INNOVATIVE SYSTEMS FOR ASSISTED ANALYSIS AND DIAGNOSIS

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ABSTRACT:

Final aim of SIINDA research project is the development of an integrated system, composed by interagents hardware and software components, oriented to support the expert in the analysis and diagnosis of the conservation state of a monument. The complex phenomenon of degradation is studied considering the monument-environment system which is investigated by a "knowledge through images" approach. Therefore, more than one visualization technique of physical-chemical data on the three-dimensional reconstruction of surface monument is available.
The three-dimensional model of the study case is, also, the interaction metaphor through which the user can select images and analyse the result of their processing. In fact the user is requested to interact in order to associate colorimetric properties of image regions to degradation typologies. Then extracted decay area are projected as visual effects on the three-dimensional model itself. Since all the acquired and processed data are collected in appropriate relational databases, the conservation state analysis is concluded by a user designed evaluation report which can be automatically produced. In this way, it is possible to obtain relevant information about both extension of different degradation typologies and eventual dangerous attainment of environmental threshold values.
Among other, characterizing methodological choices to mention are: the development of innovative techniques for surface reconstruction, colour image correction and processing which allow objective and accurate analysis of degradation as preliminary step of a monitoring process, a multiscale and multidimensional approach for dealing and representing geometrical data and the realization of assistance tools for data acquisition and process.

1. INTRODUCTION

In the last ten years, in Italy, we are having an increasing number of initiatives in which great emphasis is put on the synergy between Information and Communication Technology and the study of Cultural Heritage.
These initiatives are, mainly, proposed by the Ministry of Cultural Heritage, Italian National Research Council and Regional Administrations. One of the most note-worthy has been the National Plan of Research called PARNASO, launched by the Ministry of University and Scientific Technological Research.
One of the research proposals approved among PARNASO Plan has the title: "Research and Developments of Innovative Systems for Assisted Investigation and Diagnosis", which is the subject of the contribution here proposed.
The Project, which is actually finished, was coordinated by the Consortium called SIINDA (President Ing. Romualdo Picco, Director and Scientific Research Head Dott. Laura Moltedo, Scientific Training Head Arch. Paolo Salonia), whose members were the Italian National Research Council, Milan Polytechnic, another public research institution, the Public Administration of Valle d'Aosta Region and three private companies (CNR Institutes: IAC, ITABC, IEIIT, IMGC, Istituto Elettrotecnico Nazionale Galileo Ferraris, DEI PoliMI, Sopr. BB.CC.AA. - Valle d'Aosta Autonomous Region, CM Sistemi, FOART, MENCI SW) (official research project website: http://siinda.ieiit.cnr.it).
The general aim of the research is focused on developing and testing a knowledge Integrated System oriented to support of the experts in the analysis of the state of conservation of monuments, thus involving both theoretical and experimental activities. The system, which is composed of techniques, functions and data, uses different methodologies for information acquisition, analysis and processing in a combined, interactive and, as much as possible, automatic approach. This information is collected in a multimedial data base (Moltedo et al., 2002).
Closely connected to the above mentioned Research Project, is a parallel Project for Training different types of users by means of developed methodologies.
The present contribution is aimed at describing the main methodologies developed in the Project and some obtained results.

2. THE RESEARCH PROJECT

2.1 The study of the state of conservation

The Project is intended to contribute to the overcoming of some of the most critical aspects of the study of a monument's conservation state. These aspects concern both data acquisition, processing and presentation. In particular, the main function are the following:

- to propose non invasive investigation methods, especially the comparison of measuring techniques which do not need any contact with the surface. Such techniques improve the possibilities for an objective evaluation of the state of conservation, providing the

user with analysis procedures which help in the definition of measuring protocols and produce results repeatable and comparable in time;
- to allow the cost control and the simplicity of the acquisition and restitution phases of geometrical data, providing the user with wherever possible automatic and suitable supports. A measure of suitability could be also represented by quality, usability and relationships among the data which have been acquired by means of heterogeneous systems and maintain the compatibility of different scale levels;
- o improve the possibilities for use of the survey systems implementing innovative systems which can substitute or integrate the traditional photogrammetry ones. These systems, based on active vision techniques, operate in multiresolution and multispectral environments;
- to augment the diagnostic potentialities of specific degradation typologies, providing computation procedures for image and multidimensional data representing chemical-physical-environmental parameters. The presentation of such data is performed by means both of visualization techniques and formal classification of degradation shapes.

