NEW TECHNOLOGIES FOR CULTURAL HERITAGE DOCUMENTATION AND CONSERVATION: THE ROLE OF GEOMATICS

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ABSTRACT

The concept of Cultural Heritage is rapidly evolving, connoting the union of an intrinsic and an extrinsic value that includes several economic, territorial, environmental, academic and social aspects. The terrible natural disasters (cyclones, cloudbursts, floods, landslides, volcanic eruptions and earthquakes) that periodically occur weaken our fragile cultural heritage, which is constantly exposed to risk factors. Failing to protect it has negative effects on the sectors mentioned above, as we know that for some of these phenomena the anthropic action (i.e. pollution, improper use) actively contributed to their occurrence. In compliance with this wider view, the scientific and technological research is acting in different fields: from chemical, physical and biological sciences to nanosciences, from the methods of spatial positioning to info sciences.

Key words: Documentation, Conservation, Geomatics, Metric Survey, Cultural Heritage

1. INTRODUCTION

The concept of Cultural Heritage is rapidly evolving, connoting the union of an intrinsic and an extrinsic value that includes several economic, territorial, environmental, academic and social aspects.
The terrible natural disasters (cyclones, cloudbursts, floods, landslides, volcanic eruptions and earthquakes) that periodically occur weaken our fragile cultural heritage, which is constantly exposed to risk factors. Failing to protect it has negative effects on the sectors mentioned above, as we know that for some of these

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phenomena the anthropic action (i.e. pollution, improper use) actively contributed to their occurrence.
In compliance with this wider view, the scientific and technological research is acting in different fields: from chemical, physical and biological sciences to nanosciences, from the methods of spatial positioning to info sciences.

2. FACING THE RISK WITH MAINTENANCE MANAGEMENT

"Understanding the physical fabric of a site is an important first step in finding the right conservation strategy, and documentation is the first step in understanding" (Clark 2007).
This sentence highlights the primary role of documentation and the interdependence between knowledge and conservation strategy: you should know the object surveyed as well as the risk factors to which it is exposed, in order to plan the conservation works and the maintenance programmes useful to prevent risks and to avoid facing emergency situations.
The only possible way to hand over "heritage documentation" to future generations in modern times is through - as permanent as possible - digital records.
Digital tools and media offer new opportunities for collecting, analyzing and disseminating information about heritage sites. For the approach presented here, careful attention has been paid to the suitable role that geomatics should play to implement a thorough prevention policy, in compliance with the recent scientific approach adopted for heritage obsolescence, which aims at optimizing preventive (rather than corrective) maintenance on buildings. This method has apparently higher investment costs, but they will be amortized over the long term. This is briefly the logic at the basis of the strategy and methods of "Building maintenance management" (Lee 1993). This revolution in the philosophy and tasks of restoration, which has always been limited to repairing or renovating existing damage, emphasized the strategic importance of adopting suitable survey tools and methods to support the prevention of "expected damage". This kind of activity is based on timely detection of deterioration phenomena (as well as their mechanisms and possible causes) in order to limit their development and assess their incidence on the artefact's life cycle.
The decay curve of its "performance quality", from the very beginning up to the minimum threshold allowed for the function carried out, allows assessing its "useful life" and planning maintenance works, leaving any possible unexpected failure aside. Without preventive maintenance, small problems with monuments and buildings can quickly grow into critical issues.
If in the building industry these works normally include modification and replacement of damaged parts, in the cultural heritage sector they should not undermine the values (authenticity, artistic value, historical interest, etc.) of every artefact. The model of information required to inform conservation action is already established in the Venice Charter (Article 16) (ICOMOS 1964) and expanded in the ICOMOS Sophia Principles (ICOMOS 1996). The conservation of built heritage is developed following a series of work phases, involving analysis to establish value

and significance in order to understand the priority of action and allocation of resource, diagnosis to identify the causes of damage and decay, therapy to choose the remedial measures and controls or monitoring to review and assess the efficiency of the intervention or conservation regime (Santana Quintero et al. 2007). The contribution of Geomatics is fundamental in all the four phases described above, which should not be considered as part of a linear process with a beginning and an end, but rather than as a cycle (Figure 1): each phase requires thorough, correct and up-to-date metric knowledge of the object surveyed, even according to different levels of detail and accuracy.

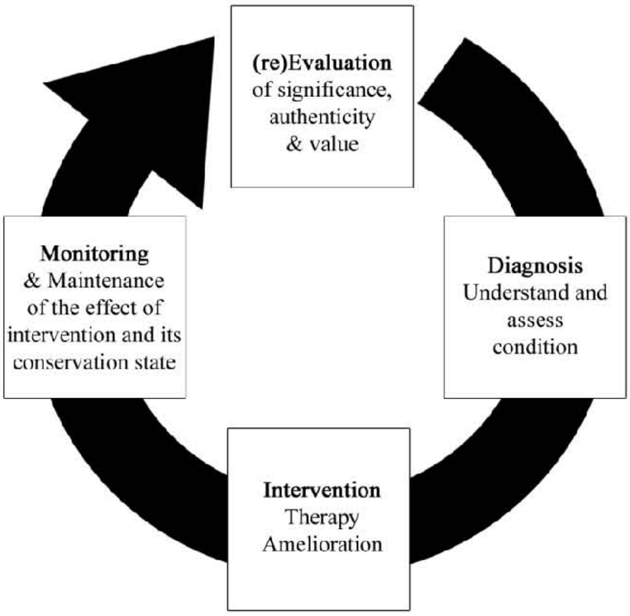

Figure 1. The Conservation cycle (from Santana Quintero et al. 2007)

3. DIGITAL RECORDS FOR HERITAGE DOCUMENTATION

Metric survey is the reference base for all types of documents required during analysis, diagnosis, intervention and monitoring. According to English Heritage, metric survey is "The measurement and pictorial presentation of land and buildings to a specified standard, supplying reliable and repeatable base data without specific thematic input" (English Heritage 2003).

