SOFTWARE INTEROPERABILITY AND FRIENDLY INTERFACES FOR ASSESSING INTERVENTIONS IN CULTURAL HERITAGE DOMAINS

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ABSTRACT:

The increasing availability of Open Source tools for satisfying demand in services and applications poses serious problems for effective integration of tools in *Architecture, Engineering and Construction* (AEC) environments. Interoperability intends to solve such effective integration involving information and software tools in complex environments. It also involves a large number of services and applications, with special troubles in *Cultural Heritage* (CH) domains. Any intervention (relative to conservation, restoration or any other similar task) in CH requires an information exchange between different tasks concerning designing, planning, executing and tracking (monitoring and data mining). The two first stages involve GIS and CAD tools, and their interoperability can be solved in a semantic framework. However, last stages (executing and tracking) are concerned with business logic. They are nearer to the harmonization between particular solutions encompassing the optimal combination and application of *Non-Destructive* (NDT) or *Semi-destructive Techniques* (SDT), which must be minimally invasive in CH domains. Image and range-based 3D surveying provide a 3D model giving a support for documenting and applying the most appropriate NDT or SDT. Protocols for photogrammetric surveying are well known (3x3x3 rules), and it is easy to extend them to range-based modeling; but they must be extended to another NDT and SDT. Smart interfaces for navigation, insertion or extraction of information on 3D modeling allow developing a dialogue on a simplified model along surveying and tracking interventions. This work is focused towards the development of a friendly smart interface capable of managing, by means of hyper-graphs, an assisted dialogue with a remote server where an expert system is in charge of different functionalities such as: a) storing new information, b) data accessing on different multimedia supports, c) providing similar examples and d) evaluating solutions. This solution is being applied to indoor and outdoor CH scenarios such as *Maritime Museum of Barcelona* and *Historic Centre of Segovia* for assessing accessibility issues for technicians.

1. INTRODUCTION

A smart system for assessing interventions in *Cultural Heritage* (CH) domains entails the specification of prerequisites and functionalities of a common software platform, able of providing support throughout the lifecycle of an intervention. This lifecycle comprises different articulations between *Documentation, Information and Management* (DIM) Systems, whose main goal is the support of advanced functionalities related to other DIM Systems. During the last decade a collection of strategies have been developed for image- and range-based techniques (and their combination in hybrid modelling), which extend and complement traditional photogrammetric techniques for surveying buildings or urban environments. These extensions have allowed the development of a wide spectrum of applications involving *Architectural, Engineering and Construction* (AEC) domains, and have achieved a precise compatibility with larger overviews, such as urban environment, by means of geometrical modelling, which are suitable for *Information Systems* (IS).

Geographical Information Systems (GIS) provide a very useful methodology for IS in AEC environments, but the inclusion of implicit knowledge from experts demands an enlargement of the support with software tools, which in turn requires developing a superimposed semantic layer on geometrical models and georeferenced data (i.e. *CityGML*, an open source framework for GIS with semantic capabilities). Such semantic approach should specify a conceptual model (i.e. an ontology described as an entity-relation diagram) where relations between terms (lexicon) correspond to definitions (thesauri), and logical rules (taxonomies) involve concepts or tasks. Furthermore, activities (update, validation and amendment) carried out by users demand a well-specified ontology, which can be encapsulated in more comprehensive *Knowledge Management Systems* (KMS). After pioneering work of the team leaded by Prof. Thomas Kolbe, this approach is well known and it is becoming more popular; in fact, it is recommended by the Open Geographic Consortium as a standard for 3D GIS applied to Urban environments.

Finally, *Management Systems* intend to support an IST-based assistance for interventions, across four stages: design, planning, execution and tracking (i.e. *Multicriterion Optimization* theoretical framework). However, there is not a software platform capable of accomplishing these functionalities in AEC environments (i.e. interventions in CH domains). But, recent integration efforts between *Documentation and Information Systems* (hybrid systems), and augmentation of functionalities related to the application of IST-based monitoring and tracking the state of a building, are generating a convergence between different technologies and practices, for which, standards are crucial. A paradigm for *Management Systems* in AEC is given by *Building Information Modelling* (BIM), which has provided support of increasing use for generating and managing data concerning to AEC environments during its lifecycle.

