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SURVEY, MODELING, INTERPRETATION AS MULTIDISCIPLINARY COMPONENTS OF A KNOWLEDGE SYSTEM

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Abstract

Cultural Heritage represents a very difficult subject to be handled. Despite its cross-cutting and multi-level characters (scientific, social, economic, political, etc.), nevertheless the topic can hardly be framed in a proper and comprehensive way. Any project addressing Cultural Heritage (documentation, preservation, retrofitting, valorisation and so on) actually tends to exalt a specific point of view and, therefore, to neglect potentially crucial contributions coming from different fields of expertise. Comprehensive solutions to this problem seem by now available thanks to ICT and the 3D Digitalization and Multimedia Technologies: nevertheless the more the platforms improve their multidisciplinary capabilities and interoperability, the more they need an intelligent design and an accurate control during the implementation phase. Built Cultural Heritage (as historic buildings, districts, sites, etc.) perfectly represents the wide range of situations, which have to be tackled. Any intervention, in fact, from the design phase to its realization and validation, actually deals with several different interlaced layers that together depict a "complex system".
The construction of a Knowledge System represents a crucial step in correctly addressing the problem.

Keywords

3D capturing, 3D modelling, Integrated survey, Knowledge System, Cultural Heritage

1. *Generalities*

Cultural Heritage represents a very difficult subject to be handled. Despite its cross-cutting and multi-level characters (scientific, social, economic, political, etc.), nevertheless the topic can hardly be framed in a proper and comprehensive way.

Each actor involved in any project addressing Built Cultural Heritage (knowledge, preservation, valorization and so on) actually tends to exalt its own specific point of view and, therefore, to neglect potentially crucial contributions coming from outside his/her specific field of expertise.

A comprehensive solution to this problem can be found only through the development of an equally comprehensive multi-disciplinary platform: that is, either the "place" where different actors can work together to accomplish a common goal or the "set of tools" through which this result is achieved. Last but not least, each actor should become quite aware that his/her own activities would lead in any case to a "restyling" of the considered piece of heritage according to our times and our cultural sensitivity.

Whatever the approach, though, there can be no doubt that the first step in approaching the study of any built element is constructing a Knowledge System suitable for collecting, interpreting and storing information about it.

The components making up this system, however, are of various types: *quantitative*, first and foremost (essentially resulting from surveying operations), but also *qualitative*.

While the former should advisably be channeled through a rigorous scientific approach, the latter mainly draw on the investigator's sensitivity and interpretative skill, often the most important ingredient for achieving levels of understanding that are denied to simple "measurement".

For Built Cultural Heritage this process is particularly relevant: not only is it necessary to construct a multidisciplinary database that is as consistent and rigorous as possible, but also many different skills must be integrated in order to suggest interpretations that transcend the sectorial.