2.2 The Project structure

The Project is structured into 17 Work Package (WP) included in 5 specific Phases of the investigation process:
- Phase 1 - Design analysis and validation - which includes WP1: Measure protocols and WP2: Validation requirements;
- Phase 2 - In situ and in laboratory data acquisition - which includes WP3: Stereoscopic System of active vision, WP4: Techniques for digital camera acquisition, WP5: Software for assisted acquisition, WP7: Chemical data acquisition, WP8: Physical-environmental data acquisition, WP9: Photogrammetric survey;
- Phase 3 - Data pre-processing - for image correction and restitution which includes WP10: Software for image correction, WP11: Software for the integration of automatic restitution techniques;
- Phase 4 - Data processing - for visualization and image analysis which includes WP6: Image coding, WP12: Raster 3-D model, WP13: Surface reconstruction, WP14: Multidimensional data visualization, WP15: Classification of image regions of interest;
- Phase 5 – Archiving and integration - which includes WP16: Multimedial database, WP17: Integrated System.

2.3. The study case

The study case is the Ancient Roman Theatre in the city of Aosta situated in the north of Italy.
The Roman Theatre of Aosta is a monument dating back to the Augustan age built inside the city walls in the vicinity of Porta Praetoria. In elevation it consists of the remains of the façade, about 22 metres high, which is architecturally composed of a series of arches and three superimposed orders of various sizes windows, alternating with powerful buttresses. The rustic type masonry consists of ashlars of pudding-stone and travertine.
The sets of data we are dealing with, most of them acquired within the Project itself, are, other than images, mainly geometrical values at different scale levels (from the complete monument to the individual composing element) and chemical-physical-environmental data.

2.4. Main aims and fundamental choices

The objective of the Project was to develop and test an Integrated System of knowledge, monitoring and forecasting, that is a set of techniques, functions and data that can be used for the computer-assisted introduction of different levels of objectivity in the evaluation of a building's state of conservation. The integrated storage of heterogeneous data and the subsequent monitoring phases lead to the build up of "experience" required to plan "programmed conservation" action. This objective was attained by means of the combined, interactive and, as far as possible, automatic use of several different methods of acquisition, analysis and processing methods, thus making the information accessible through an integrated multi-level and multi-scale ICT system and using the colour (and thus the processing of colorimetric data and of the corresponding images) as the main indicator of the various degradation pathologies.
The user interface of the Integrated System was of non-immersive virtual reality type and the three-dimensional model represents the metaphor of interactivity.

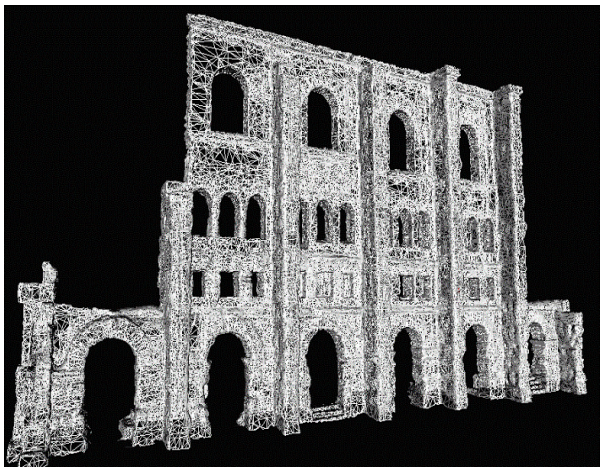

Figure 1. SIINDA Project – The 3D model of the Roman Theatre is the "metaphor" of intereractivity for heterogeneous data displaying and consulting (interface and data processing by CM Sistemi). [SIINDA Consortium]

It follows that the user can adopt this model as a basis for displaying other information projectable onto it, in order both to consult data stored in the database and to activate the processing functions of these data.