The output of the contemporary metric survey is an information system where information can be structured according to geometry, materials, pathology, and so on, and linked to a database. It is thus possible to provide graphic representations responding to specific queries from time to time. That is why metric survey should

become an aggregation element of multidisciplinary contributions, a common platform hosting every kind of knowledge and not only a simple "service" activity.
The information coming from diagnostic tests and the manifold multidisciplinary contributions should be gathered to form an information system, which will be used from time to time to extract important outputs for the assessment of the "useful life" of artefacts or elements, evaluating their vulnerability in case of natural or anthropic risks.
Good conservation of our cultural heritage is based on informed decisions. The first and effective step towards prevention is an up-to-date documentation of what needs to be pre-emptively defended: the Heritage itself and not documentation for documentation's sake. Documentation is expensive, but contributing towards a better knowledge of the building and its problems brings the conservation costs down as low as possible.

3.1 Level of detail pyramid

Survey should be planned and carried out to reach a level of detail that can provide helpful information by optimizing the invested resources. The frequent need to have data with different scales underlines the importance of integrating various levels of detail into a single documentation project. On top of the pyramid scheme (Figure 2) there are catalogues and inventories, which are the most basic form of knowledge, as they require only "identification" and recording of data. Therefore, each element belonging to Cultural Heritage must first be identified, then geo-referenced and finally stored, associating its position to other basic information, if necessary. At the base of the pyramid there are high-resolution 3D models, whose level of detail allows describing the materials and conservation status by means of a texture. In the middle there are all other types of 2D or 3D representations, carried out with metric data.

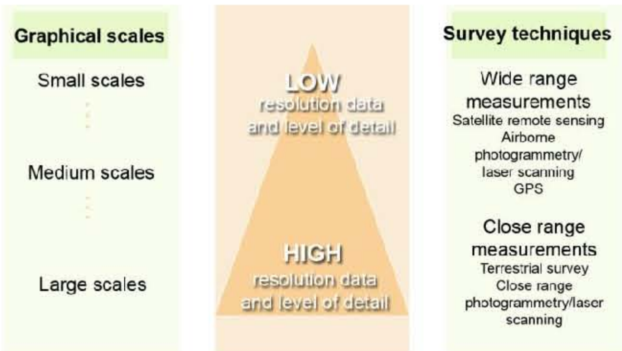

Figure 2. Level of detail pyramid

4. DIGITAL TOOLS FOR HERITAGE DOCUMENTATION

Currently, a wide range of digital sensors for documenting cultural heritage is available. Survey tools can be divided into "direct" and "indirect". The former

require the operator to first build a mental model (and then a virtual one) of the object by selecting all the measures necessary for its construction one after the other, while the latter can postpone modelling according to the density of the object sampled.
In the last decay we have seen the final digital transposition of photography and photogrammetry, the development of scanning systems based on different technologies, electronic total stations and satellite receivers. Except for the natural progressive optimization of these tools, no new kind of sensors has been introduced recently (and this trend will probably continue in the future).
We are instead witnessing the birth of “hybrid” sensors, such as total stations with GPS antennas or laser scanners with cameras, sometimes placed on supports that can acquire data on the move, such as those cameras mounted on drones or UAV, mobile mapping systems, digital cameras on rotating heads, range cameras, which integrate distance measurements and imaging aspects.
After the development of sensors that can acquire high quality data, we are now witness to a process aiming at optimising productivity. Only a few years ago, in 2007 we spent entire nights surveying the Basilica of the Holy Sepulchre in Jerusalem, which required approximately three hours for each scan. With the scanner we use now in our laboratory the whole work would take only ten minutes. We are presently working on a system mounted on a motor vehicle integrating laser scanner, GPS, IMU and digital camera.

5. APPEAL AND RISKS OF VIRTUAL WORLDS

The higher and higher resolution of data and their more and more rapid acquisition risk leading to a separation between the surveyor and the object surveyed. The time spent in the past to observe and draw an object before writing measures down was the first step of a knowledge process in which measurement was often the element confirming or denying a hypothesis (concerning shape, construction, structure and so on) put forward by the surveyor “while” observing the object. Nowadays the shorter time spent on site postpones interpretation. Therefore, the acquisition of very high resolution data is often linked to the possibility of considering the digital reference sufficient to represent the real object rather than to the need for describing tiny variations during the representation phase of the object surveyed.
As Carlo Monti pointed out, even though the situation has changed, the “problem of measurement” still remains “a central element in the issue of scientific knowledge applied to real life. [...] It is an uninterrupted alternation of analysis and synthesis of the object detected, where size measurement is the analysis and model is the synthesis and they can hardly be separated because they are always present at the same time.” The survey tools and methods available today allow, according to Monti, “passing from the monument to a realistic model, where geometries are real within the measurement uncertainty and ‘shapes’ are not interpreted according to historical and stylistic experience, but according to the positioning of several points belonging to architectural elements within a suitable reference system”. (Monti et al.

