An Integrated System for the Study and Management of Historical Buildings

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Procedures for recording the material structure of historical buildings has evolved rapidly in recent years, according to the exponential increase in the power of computer and digital technologies. In particular, current technologies for digital photography allow capturing highly detailed information, so that a large part of the work that previously had to be carried out on the field, can be now managed in the laboratory. Several skills are required for recording features of buildings, concerning archaeology, engineering, conservation and restoration. Therefore, it is necessary to establish a consistent "Integrated System" that allows scholars and users to deal with all the different building features. In this contribution, an integrated system is proposed for cataloguing and managing historical buildings, in line with the Italian rules in force about seismic risk.

Keywords: Integrated System, GIS, Building Archaeology.

1. Introduction

Acquiring data for the study of historical buildings faces specific problems:

- a relevant number of buildings to be surveyed (thousands of historical buildings need to be recorded);
- the integration of data of different types;
- the survey of the external walls of the buildings;
- the management of information concerning vertical surfaces.

This contribution proposes an Integrated System for the localization of historical buildings linked to an on-line database designed for the primary description of a complex or a simple building-unit. The aim is to develop a system that can be used to carry out simple and affordable instrumental surveys in situations of natural disasters (e.g. after an earthquake), providing 3D models with photographic layouts, orthophotos and a GIS for the monitoring and management of the first conservation work and the following steps of the work.

The Integrated System foresees the use and integration of software that represents standards for the Italian regulations concerning Cultural Heritage. The System is also integrated with applications already in use by the Italian supervision boards for Cultural Heritages, i.e. the *Soprintendenze* for the management of seismic emergencies and the monitoring of historical buildings. The proposed System exploits an open source GIS based on general aerial photos for the location of sites and buildings, implementing the available images through Google Earth or other satellite- or aerial-images. Such a base can be geo-referenced and put on-line, at very high definition, into the GIS system and arranged for the interconnection with the system for managing the damage survey cards (ArtIn XML) and the 2D GIS system for the recording of vertical surfaces, in order to better plan future interventions of restoration (SICaR w/b). The 3D models are created with new, fast and reliable methodologies, are geo-referenced on the available cartographic base and can be displayed by means of a viewer.

2. Towards an Integrated System

After the 1976 earthquake in Friuli (Italy), many photographic surveys were carried out between May and September of that year, in order to develop new procedures and protocols for cataloguing historic buildings; furthermore, useful proposals were put forward for the analysis of the damage (DOGLIONI *et al.*, 1994).

After the 1997 earthquake in Umbria and Marche, and the 2002 earthquake in Molise, types of "Iterative Damage Mechanisms" were defined, according to the "macro-elements" of the building (façade, lateral walls, apse and transept, covering, etc.). In 2008, the Italian Ministry of Cultural Heritage published the document "Linee Guida per la valutazione e riduzione del rischio sismico del patrimonio culturale" (Guidelines for the evaluation and reduction of the seismic risk of cultural heritage-MiBAC, 2007), now approved as an official Directive.

The "Guidelines" clearly indicate that the stratigraphic analysis of a building is necessary for its complete evaluation. According to this new scenario, the goal of this paper is to illustrate a project for cataloguing a historic building after an earthquake, and to propose an integrated system that can manage all the building features.

We consider it essential to point out the importance of the following issues of such a project:

- an integrated system for cataloguing the damaged buildings that allows them to be precisely located in space;

- a data set with the results of the instrumental surveys of the standing buildings;

- the development of an on-line GIS, based on these data.

In 2009 a major earthquake rocked the Italian Region of Abruzzo. The earthquake of April the 6th 2009 struck the historical centre of the main town L'Aquila and 49 other municipalities. A large amount of historical buildings and monuments were destroyed or heavily damaged.