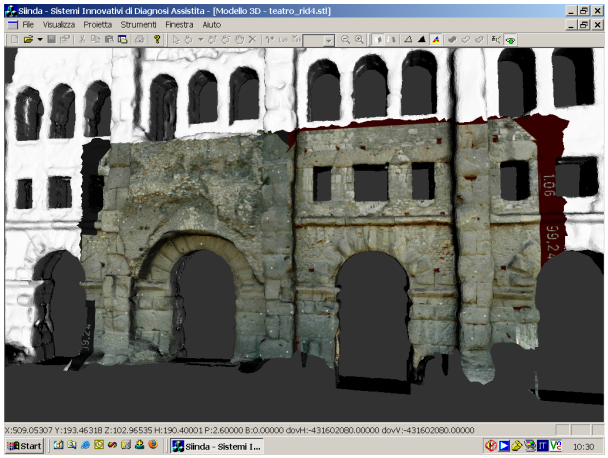

Figure 2. SIINDA Project – 3D model as a basis for displaying information projectable onto it (here an ortophoto of photogrammetric survey by Fo.A.R.T, interface and data processing by CM Sistemi) [SIINDA Consortium]

Furthermore, the System was conceived and implemented using a modular structure and its modules consist of individual autonomous tools, each with its own specific and

highly specialist task to perform.
As the final stage in the gathering of the more significant information of importance for evaluative synthesis, an automated "assessment form" structure was developed, linked to the methods used for measuring the degradation. This synthesis tool is used to gather many heterogeneous information, including that deriving from laboratory analyses, and offers the possibility of linking them up via the definition of a framework that synthesizes the respective influences on the state of conservation as a function also of the quality of the environment-monument system.
The form may be updated and adapted as required by the user to the type of monument investigated and guarantees a method for a suitable assessment of the general interpretation of the problems involved in the monument's conservation.
Such a form is divided into two sectors. The first one contains information deriving from the data gathered and processed by the Integrated System. The second one gathers data referring to environment type data that the System has been designed to collect and process with reference to specific assessments. For instance, these data concern the number of events deemed dangerous by the expert that have occurred during the considered time in the proximity of the monument.
It was decided to assign to each of these specific measurements a "weight" that depends on a number of parameters such as the type of present degradation and the nature of the constitutive building materials. Clearly, this percentage incidence value renders the individual data significant and produces the real reference value of the kinetic index of degradation. Special attention was therefore paid to an examination of the role played by the "weight" factor in each specific measurement. It was deemed of fundamental importance for its value to be determined in each specific case by the individual user as a function of the geometric-morphological and material characteristics of the building in question, of the specific forms of degradation and of the environmental boundary conditions.
In order to tackle the delicate cause/effect problem, the boundary data section has the purpose of providing the operator with a summary of the climatic-environmental situations having occurred in the time elapsing between one acquisition and the next, so that it is possible to determine the existence, if any, of a direct link between certain observed degradation phenomena and a prevailing situation around the monument (Chella et al., 2006).

2.5. The results

The results obtained in the Project could be classified into four categories: software prototypes, demonstrative systems, data sets and technical reports. In particular, we would like to underline the following two main results:

- a prototype Integrated System which will appropriately interface techniques and specific subsystems usable also in autonomous way;
- a multimedial data base upon which the Integrated System has been realized. The data base includes information relevant to the characterization of degradation. Input data are acquired in situ as well as in laboratory and produced by specific programs. The interface of such data base could be accessed by means of a Web browser.