2004) In any case, it is clear that the transposition of analyses from the real world to the virtual one is both fascinating and potentially dangerous.
Roberto Pane's remark stating that "Briefly, we need to understand that the only real and complete representation of a monument is… the monument itself" (Pane 1948) seems to be questioned by the unstoppable technological progress. But if we consider a documentation project as a series of investigations looking for a series of answers, the only thing we can do is acknowledging the fact that the choice of the questions is the fundamental moment and confirming the leading role of the person operating the tool. Even though we use objective tools to quantify information, its recording is still a selection and interpretation operation influenced by the experience, the cultural context and the time in which the surveyor works.
The degree of "automation" reached by some tools should be considered as the possibility of managing repetitive and complex processes and operations requiring limited human intervention, but we should not confuse it with "autonomy", which is the capacity of choosing among different alternatives without the direct intervention of the user. According to this definition, therefore, an "autonomous" system would be able to work without any specific parameter, which could be inferred from the past knowledge.

6. MODERN SURVEY SYSTEMS FOR CLOSE RANGE APPLICATIONS

Even though it is essential to remember that the materials used for buildings and their virtual representation should not be considered completely interchangeable, the digital representation of a building can originate from different survey systems. A possible classification of the most widespread tools is divided into "image-based" systems and "range-based" systems.
Range-based systems directly provide 3D coordinates. They are based on the measurement of sensor to target distance, having the *a priori* knowledge of angles through the controller orientation of the range measurement device, or on triangulation (with laser light or stripe projection).
Image-based systems refer to photogrammetry and computer vision, paying higher attention to the metric value in the first case and to the efficiency and effectiveness of the vision in the second. In both cases 3D measurements are acquired from multiple views. In image-based systems, field acquisition is limited to shooting a series of frames and recording some measures of elements that can be clearly identified in images. (Remondino and El-Hakim 2006)
Close range applications have specific problems that generally require case by case planning, as well as the integrated use of different tools, as one single system is often unable to satisfy all requirements. (Beraldin 2004)
The diagram below (Figure 3), derived from Böhler presentation CIPA symposium 2001, Potsdam (Böhler 2001), summarises different techniques in terms of scale and object complexity.

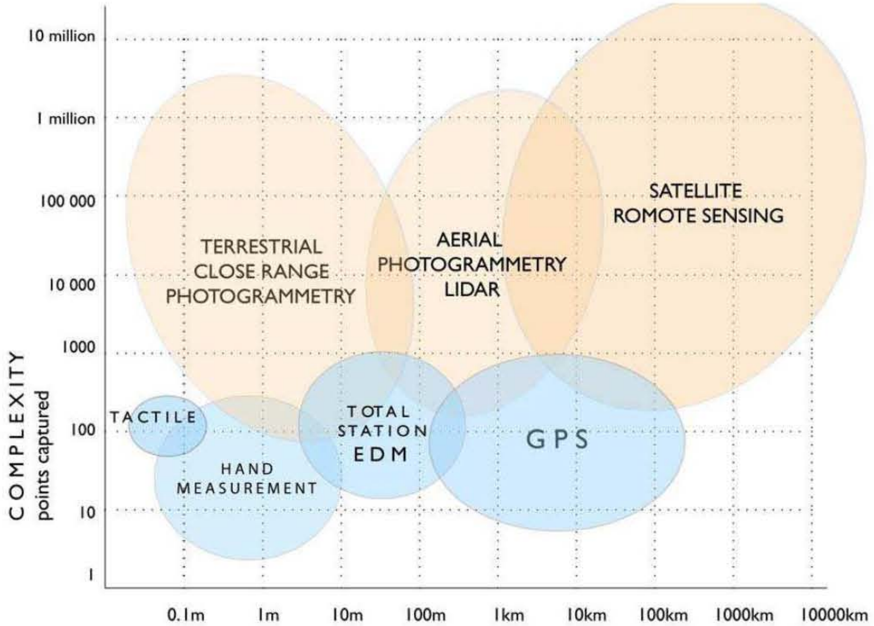

Figure 3. Metric survey techniques related to object complexity and scale of analisys

Finally, it is important to bear in mind that there is a close relation between hardware and software, because the electronic parts of a scanner require a parameter setting monitoring system, which is also useful to carry out a first visual check of the surveyed data. The software used to control the scanner is often the same used to carry out the first processing operations (data cleaning, scan alignment and referentiation, etc.). It is difficult to choose the software to be used for subsequent graphic processing without taking into consideration the acquisition system, because of strictly commercial logics: unfortunately, data are often stored in a closed file format and sometimes long conversion operations become necessary.

7. CHARACTERISTICS OF THE SURVEYED DATA

A 3D reconstruction of an object derives more and more frequently from high resolution point data: they are called range maps, point clouds, scans, and so on, with slight differences in meaning that are not worth taking into account in this work.