In such a situation, i.e. with a very large amount of buildings to be recorded, with the need to do the job as quickly and safely as possible, it is necessary to develop an operating procedure that guarantees the accuracy of the data capture and the safety of technicians in charge of the survey. In particular, it is important that:

- data are consistent and easy to share with different archives;
- different users are allowed to access the data and the data meet the needs of other scholars and technicians;
- the system is the result of "collaborative" work, carried out in synergy by all investigators (engineers, architects, building archaeologists, art historians).

2.1. Data-capture and structure of the Integrated System

The system aims to deal with the data concerning all the phases of the project, starting from the first census and survey of the damage, up to the analysis of the building techniques, the conservation and the following management and monitoring of the building.

In each phase, special software is adopted, which is well known in the Italian domain of Cultural Heritage management, and a new process for integrating and sharing data is proposed.

The different steps of the system's management are:

1 – Localization of buildings with geographic coordinates on the basis of a zenithal photo survey

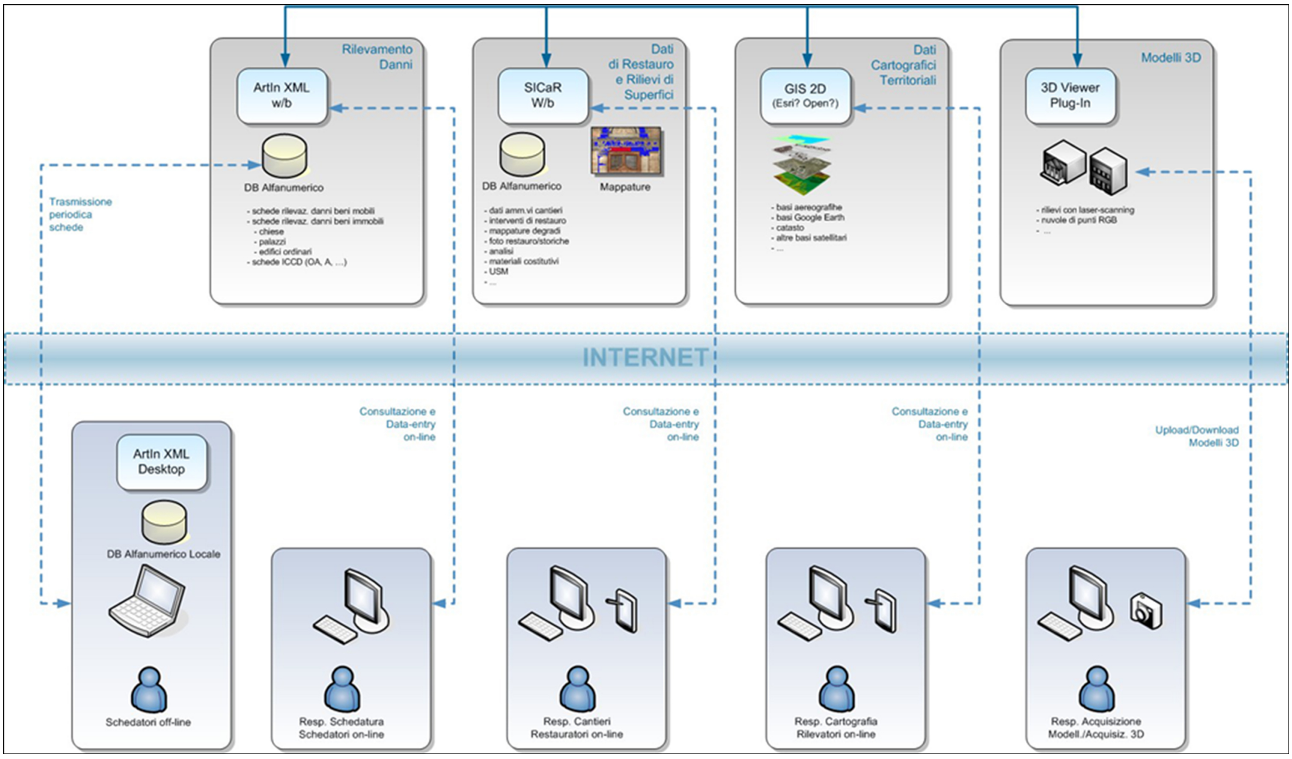

Figure 1: *The conceptual scheme of the Integrated System.*

(mainly, but not exclusively, by means of satellite photos), without limits for their degree of definition.