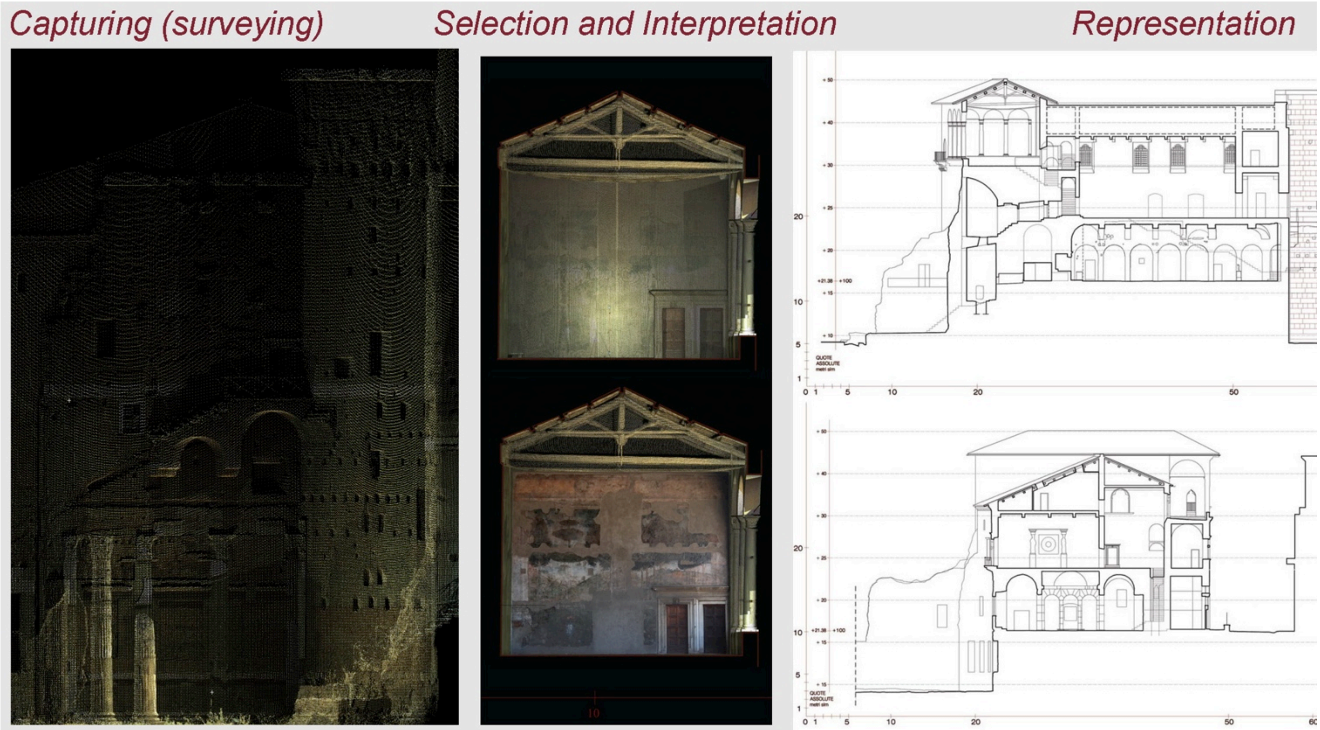

Fig. 1: The three phases of the Survey process : Data capturing, Selection/Interpretation and Representation (Casa dei Cavalieri di Rodi – Rome)

If the qualitative component relies on the concept of irrefutability (in the sense proposed by Popper), the quantitative one relies on the Survey, one of the most powerful and reliable tools developed over the years by researchers (archaeologist, architects, historians, etc.) to achieve what Descartes used to define "profound knowledge"[1]. It actually implies the idea of measurement, that is the possibility of turning into quantity some qualities of the studied phenomenon (in this case an artifact, a building, a site, etc.) by using the ratio between the measured quantity and an appropriate unit of measure. It is just thanks to this method that we can build a simplified *model* of the complex phenomenon we are investigating. Quite apart from the theoretical framework, it's paramount how in practical terms the implementation of this strategy depends on the available measurement technologies. For centuries the limited amount of measurable points required a preliminary accurate design of the survey operations in order to capture the really significant ones (*selection* before *acquisition*). In the last decades, instead, this order has been somehow inverted thanks to new massive measurement technologies in which selection follows acquisition.

Let's try then to clarify this fundamental point, firstly from a linguistic point of view: the term *Survey* refers in fact to a very structured process that leads to the construction of 2D or 3D models starting from a real object. The whole workflow can be broken-down into several different tasks of which, certainly, the *acquisition of data* (*surveying*) represents the first step. All subsequent tasks (in the survey process) dealing with *selection*, *interpretation* and *representation* of acquired data actually lead to models (3D, 2D-drawings, etc.) that somehow concur in enlightening the investigated phenomenon. The traditional survey approach implied (and obviously still implies) a strict dependence of the *surveying* phase on a preliminary accurate investigation able to guide the limited measurement possibilities (Fig. 4).

[1] Whenever human beings have had to deal with complex phenomena during their evolution journey, they always tried to develop learning strategies that would allow them to overcome the limits of their own senses. Descartes well explained how this approach involves two different kind of knowledge: *common sense* (that we acquire through experience) and *profound* which instead can be obtained by investigation methods and techniques that can reveal to the mind what our senses cannot.

Fig. 2: The Tempietto of San Pietro in Montorio (Rome): data acquired using 3D scanning.