Range map is a metric representation of an object from a specific point of view through a set of 3D points properly spaced apart, according to the complexity of the imaged surface. (Guidi and Remondino 2012)

Irrespective of the specific technological solutions implemented in the various measurement systems, the surveyed data present some common characteristics:

- They are always digital data (real-world information is converted to and stored as binary numeric form), with several advantages regarding flexibility, transmissibility, sharing, possible automatic storage of metadata, etc. We should bear in mind that the documentary heritage created in digital form will remain at risk of digital obsolescence and also of the fragilities inherent to digital media.
- They are 3D. A metric survey records the position, size and shape of every part of the object analysed; even though the need for plans, sections and profiles plotted on hardcopy is still strong (e.g. for direct use on site), the modern survey techniques always generate three-dimensional survey information.
- At the moment of acquisition, they are undifferentiated. In fact, they come from a sampling carried out directly on the surface of the object (in case of range-based systems) or on photographs (image-based systems). Automatic systems of segmentation and classification give good results on urban and local scales, while at the moment they are hardly used for the semantic structuring of models in close range applications.
- The time required for their on-site acquisition is very short. The most recent scanning systems work at a higher and higher speed: it takes only a few minutes to survey a room or the façade of a building. In the image-based systems the only activity to perform on site is to take photographs. In both cases you should not underestimate the time needed for the planning of essential operations. Furthermore, if we can consider acquisition as "near real time", the subsequent processing carried out to meet various needs will require pretty long time.
- Survey is always carried out without touching the object.
- The object is sampled at high resolution. The concept of resolution during acquisition (resolution is "the smallest change in a quantity being measured that causes a perceptible change in the corresponding indication", VIM 2008) is directly linked to the concept of "level of detail" during restitution: the higher the resolution, the smaller the geometric detail documented by the model.
- Geometric data are often associated to information on texture coming from photographic images: raster and vector data can be combined in 3D modelling software.

Finally, as far as data are concerned, we need to point out that the efficiency with which they can represent the real world should not be confused with the accuracy of the representation itself, defined by VIM as "the closeness of agreement between the average of an infinite number of replicate measured quantity values and a reference quantity value." (VIM 2008)

8. GRAPHIC PROCESSING: SOME EXPERIENCES FROM GECO LAB.

Various types of processing can be performed starting from the surveyed data. The most suitable ones should be detected from time to time according to the main purposes of the project under way. Many design activities require conventional representations such as plans, views and sections as basic drawings. Vector drawings can incorporate raster images to integrate the description of geometry into the description of materials and their conservation status.
For all the section planes the rules and exceptions typical of the technical drawing hold true, such as the need to pass through openings, avoid structural elements such as pillars and columns, and cross vaults next to the keystone. On the 3D reference too, i.e. the model of the real building, you should act in a similar way, with careful translations of the section plane and the graphic restitution of only the important elements from time to time.

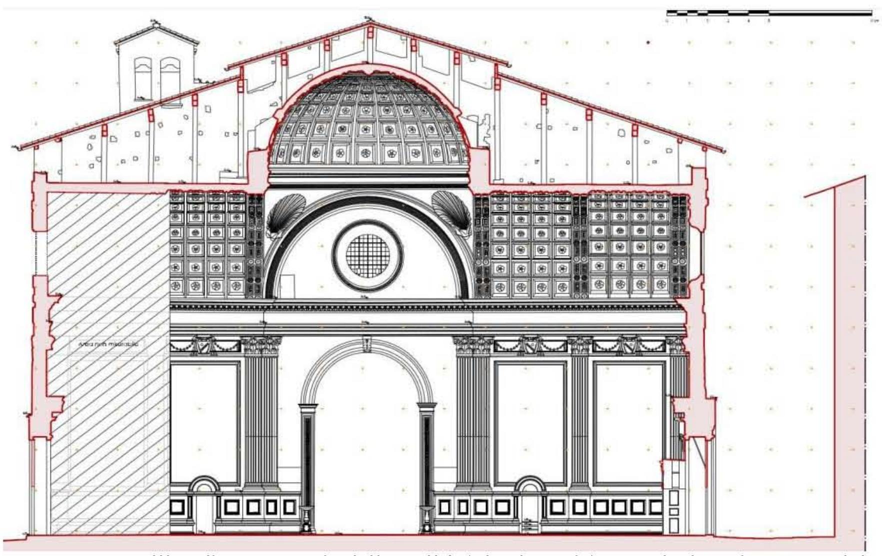

Figure 4. Basilica di Santa Maria dell'Umiltà (Pistoia, Italy) – vertical section, vectorial drawing (graphical elaboration from a laser scanner survey)

The orthogonal views can be integrated with the photographic information coming directly from the model (in case of scanners with integrated cameras or image-based systems), or applied afterwards, as it generally happens when good resolution and high photographic quality of the texture are required.

Figure 5. Frieze of the Ospedale del Ceppo (Pistoia, Italy) – orthoimage and DSM model

Figure 6. Arezzo Fortress (Italy) – Elevation, vectorial drawing integrated with rectified image. In the small image, a view of the 3D model

The texture representing the status of a surface during its survey can be overlapped with maps thematising the different materials that compose it, the pathologies detected and the treatments planned.

Figure 7. Pisa (Italy), walls of the city – 3D model texturized with the deterioration mapping

Other representations keep the three-dimensionality of the initial data and allow exploring the model interactively, an activity that proves to be very useful to communicate complex spatial realities and materials, as well as to forecast the outcomes of design works.