2 – Development of a database, on-line or desktop, for the description of all data concerning the first emergency survey.

3 – Development of a 3D survey with vector data, orthophotos, 3D photo high-resolution models of the surfaces.

4 – Development of a GIS for the vertical standing surfaces, in order to enter data concerning building techniques, building materials, analyses, conservation procedures, monitoring, etc.

5 – On-line access to the above mentioned data.

All these data need to be collected with topographical, cartographical and historical data for the following management and monitoring of the building itself.

We propose to adopt a specific open-source GIS for cartographic data. For damage survey cards, we propose ArtIn XML (www.liberologico.com/artinxml), available both on-line and desktop. For the instrumental survey, we propose to use the application Z-Scan by Mencisoftware (www.menci.com: see “photogrammetry and point clouds”). For conservation data, we suggest the SICaR system, by Liberologico (www.liberologico.com/sicar: GIS-based and open source). Data sharing will be possible on-line, with three access levels: a first one for full open access to the data (for scientific coordinators and administrators), a second one with restricted access for the other participants in the “Working Teams” (that allows access to data filled in by other people, but without the possibility to modify them); and further restricted access, for consultation only, for the whole scientific community.

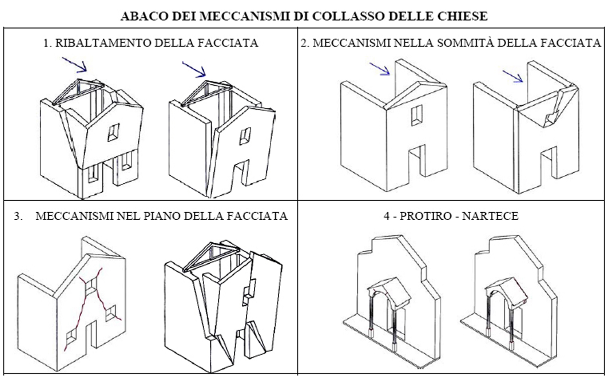

Figure 2: *Abacus of the church collapse mechanism, no. 4 of 28 (Gazzetta Ufficiale 55, March 7, 2006).*

3. ArtIn XML

ArtIn XML is the software for cataloguing (standard ICCD) that about 30 Italian “Soprintendenze” participating in the ARTPAST programme use (www.artpast.org), promoted by the Italian Ministry of Cultural Heritage (MiBAC) with the scientific collaboration of the *Scuola Normale Superiore* di Pisa. It is a multi-standard data entry platform, articulated in three integrated formats:

- ArtIn XML desktop: system for the multi-standard catalogue in the desktop version;
- ArtIn XML w/b: system for the multi-standard catalogue in the web-based version;
- ArtIn XML WebGIS: GIS web-based version for geo-referencing the catalogued heritage.

The software allows planning both on-line and off-line sessions of data-entry, and safeguards information storage in a single sure and shared repository. The peculiarity of ArtIn XML consists in the independence from the catalographic formats that it can manage. ArtIn XML can import and manage every card’s layout. The system is developed in order to manage every XML file (shaped with the SIGEC standards) and to set itself up autonomously. The adopted solution ensures that personalization or future versions of a layout in ICCD standards and of other formats can be easily managed by the system. ArtIn XML, in both the desktop and in the web-based version, provides mechanisms for synchronization of the base data on import / export in the standard formats of interchange ICCD (*.trc) and XML, thanks to which it is possible to plan on-line and off-line cataloguing sessions, with memorization and management of data in a shared, sure and centralized file. In the desktop version, the application has been used with success within the project ARTPAST (www.artpast.org). The web version of ArtIn XML, autonomously developed by Liberologico, is already in use in several public and private institutions (es. National institute for the Graphics, Cini Foundation, etc.). For each 3D model of a building, a recording card for the technical data can be produced, to enable the indication of the collapse mechanisms of the macroelements (28 for churches and 23 for other buildings) (*Gazzetta Ufficiale* 55, March 7, 2006) that can be integrated in the ArtIn XML system.

