountered in this work is the lack of indication of the position of station points: for the main phase, we choose the points indicated by the reasonable and convincing deductions of some scholars that however have not given any indications about the third point of the station, chosen by us in positions appropriate to current operational practice.

The results of the simulations, as it is to be expected, show that the precision in the case of triple intersections is for some points significantly better than in the case of simple intersections.

The most obvious result is that the greater uncertainty (even considering the case of the triple intersections) is obtained on those points where the Albertian drawing deviates from the current one. If you look at error ellipses in Fig. 6, it is possible to notice that their sizes are consistent with the difference in the path of the Aurelian walls.

It is therefore possible to conclude that Leon Battista Alberti, despite having identified and followed some "rules" of surveying deduced from the observations that certain geometric configurations introduce errors, not disposing of the necessary analytical–statistical apparatus, could not fully benefit from his insights. However, the reasons for the deviation of the Albertian track from the real one are clear and are quantifiable and demonstrable with the equipment that we use today.

Beyond the investigations on Alberti's studies regarding the survey, the very fact of being able to apply the tools of calculation and analysis to his work shows the continuity of some operational methods of the surveying science throughout the centuries.

5 Conclusions

This article affords a synthetic overview of the actual Geomatic methods and techniques used for surveying, digital documentation and 3D modelling applications in the CH field and looks for their roots in a faraway tradition.

The application of modern computing techniques (networks simulations, rigorous compensation) to historical data (as the Alberti's Rome survey) underlines continuity in the survey's tradition regarding both tools and methods. Some practical procedures, today analytically demonstrated, were identified and selected thanks to geometrical considerations based on empirical observations. The link between Geomatics and CH is deep, and existed before the disciplinary definition of both Geomatics and CH. The latter, which are recognized by the *in nuce* protagonists of Humanism and the Renaissance in some artefacts, required at that time for their study and conservation the application of instrumental survey techniques that today belong to the Geomatics.

Conflict of interest The authors declare no conflict of interest.

Compliance with ethics requirements This article does not contain any studies with human or animal subjects.

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