Figure 8. Certaldo Alto (Florence, Italy), video shoving the results of a 3D city modelling project

The metric validity of the model allows obtaining linear and angular measurements, as well as surface and volume measurements even in real time, which are useful to check similarities and differences in terms of costs, works to be performed and materials

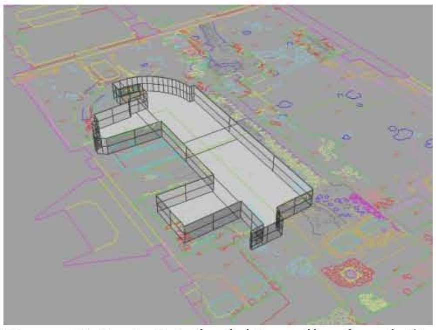
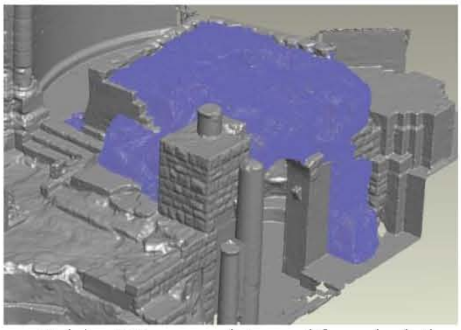

Figure 9. Santa Maria del Lavello church (Lecco, Italy) – 3D survey data used for calculation of the volume of land to be removed in the next step of an archaeological excavation
Figure 10. The Grotto of the Annunciation (Nazareth, Palestine) – calculation of the surface to be treated in restauration works on the 3D model

Additive manufacturing systems allow giving physicality to 3D models and reproduce small objects or whole architectural complex in full or reduced scale.

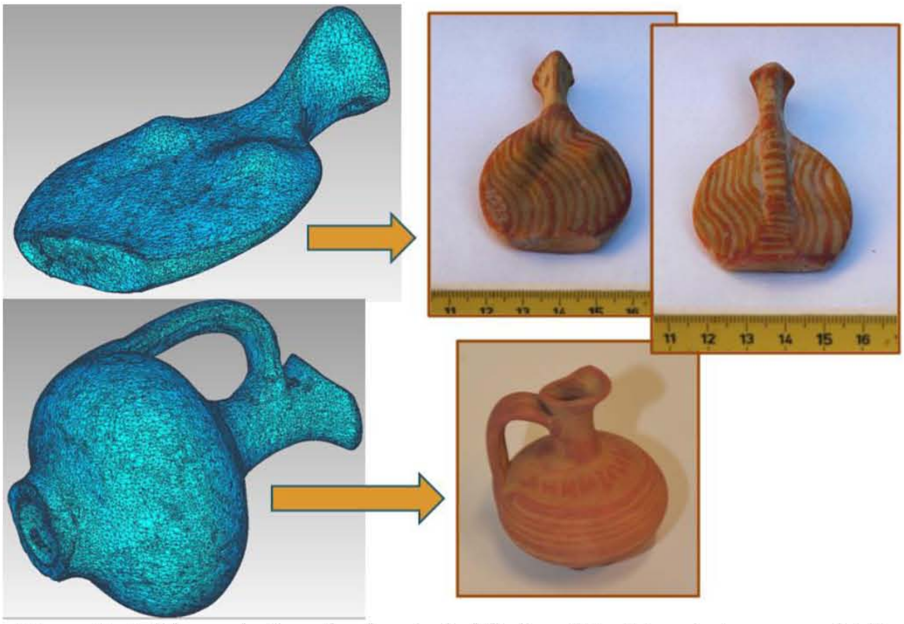

Figure 11. Solid reproduction of archaeological findings (Mus.Int project, www.musint.it)

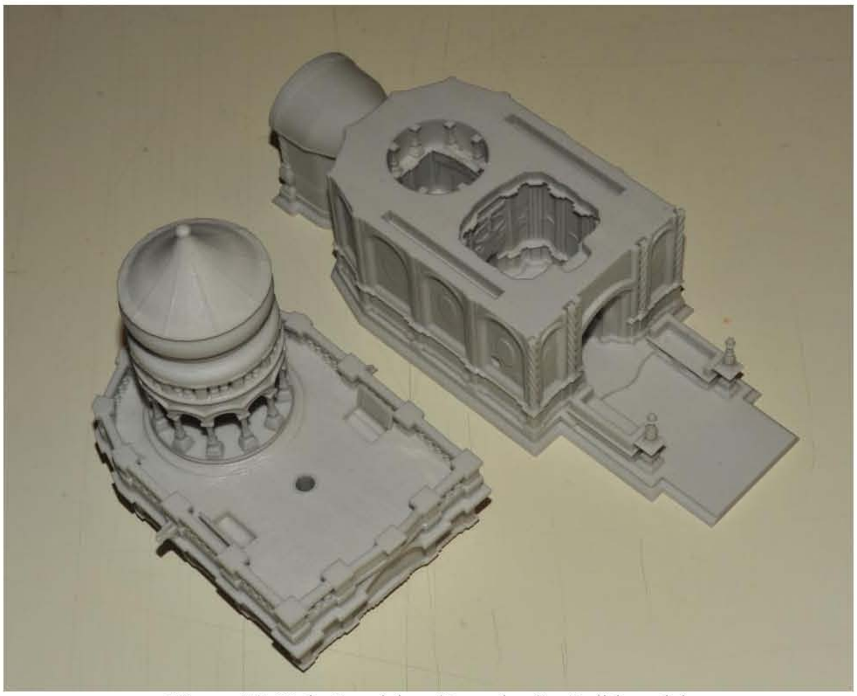

Figure 12. Holy Sepulcher (Jerusalem) – Solid model

Keeping in mind that "the preservation of the historical memory should be entrusted to accurate recording systems of the events involving the building, as well as to the works performed on it" (Torsello 2005), it is possible to coherently record survey campaigns over time, providing a diachronic reading of the building - let's think about, for example, the inevitably destructive progress of an archaeological excavation.

