An Easy-to-use Multidimensional Database for the Management of Cultural Heritage Buildings

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Abstract—**Multidimensional databases constitute a handy solution to store and display data collected in the fields of conservation and restoration. However, knowledge on the current state of monuments depends on a heterogeneous corpus of data (cartography of degradation/materials, past restoration actions, core samples, photogrammetric data, analysis data, etc.). With the purpose of structuring this large volume of data, visual aspects characterizing the surfaces of heritage buildings can be semantically annotated in NUBES, an information system specific for architecture. Annotations are treated by defining relationships between the 3D elements and their textures. In this way, annotated elements can be displayed and retrieved in the 3D scene. Based on our previous experience, this article proposes a refinement of the data structuring according to time criteria. This time-structuring is applied to the "Chapelle de Fresques" of the Charterhouse of Villeneuve-les-Avignon, and integrates validated thesauri such as the ICOMOS - ISCS glossary and other common use lexica from the conservation field. This protocol is accompanied with customized descriptive tables that contribute to structure the information according to multiple hierarchical levels chosen by the user. The final aim is to give an easy-to-use analysis tool for conservation experts. Data from different time states can be added, current diagnosis states can be supported, and data can be cross-referenced against each other. This interface constitutes the basis of a new predictive tool for conservation management.**

Keywords—multi-dimensional database; cartography; information systems; thesaurus; semantic annotation

I. INTRODUCTION

The Saint Jean-Baptiste chapel in the "Chartreuse du Val des Bénédictins" in Villeneuve-lès-Avignon (France) is an important example of cultural heritage for its complex architecture and wall paintings. The painted chapel, also named "Chapelle des Fresques", was decorated by the Italian painter Matteo Giovannetti (Pope Innocent VI's official painter). A report done in 2010 showed that the decorations suffered from significant degradations over time and underwent several restoration campaigns over more than a century. The reason for degradations is still unclear and is currently being researched. Future restorations will be defined according to a synthetic analysis of all the existing documents on previous campaigns, the story of the chapel and its paintings as well as an up-to-date conservation diagnosis. As a consequence, relating, accessing, and filtering heterogeneous data into a unique system will permit to better understand degradation mechanisms otherwise difficult to comprehend with simple *in situ* observation and analysis of paper documentation.

This paper describes the methodological approach adopted for the full knowledge of the actual state of buildings and the practical experience concerning the time structuring of data of the « Chapelle de Fresques ». It is organized in the following way. After fundamental problem and current research presented in this session, section II presents the on-going database collecting heterogeneous data on the chapel and section III details the adopted 3D information system for displaying and filtering data. Section IV lays out the practical aspects chosen for the structuring of data in the specific case of the Frescoes Chapel. Finally, the last chapter outlines some limits of the approach and some research perspectives.

A. Related Works

In the last years, in the field of heritage conservation, digital representation of buildings became the support to define, manage, and display the state of conservation and the restoration actions of heritage sites. In order to improve the analysis of surfaces of buildings, NDT (Non Destructive Techniques) are used to investigate the state of surfaces and structures of buildings, and include active thermography, radar, X-ray, or ultrasound injection. As matter of example, some studies connect heterogeneous data to the graphic representation of buildings, joining the use of laser scanner and photogrammetry [1], [2]. Relaying on these new methodologies, some research aims at using photogrammetric characterization techniques based on 2D and 3D representations. While [3] combines image-based-modelling techniques, reverse engineering modelling and a 3D layer-like annotation technique in a CAD environment, other studies [4], [5] combine 2D hierarchical heritage data based on GIS (Geographic Information System), through the structuring of 2D geometric entities organized in multiple layers. In both cases, as data structuring in hierarchical layers preserves geometric information, the displayed information can be filtered according to the analysis goal. However, none of these systems seems to support a time structuring jointly to validated *thesauri* from the conservation field.

B. Fundamental Problem

Today there is the urgent need to relate the state of conservation of buildings with the origin of damages, the kind of material, the surrounding environment, and past interventions. Even if Information and Communication Technology (ICT) contribute to improve the analysis of buildings, a major problem arises on the structuring of heterogeneous data according to time. In fact, knowledge on historical buildings should include their previous restorations and evolution of degradations, so to be available to CH experts.