This work is focused on some aspects concerning techniques for *Surveying, Rehabilitation and Conservation* in CH. Following the traditional approach, one has *Non-Destructive* (NDT) and *Semi-destructive Techniques* (SDT), with large diversity (sometimes very casuistic approach) and low-structured knowledge organization. We develop a two-fold morphological- and functional- approach that combines some aspects of GIS and KMS for assisting interventions in CH buildings:

- Morphological aspects concern to the development of a methodology based on the capture of georeferenced geometric aspects (sourced from image and range data), which provide the basis for the other NDT or SDT, for generating an updatable 3D model.
- Functional aspects concern to the design and implementation of KMS on a self-organizing model around different types of associative rules for management of implicit knowledge. Following our scheme, each task to be developed is represented as a path in the working space with a collection of landmarks, which must be specified, surveyed and validated as part of the intervention process.

According to previous scheme, we have organized this paper as follows: second section is devoted to identify the most appropriate models for knowledge management in AEC environments, and more specifically for CH interventions. Next, we specify some general aspects involving the representation of semantics in the KMS framework in connection to techniques used in interventions. The fourth section is the technical core of our work, and includes a description of some of the tools used for managing knowledge in terms of hyper-graphs, which are illustrated with an application. We conclude with some remarks including on-going and future work.

2. EXPERT SYSTEMS FOR MANAGING KNOWLEDGE IN INTERVENTIONS

Non-Destructive and *Semi-Destructive Techniques* (NDT and SDT, in the successive) interventions are commonly referred to a physical domain in which there can be several Levels of Detail (LoD) involving the environment (i.e. topography and cartography, and digital terrain maps), the visible part (i.e. photogrammetry, 3D laser,…) and the non-visible part (i.e. georradar, acoustic method,…). All of them are referenced to a 3D model (vector information), which extends traditional photogrammetric representations, as it includes additional information arising from non-visible parts to identify structural defects. Likewise traditional GIS, there are distinct layers, each one corresponding to a technique; these layers are superimposed to a georeferenced geometrical object (objective data) where tasks are represented as functionalities of the software application in connection with each specific layer for every type of technician.

From a functional viewpoint, managing knowledge is composed of information acquisition, recognition, indexation and classification of the most interesting features, before generating knowledge properly said. Several methodologies have been developed in relation to early stages of learning about interventions in CH domains, e-Learning for NDT (Burgos et al., 2009) and e-Training for SDT (Vidal et al., 2010). While typical approaches concern mainly to the use of technologies, they do not to the management of knowledge, as it involves to the design and implementation of expert systems, strongly related with the development of techniques. Since early nineties, there have been lots of approaches to expert systems, but mostly about fundamental sciences and biomedical knowledge domains, which lacked a more technological orientation, and applications to AEC environments were unknown to the authors at the time of this research. For these reasons, it seems necessary to try identifying the most meaningful expert systems for interventions in AEC environments and adapting them to CH domains.

The description given in (Liao, 2005), leads us to identify several useful methodologies for knowledge integration in relation to a platform for CH interventions. We illustrate some elements of this scheme in the context of typical strategies for NDT and SDT in CH:

- <u>Rule-based systems</u>
  Data capture of visible elements, based in photogrammetry or 3D laser, follows a very well defined methodology with 3x3 rules (P. Waldhaus) or its almost obvious extension to 3D laser-based surveying.
  Similar behaviour can be adapted to non-visible components captured from NDT (including acoustic, thermo graphic, georadar).
- <u>Knowledge-based systems</u> (Dhaliwal et al., 1996)
  Expected parameters in terms of structural or material characteristics are compared with values taken in the field, which conform the knowledge base. For instance, the measures of the deformation or displacements in terms of structural properties of building involving physical or mechanic properties.
  Additional analysis related to durability is especially appropriate for the best choice (taken with the help of the inference engine) of interventions.
- <u>Object-oriented methodologies (OO)</u>
  Inheritance mechanism, which powers the OO paradigm, is of particular interest for AEC domains, because not only allows a hierarchical classification of knowledge (i.e. taxonomies, LoDs,…) but also entitles to abstraction of the semantics encapsulated as objects (i.e. interventions, buildings, maps, NDT and SDT,...).
  This is the approach that we have followed for the design and implementation of our application, and some additional details are given below.
- <u>Case-based reasoning (CBR)</u>
  The diversity of situations and the heterogeneity of techniques that can be applied, justify the use of this strategy in most cases for interventions in AEC environments.
  To avoid excessive casuistic and to incorporate the implicit knowledge arising from the expertise of technicians, it is desirable a software platform to integrate such expertise in an interactive and friendly way, by means of an appropriate design of interfaces and implicit expert system.
- <u>Modelling</u>
  The foundations of a model are the close (to reality) descriptions of the behaviour of a CH domain's stakeholders, but also the analysis methodologies are relevant as new knowledge is be inferred from the results of the analysis (i.e. fissure prediction models for scheduling the severity of interventions).
- <u>System architecture</u>
  The architecture of such AEC environment is complex because there are many subsystems, protocols, interfaces and flows of information. In our CH domain, an intervention is a module, which communicates with other modules (i.e. database, GIS,…) using standardized protocols.
- <u>Database methodologies</u>
  AEC domains are a practical case where large amounts of data are generated by many stakeholders and from multiple

sources (i.e. GIS, intervention assessments, buildings characteristics,…).
But more significant than storing this information in a centralized system, is the efficiency when extracting the diverse knowledge, and mining the data poses a challenge in such environments.

- Ontologies
Any domain has a vocabulary, used to describe the domain, and a set of descriptions of each vocabulary term (Guarino, 1998). Given our AEC environment, it seems reasonable to delimitate the scope of the vocabulary (thesauri) that technicians will use, but at the same time take advantage of the usage of a term in other subdomains within the domain of CH.
Hence, knowledge engineering (interoperability) of interventions at different layers (ontologies) should increase the overall knowledge of the AEC environment and facilitate the communication.

Some other strategies for design and implementation of experts systems not considered in our approach concern to artificial neural networks, fuzzy expert systems and intelligent agents.

3. DESIGN OF AN INTERFACE FOR DOCUMENTING PATHOLOGIES AND ACCESIBILITY ISSUES

The aim of this project is to provide an interactive web tool that provides guidance to technicians through the different documentation steps and allows them to insert data throughout the documentation process. As complex as it is, the data may be stored in a wide range of different formats (audio, video, image, text), but must be accessed the same way. These potential users will have small- or medium-screened laptops and ultra mobile PC's at their disposal; therefore, the design will need to make the best of the available screen.

Along with the guidance, this web interface will also provide 3D navigation through the monument model and its difficulties: accessibility issues, which prevent certain visitors from being able to access some part of the construction, or pathologies in the structure of the monument, both of which need to be repaired. These difficulties will appear marked with a specific icon in the exact position of the model where they are in the real scenario (georeferencing). The navigation within the model will be exhaustive, allowing the user to visit it completely.

The combination between the documentation protocol guidance and the 3D model navigation makes this tool attractive to the technical staff, who won't need to be worried about how the data is stored and will be able to access all the available information about an specific monument everywhere.
This information also needs to be adaptive in two different ways:

- Each technician should only access the information about the monuments he is allowed to see, and modify/enter new information about his areas of expertise.
- The user should be able to see at every moment only the data he wants to see, hiding what he is not interested at (e.g. the 3D navigation map), achieving this way improved performance.

However, although the case study is focused on Cultural Heritage and it is being applied in indoor and outdoor CH scenarios (such as Maritime Museum of Barcelona and Historic Centre of Segovia), the proposed model may also be applied in different constructive contexts to assess protocols and interventions.