This "genetic" limitation obliges somehow to an as accurate as possible design of the surveying operations in which selection, interpretation and representation of data come even before the measurement, as if the survey existed in the surveyor mind before the physical set up of the operations: the Survey's workflow is in this framework potentially defined right from the start. Massive acquisition technologies have separated all different steps: site preliminary study is only oriented to the position and number of stations (scans, shots, etc.) while the topographic support is reduced to the minimum if no completely redundant.

Selection, interpretation, and representation of data are instead carried out in a second phase.

Together, these considerations thus establish the research horizon, putting the Survey process in the more general framework of a Knowledge System as the non-additive result of single sectorial contributions, where there is a clear boundary between the procedures for acquiring and organizing data (which strive for the maximum objectivity) and the criteria for selecting and processing the database itself (critical expressions invariably subjective).

2. *Towards a "scientific" surveying*

It is precisely by establishing this boundary that we can revisit the entire matter in the light of the Scientific Method putting it to the test of Karl Popper's "principle of falsifiability", still the benchmark for evaluating scientific theories[2].

The Surveying phase, in fact, seems to be highly compatible with the strict scientific methodological assessment consolidated among the various communities of researchers.

Even if an exhaustive discussion concerning the Scientific Method would be redundant, nevertheless we cannot proceed without listing at

[2] With this principle, Popper sought to resolve the impasse that arose between Russell's fruitless attempts to construct "complete" logical deductive systems, and the cataclysm that swept through epistemological thinking following Kurt Gödel's proof of the Incompleteness Theorem. Popper, well aware of the inherent inadequacy of the tools that human beings have for cognizing reality and that, in the final analysis, it is substantially impossible to provide "positive" proof that any given statement is true, shifts the centre of gravity of knowledge from proving that something is true to showing that it is false: for Popper, a theory is scientific only if it is possible to devise experiments that demonstrate its inadequacy, i.e., that refute it as false. This approach has revealed as highly profitable in terms of advancing knowledge: if a theory withstands an attempt to falsify it, it will be stronger, more general and thus closer to the truth; if, conversely, the attempt succeeds, an aspect will be revealed that the theory was unable to explain, and a new and stimulating line of research will thus be opened up.

least the crucial points of this method: currently is considered scientific (1) *the investigation of a phenomenon developed using a set of techniques*; (2) *based on the gathering of observable, empiric and measureable data affected by a controlled and declared level of uncertainty*; (3) *those data will have to be archived, shared and independently assessed*; (4) *all used procedures have to be replicable in order to eventually acquire a comparable set of data*.

These four main points can be substantially respected during the Acquisition phase:

1. *The investigation of the phenomenon has to be developed using a set of techniques* (fig. 5) – The “phenomenon” is in our case the element to be investigated and thus this prescription is clearly respected because any survey relies on methods and techniques able to guide the surveyor during the measurement phase.