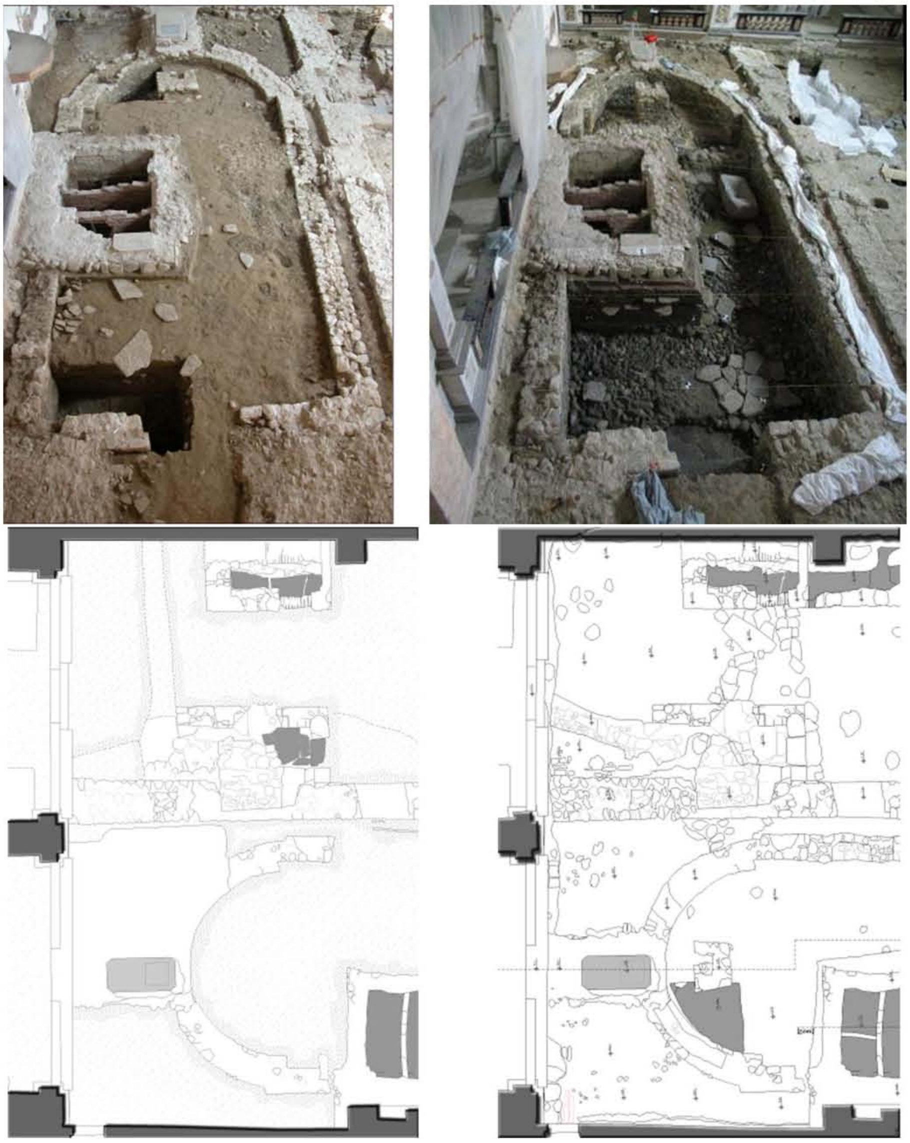

Figure 13. Archaeological survey update

Static, perspective or orthogonal images can represent space from unusual or unreachable points of view, increasing the knowledge of the object and even putting forward interpretations never taken into consideration before.