Apart from the two previous mentioned ones, the Project has produced other relevant results:

- a stereoscopic system for geometrical survey, based on computer vision techniques, which can be used in situ or in laboratory for the real time acquisition of multiscale geometrical data and colorimetric and multispectral analysis (Gelli et al., 2003). The system is easy to handle and transport and the method of acquisition of data is not invasive;
- techniques which integrate the traditional photogrammetry by means of using digital cameras for acquiring, without prior calibration, chromatically corrected images used for the 3D reconstruction of surface artifacts;
- a software which can assist the operator in both the design of topographical points and the complete procedure of acquisition;
- a software for integrating different techniques aimed at the automatic reconstruction of images acquired by metric and non-metric cameras;
- programs for linking images acquired by different systems and having different orientations and representation scales;
- programs which implement new models for coding images with and without loss of information;
- programs for classifying and recognizing image regions which characterize, in as much as possible automatic and objective way, the state of conservation of the material of which the artifact consists (Appolonia et al., 2006);
- programs for the visualization of multidimensional data which allow the 3D representation of the artifact "plunged" in scalar and vectorial fields characterizing the environment around it (Chiappini et al., 2004).

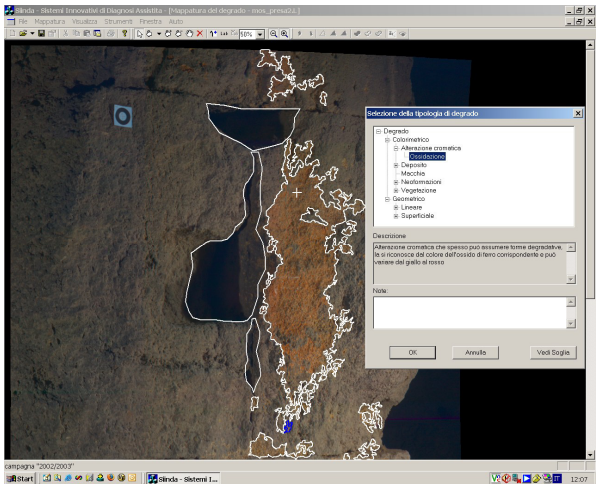

Figure 3. SIINDA Project – Mapping homogeneous degradation regions on colorimetric data: extracted edges by segmentation algorithm starting from colour images (algorithm by CNR IAC, interface and data processing by CM Sistemi). [SIINDA Consortium]

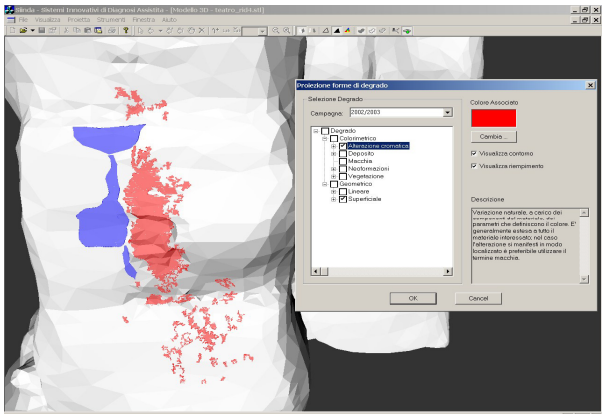

Figure 4. SIINDA Project – Projection of the extracted edges on the 3D model and window with decay data (algorithm by CNR IAC, interface and data processing by CM Sistemi). [SIINDA Consortium]

It is possible to identify different user-types of the Project's results. The user of the multimedial data base and the

integrated system is, in general, a person who is involved in the diagnosis of the conservation state. The systems for data acquisition are, typically, usable "*in situ*" by operators who can be helped by specialized software for tasks planning. Other appropriate software can assist operators who uses systems for the data restitution "in laboratory".