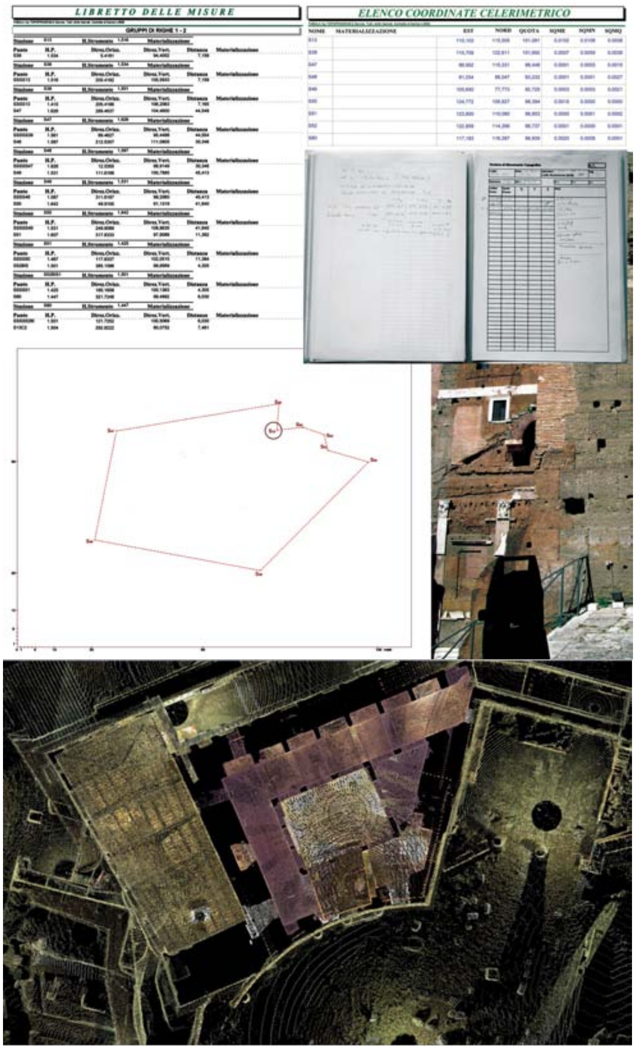

Fig. 3: The observable, empiric, measurable data acquired on site (Casa dei Cavalieri di Rodi – Rome)

2. *Based on the gathering of observable, empiric and measurable data affected by a controlled and declared level of uncertainty* (fig. 6, 7) – All data are actually observable (they represent the “material” points of the object), empiric (they result from experimental activities), measurable (they are acquired using measure equipment and techniques) and affected by a controlled and declared level of uncertainty (resulting from the instruments, the systematic errors, etc.). The actual compliance with this requirement can be assured provided that all steps (from the survey project to the measurement and assessment process) are documented with accuracy and attached to the data themselves, so to create a unique set composed by data (the measures) and metadata (the process information).
3. *Data will have to be archived, shared and independently assessed* – The so-called “digital revolution” has deeply affected this aspect. In the specific field of architectural Survey, for instance, until recently there wasn’t a consolidated habit to arrange and archive systematically both the final deliverables and the metadata describing the procedure used during the experiment called “survey” (survey project, field notebook, measured points monograph, instrumental features, etc.).
The quick and sudden switch to new equipment for 3D capturing has highly partially solved this problem as metadata are mostly archived in a database form by the instruments themselves. Furthermore, archives are “born digital” with clear advantages in terms of transmission, sharing and duplicability, features that until recently were impossible being each archive a single, original set of data. The sharing and independent assessment is still a critical aspect: differently from other research areas that routinely share online of experimental data, the built cultural heritage sector is still too afflicted by a plague called “privacy”.
We should thus all work to catch up with other research areas so that the archived data could more easily circulate within our scientific community and any researcher could develop its activity on high quality data.
4. *All used procedures have to be replicable in order to eventually acquire a comparable set of data* – This last point actually comes up as a sort of corollary form the previous three.

Nevertheless, it can show a great relevance also for the "diachronic" integration of data acquired in different time segments and with different technologies. In this way all information connected with a certain object would find a compatible space in a single database that, in case of new investigations, would not start from scratch but simply be updated and improved with additional data.

3. *From Acquisition to Selection and Interpretation of data: from Surveying to the Models*

Selection and interpretation complete the proposed workflow for Survey. It has been already widely discussed how both phases concur not secondarily to the construction of the *geometric model* of the surveyed object, that is to say, the simplification process of the objective multi-dimensional complexity to its geometric essence made of points, lines, surfaces. A biunique correspondence is set in this way between the object and its virtual substitute, which can be used to simulate different operations as they were made directly on the object itself.

From a strictly epistemological point of view such a model can be considered the result of a selection carried out by a subject aiming at extracting some of the potentially infinite available information pertaining an object. The selected data, though, are not the result of a random or automatic reading: on the contrary they strictly comply with rules set by the subject himself. In this way a stable relationship real object/model is created: a relationship that intrinsically already represents itself an interpretation of the selected data. In other words, starting from the selected set of data, we always tend to demonstrate a hypothesis we have beforehand formulated.

This particular process has been traditionally rooted in the following principles:

- Human beings have an ability, innate or acquired, to conceive the qualities of physical space;
- Of the *n* qualities of physical space, the geometrical qualities optimize the operations of control and manipulation;
- Space can be concretely manipulated and modified thanks to the correspondence between the real object and its geometric abstraction (Geometric Model);
- The Geometric Model, through the process of Representation becomes a Two Dimensional Geometric Model;
- The tool that ensures that the mechanisms for controlling and manipulating the graphic model are effective is Drawing.