4. The Geometric Survey

One of the first steps in acquiring knowledge of a historical building consists of its geometric survey. Knowledge of a building may help to draw up its history of construction, and to understand the differences between construction techniques of various historical periods.

Furthermore, in strongly seismic areas, it helps:

1. to identify damage and repairs due to ancient earthquakes;
2. to draw up the kinematic mechanism of damage;
3. to improve the vulnerability of the building.

The geometric surveys constitute a necessary basis for many “Working Teams”. The adoption of new

Figure 3: *3D high-resolution photo model of the Church of San Pietro, Coppito, L'Aquila, Italy.*

economical and easy-to-use tools has modified the recording strategy of the material structure.

We are currently testing a 3D scanning instrument for point cloud acquisition through a digital camera. The software is very user-friendly and easy-to-use; 3D RGB Model acquisition and computation are done using digital images only. From this instrument we can obtain:

- 3D models of the building with photography resolution of the surfaces;

- surveys characterized by geometric and chromatic accuracy;

- stereometric surveys.

ZScan (www.menci.com/zscan) is the instrument that we use for the survey of the historical buildings (GHEZZI *et al*., 2009). It is a 3D scanning instrument for point cloud acquisition through a digital camera, slide bar and software. It is characterized by geometric and chromatic accuracy and solid components.

For the generation of a 3D point cloud from pictures, we work with a different specific software: ZMap Laser (www.menci.com/zmap). This is a software specifically projected for CAD drawing and orthophoto production on point clouds. Vectorized 3D wall surfaces are generated, on which all necessary analyses can be successively carried out (reading of the stratigraphy, characterization of dimensions, presence of modern and ancient repairs, results of archaeometrical analyses, etc.). Data will be available on-line after they have been processed. Moreover, Z-Map Laser allows several advanced specific functions, such as editing surfaces, building orthophoto-mosaics, handling and merging 3D models, orienting and drawing on images. On 3D models, we can work and register the whole material structure of a building. We could obtain specifically 3D CAD models with the building phases of the structure.

Figure 4: *Detail of the dislocation of ashlars of the main apse of the Church of San Pietro, Coppito, L'Aquila, Italy.*

It is also possible to register all the essential features of the material structure and, for example, to characterize the construction techniques of the building, and even the very small lesions (up to ca. 5 mm) caused by an earthquake.

All the above mentioned information is fundamental for monitoring the building and for the following restoration project.

We have tested this instrument in some churches in L'Aquila, which were partially or totally destroyed by the 2009 earthquake. We achieved the following results: a 3D model with high photorealistic definition of the surface, in which it was possible to record the primary dimensional features, macroelements, lesions, stratigraphic sequence, finishes and workmanship and characterization of the main building techniques. In a second phase of post-processing work, we could quickly obtain: a Digital Elevation Model of the surfaces, specific sections of the building and specific geometric and structural analyses. This process allowed us to provide all the useful elaborated data to the various investigators of the Working Team (engineers, architects, archaeologists, art historians), in order to carry on a complete analysis of the building. In fact, the software allows the generation of orthophotos on which a first reading of the stratigraphy is possible, in order to distinguish the different building-phases; indeed, the 3D model allows us to recognize materials and constructive elements for the individualization of the behaviour of the macroelements. With the generation of the DEM (Digital Elevation Model), we can calculate all the geometric deformations of the surfaces.