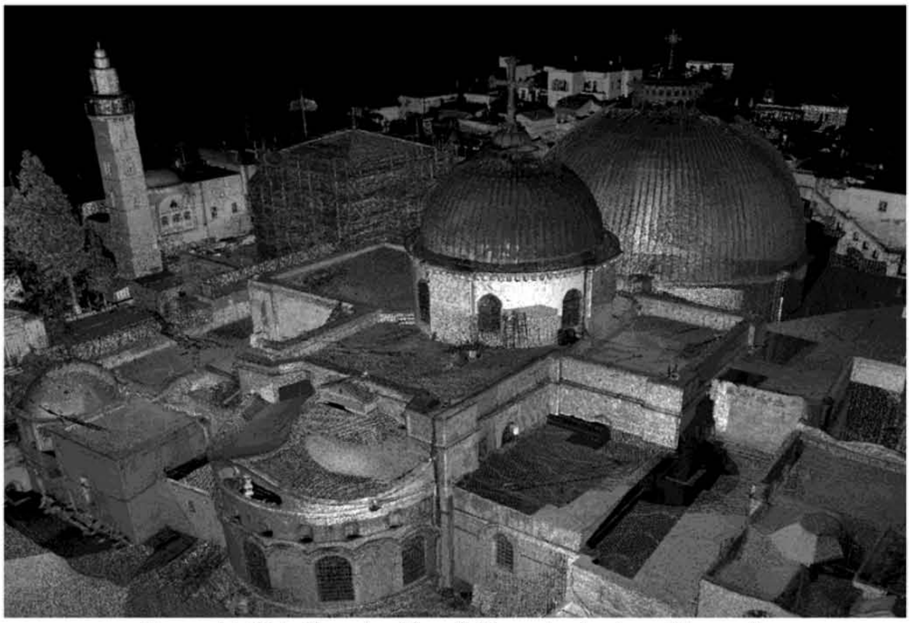

Figure 14. Holy Sepucher Church (Jerusalem), view of the roofs

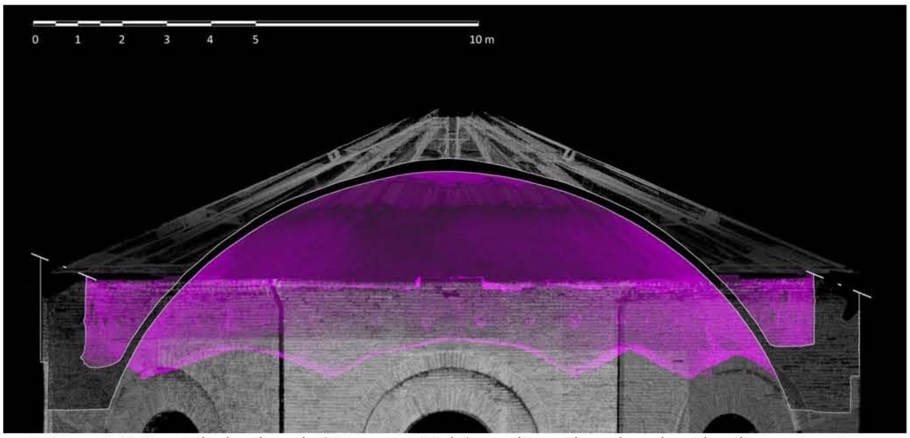

Figure 15. San Vitale church (Ravenna, Italy) vault section showing the dome structure

The common structure of the data required to represent both the current condition (i.e. the survey) and the project allows considering the virtual model as a "true research 'laboratory', where you can test and analyse hypotheses concerning historical reconstructions, integrations, releases, completions and such" [Torsello 2005], up to anastylosis operations that can now be accepted only for the virtual reference of a building.

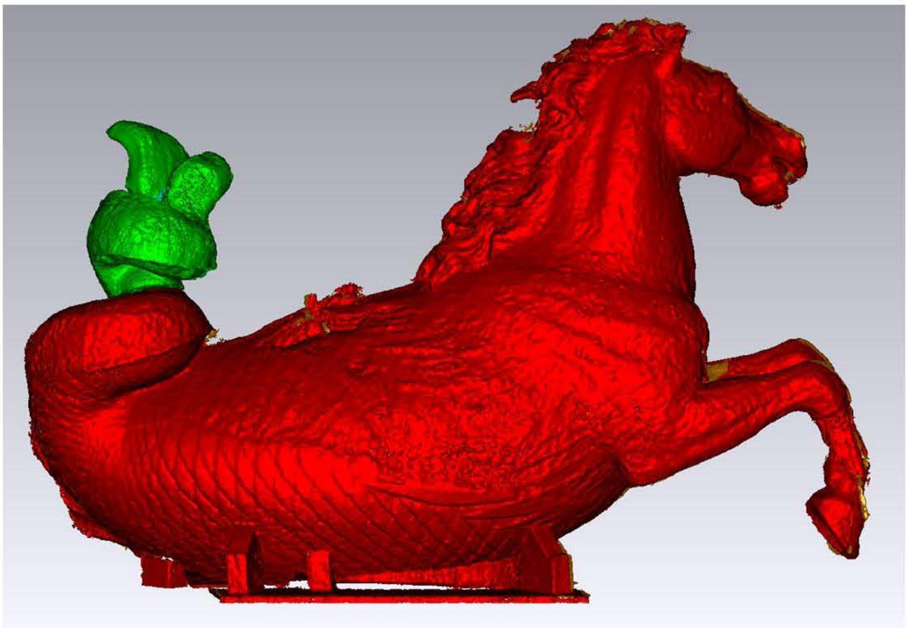

Figure 16. Pegasus statue, reconstruction of the tail

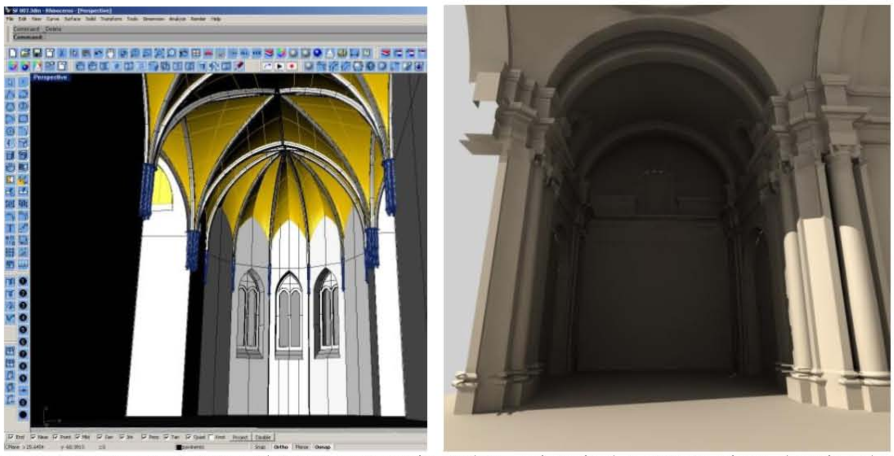

Figure 17. San Francesco al Campo (Perugia, Italy) – Historical reconstructions showing the building in different periods (3D modelling software and render)