3.1 Architectonical system structure

Because of the public and academic context of the project, Open Source technologies were considered the best solution to reach the proposed goals. Therefore, Sun's web server *Glassfish 3* was selected, while the interface was based on the server side by Java-powered technologies (i.e. *Java Server Pages*) and on the client-side the following web standards: *(X)HTML*, *CSS* and *JavaScript* (i.e. *JQuery* framework). We also took advantage of new trends on web development towards interactivity, rich application development and better response times, such as *Ajax*-powered solutions. The database that we chose is the object-relational *SQL* compliant *PostgreSQL* database management server.

GIS support for 3D modelling was provided via the free *Google Earth API*, which allows the superposition of layers in order to show any new data that developer wants on the maps. Therefore, the *XML* derivation named *Keyhole Markup Language* (KML), which is often distributed in the compressed form of KMZ archives, was employed to display the monuments' models on the corresponding coordinates of the default's view of the *Google Earth* map.

The system architecture of the application considers the well-known classical structure of a dynamic system: client-server architecture.
The control flow starts when the user sends a request through the web interface (see Fig. 1), which, by means of the previously explained *Ajax*-powered technologies, handles the update of the multimedia content and replies back to the user.

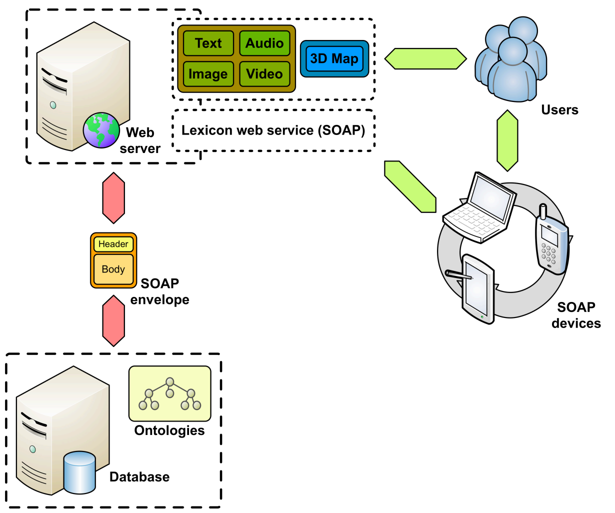

Figure 1. (Partial) overview of the system's architecture

In case the user's request requires information from the database, the application on the web server will send a *SOAP* request (envelope) to the database server (which provides a web service described with the *XML*-based modelling language for web services, Web Services Description Language, *WSDL*). *SOAP* (Simple Object Access Protocol) is a standard protocol that defines the mechanisms for which two different "objects" can communicate through the exchange of information mark up in an *XML*-based language.
Once the database server has retrieved the necessary data from the database, it replies back to the web server encapsulating the

information in another *SOAP* envelope. After the web server receives this envelope, it is parsed and the logical of our application will reply back to the user (its web browser) in a *(X)HTML*-complaint webpage.
On the other side, if the request is to be dealt with locally because there is no need to access the database, the actions of the flow control will not go beyond the web server; hence, there will not be any exchange of *SOAP* envelopes.

Our database is based on an exhaustive ontology (mostly for performance reasons as it the ontology should have the knowledge itself) that accurately represents the large amounts of data related to CH domains.
As a means to appropriately manage the data that the technical-profile users need to handle (i.e. documentation of a certain pathology or accessibility issue in a monument according to certain NDT protocol), the database was required to be expanded with the concepts for geometric documentation described in (Tapinaki et al., 2005).
The association between the new database content and the old one relies on the relationships between the difficulties and pathologies, and the techniques described in the protocols.

3.2 Use of interactive web interface

When accessing the designed interface with a web browser, the user first needs to log in with its credentials (see Fig. 2). If the credentials are successfully validated, the profile of the user, stored in the database, will be set on a session attribute so that the user is the only one who can access the monuments and information related to them that the system gives access to.
As of now, the interface provides with the ability of choosing a monument or an area of interest, which, once selected, the corresponding model is loaded on top of a map as a new layer using the *Google Earth API*. At this point, the user can easily navigate all over the 3D model, where difficulties are shown and detailed with the available multimedia content.