It is also possible to draw vertical and horizontal sections of the building on the DEM surface. From these sections misalignments, deformations and dislocation of ashlars are immediately pointed out. All these data are required by the Italian rules, according to the above mentioned "Guidelines", and are fundamental for the first quick recording of the building (MiBAC, 2007).

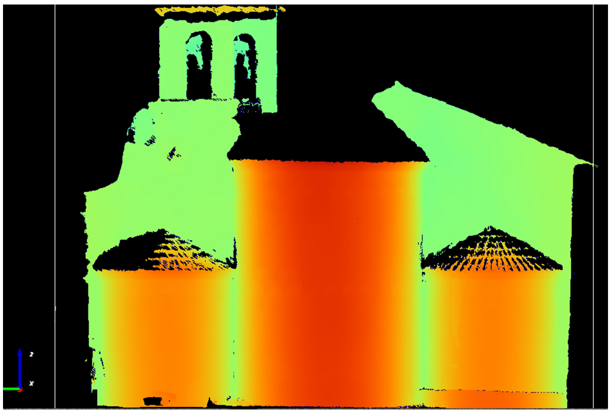

Figure 5: *DEM of the apse of the Church of San Pietro.*

5. SICaR w/b

SICaR w/b is the acronym for *Sistema Informatico per la Catalogazione dei cantieri Restauro*. It is a web-based GIS for the management of data concerning one or more conservation projects. Data managed in SICaR w/b can be alphanumeric and geometric.

Alphanumeric data are stored in four main repositories:

1. general data;
2. historic and artistic data;
3. conservation and diagnostic;
4. material structure.

Geometric data are vector drawings and high-definition raster images, as well as maps that can be drawn by the user on the surface of the analyzed object. Also a photo-realistic representation of the building can be displayed. These graphic data can be derived from building survey with ZScan, ZMap.

The testing of this system has been the occasion for reconsidering the protocol for stratigraphic analysis of architectural heritage, with the aim of developing a new GIS, open to multi-discipline research.

5.1. The SICaR w/b technologies. Server Side

SICaR w/b uses the Apache HTTP Server, which is wide-spread and web-based and can operate on UNIX-Linux and Microsoft. Apache software performs the functions of carrying information, and connecting to the internet, with the advantage of also offering control functions for the safety of the informations.

PHP is an embedded scripting language, with an open source license, used in SICaR.

SICaR employs MySQL, a relational Database Management System (DBMS), composed by client and server sides. Both sides are available for the Unix and Windows systems, even if its use for Unix prevails. Since 1996 it supports most of the SQL syntax.