9. MENAGEMENT, COMMUNICATION, DISSEMINATION

Thanks to the union between range map and digital images it is now possible to "follow three different and complementary directions: the first pushes architectural analysis to the limits of materials and the transformation processes involving them; the second provides us with powerful means of calculation and orientation to make design choices and the third opens the doors of virtual reality, allowing us to forecast the outcomes of our design choices and the consequences that they will have on future transformations."
In fact, survey is not only an effective means to describe the built-up space, but it also "imposes some forms of transcription and communication... Indeed, the ability of turning the critical or scientific acquisitions of the survey into a message is the guarantee that surveying will not become a mere descriptive act with the aim of generating only useless graphic representations." (Torsello 2005)
At the same time, the digital information and communications technologies (ICT) have produced a wide range of applications for collecting and processing historical data, documenting and monitoring the physical conservation of objects and monuments, visualising historic structures and environments, and creating interactive information networks that can link professionals and scholars with students, museum-goers, and interested amateurs. The integration of Heritage with digital technology has already shown the potential for greatly enhancing many aspects of the research, management, and public involvement in the material remains of the past. However, it is important to understand that ICT is a complex field whose contribution to cultural heritage can only be realised if it is utilised in effective, sustainable ways. It cannot be considered an immediate or magical cure-all. Cultural heritage professionals must understand what ICT can do, and in which situations or contexts it is most effective. With the rapid development of digital applications for historical research and public heritage presentation, the integration of digital technologies into the field of cultural heritage must be undertaken with the full awareness of their potential uses and effects. (Brizard et al. 2007)

10. FUTURE PROSPECTS OF DEVELOPMENT

In these years we are witnessing widespread dissemination of geo-referenced data; notwithstanding the way they are produced, they could prove to be a decisive contribution for the realisation of that recurring dream (i.e. comprehensive heritage documentation), which in 1858 led Albrecht Meydenbauer (Albertz and Meydenbauer 2001), a young German architect, to use photographic images for the first time to document buildings with the aim of creating an Archive of Cultural Heritage (Denkmälerarchiv). He knew the risks that Cultural Heritage was running and he was sure that this kind of documentation would have even allowed reconstruction, if necessary. Between 1885 and 1920 2,600 buildings were filed through approximately 20,000 photographic images on plates.
To establish a parallelism with the urban and land scale, where "alternative" solutions for the production and sharing of data have been testing for a long time

and where collective participation suggests the idea of «citizen cartography», while Google calls its maps "geospatial applications", we should launch a sharing and networking process of all the outputs coming from cultural heritage surveys.
According to Mark Graham, researcher of the Oxford Internet Institute at the Oxford University, the projects carried out by digital neocartographers can be organised into three categories: virtual globes, applications and sites belonging to Web giants that allow users to virtually explore any place in the world; wiki-locals, such as Wikitravel and WikiMapia, where users actively participate in the representation of the places that can be shown in different scales, and OpenStreetMap, where maps are drawn by volunteers who pick up the GPS signals of our devices, rather than using private or government data.
How about creating a data community for Cultural Heritage? Images, drawings, models, range maps could be accessible and integrated. After all data, if suitably validated, are a common good with an extremely high value that short-sighted administrators and red tape rarely make available, entailing additional measurement operations and higher costs.(Graham 2009)
Some projects to make available geographic data concerning the territory have been launched successfully: thanks to the incredible results of the first pilot experiences, "portability" and "interoperability" have become watchwords for an ever increasing number of public administrations.
The information regarding cultural heritage is still fragmented and dispersive: similar analyses and surveys are sometimes carried out on the same object by different subjects and within separate research activities, proving to be unnecessarily expensive and redundant.
Just as cataloguing represents the lowest level of documentation, which attests only the "existence" of a good, similarly the first step could be the creation of a digital repository of Cultural Heritage resources (possibly based on open-source software, at least in theory), to prevent the fragmentation and duplication of information.
The already existing "digital repositories are often unable to guarantee affordable features in the management of 3D models and their metadata [...]. The nature of most of the available data formats for 3D encoding seems to be insufficient for the necessary portability required nowadays by 3D information across different systems." (Felicetti and Lorenzini 2011) The following aspects relating to large scale documentation are still to be taken into account or unsolved:

- Definition of a common vocabulary and identification of effective metadata concerning the digitization of cultural heritage.
- Sharing of procedural standards, even through the preparation and dissemination of specifications aiming at overcoming the outdated prescriptive approaches and adopting a more contemporary technical approach.
- Definition of open file formats for both raw data filing and subsequent processing operations.
- Need to define validation and test procedures to ensure the quality of data and the resulting information.

Training must become the key element to support this proposal, and it should embrace vocational update of qualified professionals, promotion of the scientific culture linked to 3D technologies (even among public and private customers) and awareness of heritage users in general. In fact, only an increase in the awareness towards heritage can support and improve promotion and valorisation. New technologies are the right tool to make knowledge "available", at last. In 1964 the Venice Charter (ICOMOS 1964) already stressed the importance of documentation and publication in article 16, a concept taken up in several subsequent recommendations, including the London Charter and its more recent updates (www.londoncharter.org).

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