II. An On-Going Database

Most information on the site of the Frescoes Chapel comes from the compilation of ancient data on the story of the chapel and past dated restorations (drawings, photographs, graphics, maps, analyses of materials, old or recent observations such as historical notes, and technical or scientific reports). Faced with the challenge of efficiently employing all the documentation, new research focuses on making interactive information available on heterogeneous sources. An on-going database conceived for conservation purposes [6], [7] integrates now heterogeneous data on the state of conservation of the building.

a) 3D metrical survey of the Chapel: It was obtained by complementary lasergrammetry and photogrammetry techniques. A 16 million coordinate points cloud and about 300 photos permitted to gather shapes and dimensions of the elements of the Chapel, and to represent the visual appearance of murals and their state of conservation. The largest elements have been decomposed into a *mosaic of parallel images* with a 40% superposition. After distortion processing, images have been arranged onto an orthographic view of the point cloud. Finally, a complete and accurate *3D model* was obtained using the data coming from the 3D scanner survey and a hybrid modeling approach [8] combining range-based and image-based modeling techniques.

b) Scientific photographic documentation: It consists of digital images in high resolution (38.9 million pixels) of wall paintings performed in semi-raking light conditions (Fig. 1). Infra Red images and fluorescence UV images put in evidence relief with semi-raking light conditions, highlighting aspects of the painter technique (working days, "Pontata", incisions) and degradations (scalings, blisterings, cracks, etc.). Secondly, IR images can complete information on not visible details (e.g. preparatory drawings, patterns few or not visible due to their usury, elements belonging to old interventions, etc.). Finally, fluorescence UV images can show the presence of organic materials (binders, varnishes, preparations for gilding process) that reflect the original technique or the presence of additional layers of painting.

c) Cartographies concern conservation diagnosis and restorations: They have been created on deterioration figures affecting the painted surface, on the characterization of the materials constituting the original or restored paintings, on the realization techniques of mural paintings, and on restoration materials adopted for the treatment of the surface.

Fig. 1. From left to right: image in semi-raking light conditions (left), Infra Red image (centre) and image with fluorescence UV light (right) of Apostle, S-E wall of the Frescoes Chapel. Restored parts (in intense blue) are visible on the UV image. Some of them are visible also in the IR image (for instance the end of the beard) [7].

d) Samples of the wall paintings on some parts of the frescoes: They permit to specify knowledge in materials used by Matteo Giovannetti and by further restorers. Moreover, they contribute to determine the kind of material resulting from degradation phenomena (e.g. hygroscopic salts), by using different analytical techniques (photonics and electronics microscopes, chemical analysis systems, X-ray diffraction, etc.)

III. Adopted Methodology

In order to create the 3-dimensional database, the NUBES platform has been adopted [9]. NUBES is an information system at the scale of architecture. It aims to organize multiple representations (and associated information) around a model of semantic description, according to the field of observation. The semantic description model consists in identifying the different parts of the building, in associating concepts (descriptive terms), and in expressing relationships by means of hierarchical graphs in the 3D space [10]. By linking heterogeneous sources around a structured 3D model, different types of research can be queried according to the object of analysis. This web-based application aims to respond to three distinct requirements: (i) the storage of heterogeneous data (in a MySQL database), (ii) the real-time manipulation of 3D geometric representations (with Virtools DEV), and (iii) the on-line access and data management.

The system is composed by several tools listed below, that contribute to describe the state of conservation of surfaces of heritage buildings.

A. Thesaurus Management

The NUBES system manages custom *thesauri* and attributes in order to qualify elements of the 3D scene according to multiple observation fields (vocabularies specific to some types of buildings, construction techniques, deterioration phenomena, etc.). In particular, the system integrates validated *thesauri* such as the *ICOMOS - ISCS glossary* (illustrated glossary on stone deterioration patterns) [11] and other common use *lexica* from the conservation field.