3. THE TRAINING PROJECT

The Training Project, adjoined to the Research Project, was aimed at preparing, through specific formative modules, new specialists whose presence in activities oriented to aspects of conservation has been considered an absolutely important condition. Such approach was used at different levels with reference to the typology of actions which trainees will have to do. The Project was oriented to four people subdivided, for number and qualification, in the following way:

- two people graduated in Architecture who have studied restoration problems with specific knowledge both of Conservation and Information Technology;
- one person graduated in Electronic Engineering or Physics, having know-how of different fields such as operative systems, sensoristics, signal coding, metrology, digital images;
- one person qualified in computer science.

The tasks they have to fulfil are the following:

- the first two people are able to use the Integrated System, which is the final result of the Research Project, in order to evaluate the state of conservation of artefacts;
- the third person is able to use the innovative methodologies investigated by the Research Project in different areas such as acquisition, restitution and processing of images and heterogeneous data concerning geometrical, chemical and environmental parameters;
- the last one gives technical support for using the multimedial data base and all other facilities where Information Technology is requested.

All these four people were grant-funded temporary personel in four Institutions (two CNR Institutes, one Company and the Aosta Superintendence).

As a result of the Training Project, the knowledge acquired by the trainees therefore cuts across numerous disciplines (restoration, photogrammetry, information science, database management, physics, computer graphics, artificial vision) and goes to make up a non conventional and original patrimony within the framework of the skills offered at the national level. This knowledge affords the trainees a broader view of the problems related to the management, conservation and enjoyment of works of art. This broader view certainly represents an advantage when seeking innovative solutions that would be hard to imagine in operators having knowledge in only one sector.

At the end of the Project and making an assessment of the future prospects also from the employment point of view, it is considered that these types of professional figures can represent elements of strong interest both to the Superintendencies and to specialized firms working in the sector and therefore the personnel offer represented by them is much lower than that effectively required. The job descriptions might involve the creation and maintenance of advanced skills networks (with universities, research centers, etc.) which could be used both as "problem managers" (to suggest solutions involving all allowable techniques) and promoters of studies and innovative projects.

4. MAIN MERITS OF THE PROJECT

The safeguard of Cultural Heritage is, nowadays, a great problem because integrated objective methodologies for the evaluation of the monuments' conservation state are lacking. In fact, presently, such activity is, generally, constituted by diagnostic cards in which subjective information extracted by means of a "naked eye analysis" is written using a standard language (for instance coming from UNI-NOMAL rules). Consequently, interpretative differences may occur which could cause evaluation difficulties and also mistakes in the restoration project.

Furthermore, the analysis we have mentioned above has to be made by skilled people, who are often hard to find because of the lack of personnel in Public Administration. Also, the organisation of periodic photographic surveys is an activity very expensive both in terms of necessary money and in time required to profitably compare large amounts of information coming from two or more different data samples. Even if such problems could be solved, the difficulty of using the same points of view, distances, instruments and illumination conditions in different measuring moments cannot be forgotten.

The present Project responds to these questions, mainly by means of studying and implementing technologies and computation processes which can support in an objective way the naked eye analysis carried out by the expert. To this aim the starting point is the analysis of the acquired images. In fact, providing methodologies for an assisted diagnosis can increase the quality of the analysis and reduce the cost of involved people.

One of the main peculiarities of the present version of the System is its adaptability to technological development, in the sense that each module and the ways the various modules can be combined are the result of an "open" design that allows data to be managed – from acquisition to processing and through to integration - whatever the technological level used.

It may, thus, be claimed that the Integrated System, precisely by virtue of its main characteristics, whereby it may be defined as a tool that assists geometric and colourimetric data acquisition, that indicates exportable methodologies, that represents, displays and texturizes, that processes images to identify degradation, that synthesizes heterogeneous data in support of diagnosis, is on the whole, already in its current prototype version, ready to be transferred into an operative environment, albeit at different experimental levels.

There is no doubt that the Integrated System, the final result of the Project, defined as a unique complex product, is able to express and represent added value in the operative practice now consolidated by the user identified as the reference target.