This procedure establishes a biunique correspondence between the Object and its Graphical Representation that can more appropriately be considered a Two-Dimensional Graphical Model, or in other words a virtual substitute on which the most widely varied operations can be simulated as if they were actually performed in reality[3].

However, since digital media burst on the scene and modeling software came into common use, this scheme has deeply changed. First, the correspondence between the physical space and the representation space has incomparably improved (fig. 4): each material point P_r identified by its coordinates x_r,y_r,z_r in real space univocally corresponds to a virtual point P_v, likewise identified by a unique triplet of Cartesian coordinates x_v,y_v,z_v, essentially freeing itself from any and all constraints associated with the size of the support or with projection and sectioning.

Important though it is, this new technology has not brought about any kind of practical simplification: indeed, it has significantly thinned the ranks of those who are capable of making full use of the new opportunities. If with conventional systems it was enough to know the "language" of the object to be studied (architecture, archaeology, etc.) and master the tool of "drawing", the advent of digital systems has added the need to develop additional skills related to the hardware and software used for data capture, processing, modeling and CAD drawing. Currently, this problem has opened a wide gulf between the true beneficiaries of this technological innovation (i.e. archaeologists) and hardware and software developers and specialists. The challenge, then, is two-fold:

[3] From an epistemological standpoint, we can say that the *model* is the product of the selection operation that a subject carries out on an object (real or imaginary) in order to extract some of the infinite information available from the object. It can thus be the product of a discretization, or in other words, of reading and recording certain parameters (which may be metric, angular, color parameters or other types) by an operator or an instrument which actively explores the object to identify singular points (this is the approach employed in direct and indirect surveying, as well as the procedure used by three-dimensional scanner), or, conversely, the model can be the result of the passive and uniform recording of information from the object (the photogrammetric approach).

Fig. 4: The correspondance between reality and model (Casa dei Cavalieri di Rodi – Rome)

- envisioning ways of using digital media that are better suited to the abilities of entry level users;
- increasing "the digital literacy" that can add to the pool of experts who are able to use these profitable technologies.

4. New Paradigms

The whole survey process has been traditionally reserved to personnel specifically trained in the usage of instruments for direct measuring. This is the rule of any direct survey. Already in the topographic survey we can instead point out a significant difference: the surveyor chooses the point to be measured but actually he does not "measure" himself, he simply activates a device, the distance meter.

A little further on this same line we find the 3D scanning: in this case, in fact, the surveyor does interfere directly neither with the measuring nor with the choice of the points to be measured; he can only set the scanning grid in relationship with a reference distance from the scanner (probe). The data capturing is thus generally semi-automatic with a clear tendency to become nearly automatic in the near future. But the automation of the surveying phase is not the only relevant aspect to be considered: there is in fact a parallel phenomenon that we could define of "democratization" of the surveying technologies. The technological background is the image-based modeling: not a laser beam emitted by a source that hits a material small area and is received back by a sensor measuring a certain physical parameter (time of flight, phase difference, reflection angles, etc.), but simply a light ray "naturally" emitted by that same small area. One only ray is not enough to determine the 3D position of the original source (the same univocal correspondence that binds a point and its perspective representation) but many concurrent rays can instead lead to its reconstruction thanks to an inverse intersection operation.

An actual "zero-cost survey technology" will be thus soon available: a novelty that will have an