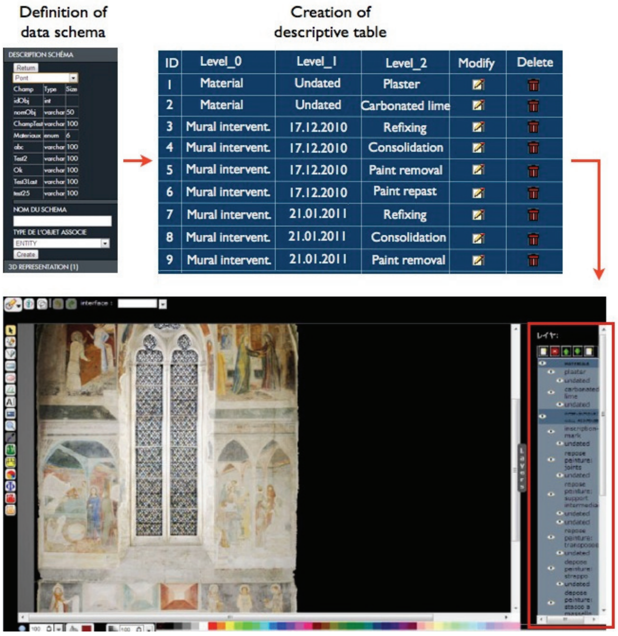

Fig. 2. Steps for the structure definition: firstly, the user defines the desired schema based on a specific thesaurus, than he creates his own descriptive table that is used to display hierarchical layers on the 2D interface.

B. Graphic Annotation of Surfaces

In order to describe the state of conservation of surfaces of heritage buildings, a module [12] of NUBES permits to enrich the 3D model with a structured description of visual aspects characterizing surfaces. The toolkit provides for:

a) Semantic annotation of surfaces: Cartographies on conservation state are drawn on specific hierarchical layers concerning specific categories of analysis. Each semantic layer contains geometrical drawn vector patterns (characterized by areas, barycentres, paths, colors, thickness, etc.) that are saved in the database.

b) Data display and interpretation: Semantic annotations can be displayed and cross-referenced so to find correlations between data in several ways: by means of interactive tools for (i) the spatial distribution of annotations in the 3D scene, and for (ii) the statistical analyses on mappings.

C. Assigning Semantic Meaning to Graphic Annotations

In order to create the structure of cartographies, the adopted thesaurus is put in relation with the protocol adopted for the semantic annotation of surfaces. From a technical point of view, information is structured according to multiple hierarchical levels chosen by the user by means of specific MySQL tables (containing lexica and descriptions of validated glossaries). The choice of the thesaurus determines hierarchical layers concerning specific categories of analysis (Fig. 2). The interface has been implemented so to give multiple choices to the user: he can create customized descriptive tables in the form of data schema (by relating to validated thesauri or by modifying existing thesauri), than he can assign data scheme to different view points and types of objects, or still he can modify the content of tables according to his need. Furthermore, it is possible to copy the scheme of an existing descriptive table, and to export in the XML data scheme for using it in other systems (including the hierarchy of the structure and the description of terms belonging to the thesaurus). Tables easily allow data to be inserted and organised into the database, by means of an automatic procedure.

IV. "PRACTICAL" ASPECTS

The main focus of this study is the integration of the temporal structuring of cartographies on the Fresco Chapel in the NUBES information system. Conversion and format of these unstructured annotations is possible because cartographies were originally produced in a *vector format.* This treatment assures a management of cartographies in an interactive way. This work was based on various stages:

a) Graphical analysis of existing vector cartographies: Previous cartographies have been done with the Illustrator vector software. During this first stage, it was necessary, at first, to verify and inventory data classifications for each side of the chapel, and secondly, to graphically format data (by correcting errors, by checking missing elements in images or texts). Concerning inventory, in order to adapt existing maps and to check uniformity of the used list of terms, a table of terms has been produced for the whole chapel (walls and vaults). It is caracterised by 57 items in total, belonging to 10 areas of analysis. This schedule revealed that the formatting of existing mapping data was not suitable for viewing and filtering purposes, and stressed some aspects:

- At the current state, the thematic order of mapping data is not suitable for viewing and filtering data in a 3D system.
- Manual and not structured annotation can be the cause of indefinite, discordant, partial, broken or grouped elements. In some cases, paths have been re-designed or re-structured with Illustrator software.
- To maintain clarity of superimposed vector paths, the more accurate is the choice of graphic aspects (brightness, opacity level, colors and thickness of contours, etc.), the clearer is the cross-reading of data for interpretation purposes.