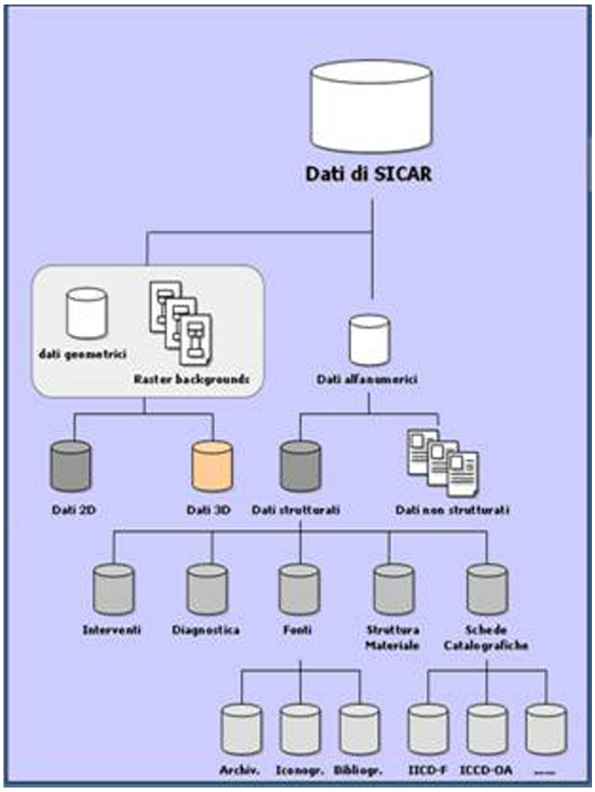

Figure 6: *The SICaR Data structure.*

5.2. The SICaR w/b technologies. Client Side

SVG, Scalable Vector Graphics, is a technology that can visualize graphic vector objects and can manage images with different dimensions and solutions. More specifically, it is a language derived from XML, developed with the goal of describing 2D static and animated figures. SVG became a recommendation (standard) of the World Wide Web Consortium (W3C) in September 2001. SICaR uses this technology for digitalizing and mapping building surfaces.

Javascript is a scripting language oriented to the objects generally used in websites. It is also a standard ISO and it is utilized on SICaR w/b.

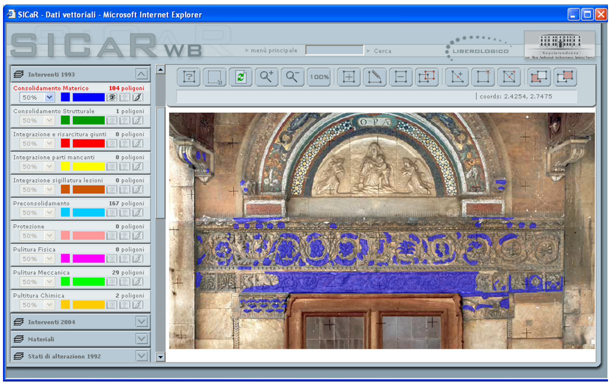

Figure 7: *Mapping surfaces on orthophoto in SICaR w/b.*

5.3. The recording of material structures and the building archaeology

The description of the objects in SICar follows a precise hierarchy. The card *edificio* (Building) contains general information (location, type of building, name etc). The building can be subdivided in more *corpi di fabbrica* (Building Items). A further card can be linked to the *corpo di fabbrica*, for the description of the state of preservation.

Each *corpo di fabbrica* can also be split into *settori* (Sectors) or *prospetti* (Façades). In this case, further description of the state of preservation is also possible.

A further level of description concerns the *sistemi di riferimento* (Reference Systems) of each sector: they are the real basis for graphic work, by means of raster orthophotos on which graphic work and geo-reference operations are performed. The advantage of this system lies in the possibility of working at different levels, from the building complex to the plaster and decoration. The versatility of SICaR allows users to overcome the overly rigid schematicism of the previous paper-cards, and allows the use of digital cards consistent with the different typologies of the various buildings.

The effectiveness and originality of the system organized in this way lie in the possibility of operating at different levels of detail. This recording methodology allows one to carry on analyses from the level of the architectural complex to the covering and coloring, according to a stratigraphic logic, i.e. it allows a high level of description of the material structures.

Figure 8: *Orthophoto of the façade with lesions and main building phases of the Church of San Pietro, Coppito (AQ).*

Conclusions

As the plug-ins for 3D drawing in a 3D GIS are still in the testing phase, only currently-available 2D GIS for recording information on vertical surface bases can be used at present, such as the SICaR.

The bulk of the information related to:

- construction history,
- damage and repairs caused by ancient earthquakes,
- qualitative characteristics of the masonry,
- diagnostic analysis and characterization of the materials,
- operative activities linked to restoration,
- and management and monitoring of the results of the restoration

are individualized in the best way on the vertical surfaces. For this reason, a GIS like SICaR nowadays represents a good solution, because it enables one to manage all required operations on the standing surfaces through the use of geo-referenced and vectorized images.

This procedure, based on the use of new IT instruments and methodologies, can provide excellent results for the study and management of historical buildings, specifically before and after natural disasters like earthquakes. The database is readily accessible and, above all, can be updated by expert users on-line, and can thus be managed by different research groups.

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