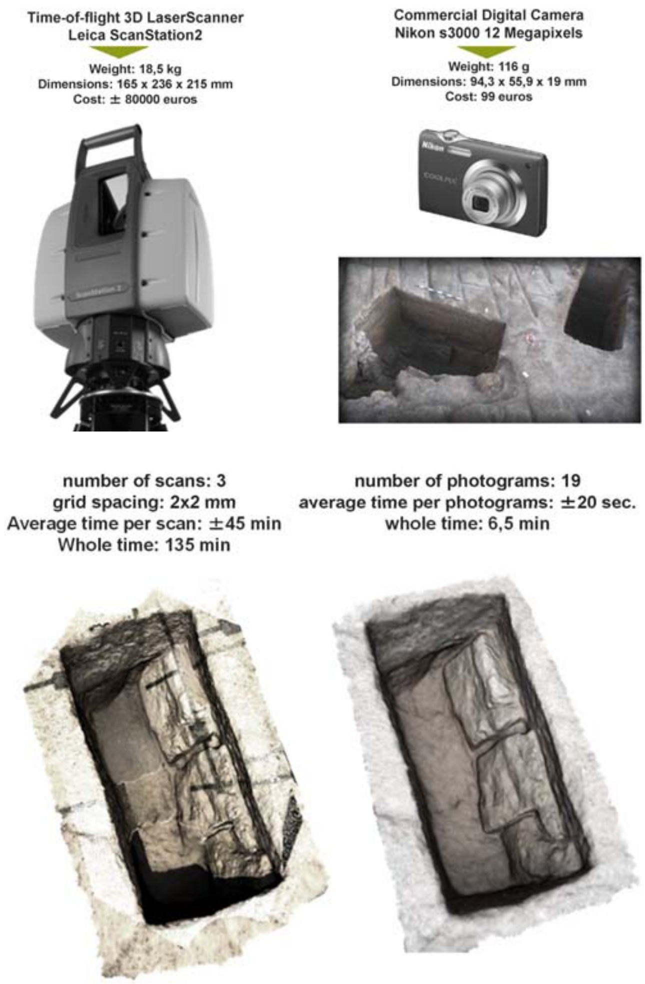

Fig. 5: 3D scanning vs. Image Based Modelling: a cost/benefits comparison (Crustumerium tombs survey – Rome)

unpredictable impact on the entire data capturing process, both on the strictly operational level and on way we shall use and share information.

Similar developments will involve the data capturing instruments themselves.

The systems that actively explore the surfaces of objects (like 3D scanners) have undergone radical changes in the last decade: they have on average become faster by one order of magnitude; significantly reduced the uncertainty on each measured point; integrated many topographic functions of a total station (forced-centering set up, compensator, etc.) and digital cameras with increasing resolution. At the same time those systems have reduced weight, power consumption and, finally, much logistic inconvenience.

The range of equipment is continuously evolving showing a clear tendency towards systems more and more "portable", flexible and at the same time accurate. Even if the reduction of the capturing time actually leads to a similar reduction of the general cost of a 3D surveying campaign, nevertheless this "segment" of the market will still remain expensive, especially for the initial capital investment represented by the scanner purchase.

Fig. 6: Photogrammetry-based device for 3D capturing

From this standpoint, the "image-based" technology appears somehow positioned at the opposite end of the same segment: an entry level digital camera can in fact be perfectly suitable for an accurate capturing campaign as well as those mounted on mobile devices (smartphones, tablets, etc.). But the near future would reveal even more bewildering: for instance, when one manufacturer will decide to install on a mobile device two cameras instead of one and to accurately position them, then we will no longer share pictures on the social platforms, but directly 3D point clouds with high resolution texturing.

5. Conclusions

The picture I've tried to outline so far (although very briefly) affects the way a surveyor can interact and govern all the described technologies within the theoretical framework described in the first part of this paper.
From a certain standpoint we can have the impression that his role has become by now obsolete: what is in fact the role of an expert in survey when anyone after a short training can acquire millions of points or even reach the same result just taking a number of simple and extemporaneous shots?
Answering this question goes straight to the core of the issue. First of all we should underline that any 3D capturing system is capable in producing a bulk of incommensurable data in comparison with the past but nevertheless widely redundant. This phenomenon is quite clear on a single object: what about more "social" approaches where thousands of users share together millions of 3D points each? In my opinion a good description of this problem can be derived from the physics and technology of communications, when a single signal has to be isolated from the noise. In this context the signal to noise ratio (SNR) represents the fundamental parameter, so that under a certain threshold of SNR a system cannot work out clear signals.
This same approach can be somehow applied also to the survey process: if I'm not able to select those few dozens of significant points out of the millions composing the 3D point cloud I will not be able to isolate the signal from the noise. In my opinion, this process in not likely to become automatic or even semi-automatic in the near future being soundly related with the epistemological concept of model that is, as already stated before, the product of a selection that a subject applies to an object so to extract some pieces of information out of the countless available. It is thus always a partial, abstract and subjective representation: in other words intelligent.

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