Indeed all those currently operating in the sector of diagnostics applied to the conservation of historical building heritage, although already benefiting, as we have seen, from technological innovation in the form of ad hoc HW and SW for several specific phases of the diagnostic process, are still lacking in procedures and techniques capable of the computer-assisted management of the phase of correlating heterogeneous data and thus of synthesizing this process, something essential for the formulation of a value judgment on the state of conservation that is grounded as far as possible on parameters that are at last objective.

Therefore equipping with a similar tool those who have the institutional task of making this judgment, on which project decisions regarding the more suitable interventions can be based, means truly introducing innovations that will ultimately modify not only the practice, procedures and protocols, but also the overall cultural attitude adopted in the face of problems of diagnostics in the field of conservation.

The foregoing also points to the possibility of new forms of work organization, with obvious savings of time and resources (both human and financial) accompanied by an

enhanced objectivity and comparability of data and the consequent diagnoses, thus ensuring substantial economies of scale.

In the specific case of the Aosta Roman Theatre, the Project has value in the context of a continuous knowledge process of the monument itself. In fact, the Aosta Superintendency has planned to provide a sequence of topographical supports at the end of the restoration. Such supports will be used for siting survey devices which will be used for testing the surface of the monument by means of both at-distance revealing tools and follow-up corrections of geometrical perspectives. The experts will be able to make a survey, or a series of surveys, using such supports as a base. The position of supports will be decided evaluating both the need revealed by the concluded restoration and the most high risk zones, such as window pilasters. The expert will have the possibility to do a systematic and fast control of the state of conservation and obtain diacronic information to be compared before deciding any necessary maintenance. This procedure, periodically repeated under definite conditions, will avoid detailed restorations that are very often invasive and heavy actions both for the conservation of constituting materials and for public commitment.

Two other main characteristics of the Project directly derive from the previous items.

The first characteristic, dealing with the monitoring, concerns the evaluation of the impact of the Integrated System, which is the final result of the Project, on the diagnosis procedures of the Cultural Heritage to be protected. A particular consideration has to be made, in fact, with regards to the cost of ordinary versus extraordinary maintenance, which are two essentially different actions. The ordinary maintenance usually concerns routine and lightly invasive operations, whereas the extraordinary maintenance requires operations in special and very often invasive conditions. Generally, the cost of the ordinary maintenance is evaluated as 1/5 of the extraordinary one. Anyway, the costs of these two types of operation are, today, influenced by the lack of easy-to-use measuring instruments. Then, the expert provided with the support of the facilities included in the Integrated System, improves the quality of the knowledge of the artifact, assuring decrease of costs. The extraordinary maintenance could be reduced and, at the same time, the "health" of the artifact could also be improved.

The second characteristic of the Project concerns the possibility to transfer its results. In fact, if is true that the Roman Theatre in the city of Aosta represents the test bed for the finalization of the Integrated System, nevertheless its general design allows it to be used also for studying the state of conservation of other buildings. That is to say that the same Aosta Superintendence could use the System for other monuments, and other Superintendencies could decide to ask and use the System for their own interests.

The functions included in the Integrated System are very general in the sense that they can be useful in other building areas (such as bridges, towers) where similar controls are necessary: the System originally aimed at Cultural Heritage can, then, be usable also in the wider industrial world. Because of both its flexibility of use and contained cost, the System can satisfy the needs not only of the public user, but also of private (single or associate) companies working in the survey field.

We have to remember that the Cultural Heritage market has an unlimited value but a limited payee, that is the Government which is the owner in almost all cases. With a different management policy of Cultural Heritage and having in mind the previous considerations, a market for the research product could also involve the professional world and the restoration companies, besides the people requiring the design procedures.

The global application of the methodology we are proposing in the present Project to the activities of the acquisition and restitution of geometrical data can influence, on the other hand, a decrease of production costs and, then, a safeguard of the occupation and, it could be, also the decrease of company expansion and the possibility to train new professional people.

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