b) Definition of the semantic structuring: Based on our previous experience, a refinement of the semantic structure has been established on Illustrator files, with reference to the terms of ICOMOS Glossary and other lexica of the field of conservation. The new semantic structure is based on five categories: alterations, materials, interventions, types of treatment, and scientific analysis. It takes into account the temporal dimension, and is based on three hierarchical levels:

- *categories,* corresponding to the area of analysis (i.e. "Materials"),
- *dates*, identifying the temporal acquisition of a specific element (i.e. "Restoration of 12.10.2010"),
- *types*, constituting the atomic element of analysis (i.e. "spalling" for painting degradations).

The main criteria to define the most suitable structure were the insertion of items in the database, the easiness of displaying and filtering data on the web, and finally the possibility of update the database in future.

c) Integration of structured annotations in NUBES system: The insertion in the NUBES system required a conversion from the proprietary Illustrator file-format to the open standard .svg format (scalable vector graphic) of the web browser editor. The content of exported .svg files has been copied into the 2D interface canvas, and stored in the database with the specific tools of the Nubes system (Fig. 3). This provided the advantage of isolating layers in the 2D interface as well as displaying and filtering data in the 3D scene in real time for the whole walls and vaults of the chapel.

V. CONCLUSIONS

This paper discussed the integration of the temporal structuring of cartographies into a specific interface of the NUBES platform, conceived for the annotation of surfaces. Moreover, this article detailed the description of the main steps for adapting and inserting vector data. As this approach is based on hierarchically structured 2D annotations, time costs for adapting such vector data can result relatively high: the effort in time lies in defining the structuring and verifying accurateness of cartographies. This work has underlined some suggestions for improvement and recommendations on future directions. Firstly, in the further step, inserted data will be crossed-referenced so to extract fundamental observations on this site, for instance on the role of treatments and of restoration. This could be possible by observing the superimposition of regions, or still their dependency/ independency, for each part of the chapel (partial vision) or by analyzing the whole chapel in the 3D scene (global vision).

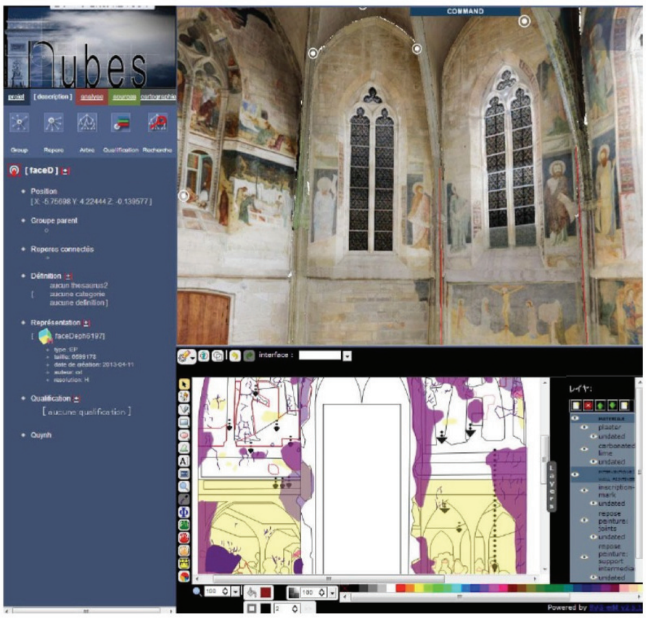

Fig. 3. Display of 2D cartography on the Nubes Information System: in the upper part, 3D scene of the Frescoes Chapel, on the bottom part, display of the degradations in 2D on the East wall of the Frescoes Chapel.

The final goal is to predict possible duration of each restoration, time interval between each intervention, and comprehension of mechanisms of active degradation in relation with their spatial position. For this reason, quantitative tools should be implemented to help expert to formulate diagnoses, such as detecting the centre of each region, or still highlighting relations between physico-chemical analysis and kind of degradations.

Secondly, with regard to data scheme, a study should be expected, in order to extend the data scheme to other standards/methodologies, such as the CIDOC Conceptual Reference Model (CRM) [13], that can provide a common semantic framework for CH documentation.

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