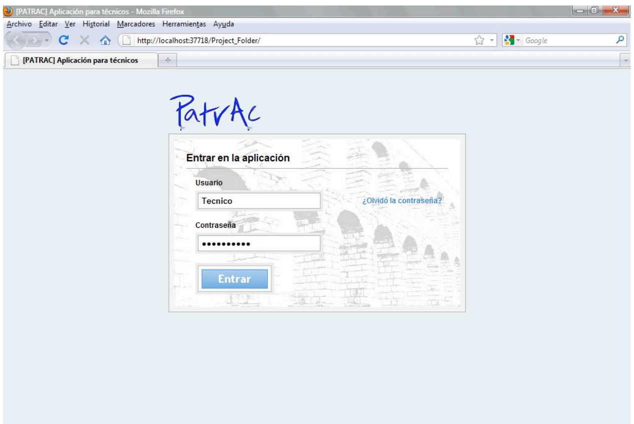

Figure 2. Technicians' login web form

Finally, the interface, which is optimized to work on a full-sized screen, has two distinct visualization modes: a model navigation mode and a consulting or inserting mode of information about a certain difficulty or pathology of a monument.
The interface also includes some extra functionalities (towards a better user experience as recommended in classical Human-Computer Interaction literature) such as a feedback form (i.e. for suggestions about the interaction experience), a brief knowledge base about the differing techniques and protocols (although without any subjective association to a particular difficulty, accessibility issue or pathology),…

4. KNOWLEDGE TAXONOMIES MODELLING

Knowledge-based systems are designed for capturing knowledge and expertise from individuals within an organization. After capturing and formalizing, it is necessary a set of key words involving typical objects, users or tasks which can be represented as nodes of a directed graph, where directions can be interpreted as "natural" hierarchies implying an order (proximity, adjacency) or inclusion relations in a discrete representation.

Directed graphs can support a system of weights, where some nodes or edges connecting them, can have variable weights. However, the semantic use of concepts needs a more refined representation in terms of entity-relation diagrams (where multiple correspondences are allowed) extending usual relational database and external transformations (i.e. corresponding to contraction or expansion of subgraphs).

There is not a unique way for representing meaning and, consequently, there are different ways for designing adequate strategies for KMS.

4.1 Ontology model

The conceptual model of a taxonomical ontology is a set of keywords and the associations that connect these keywords in a hierarchal structure to originate a classification.

For this reason, we have modelled the lexicon taxonomy as a hyper-graph (which in turn is a combination of subhyper-graphs as there are various taxonomies sharing terms) rather than directed acyclic graphs or trees.
As pointed in (Gallo et al., 1993) hyper-graphs can easily represent many to one relations, which have a richer semantic meaning in the case of the classification scheme known as taxonomy as there is no need to replicate the same associations in which a keyword can be decomposed (see Fig. 3).

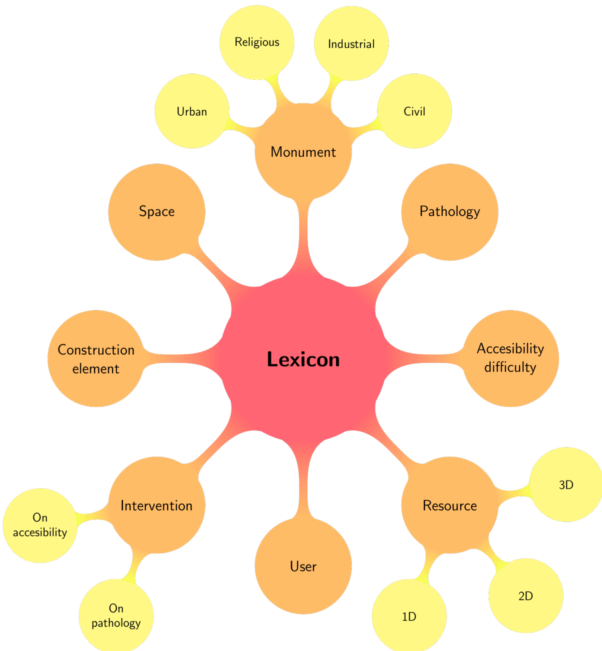

Figure 3. Taxonomical ontology representation of the lexicon

4.2 Assembly of a hyper-graph based lexicon assistant

Our interface for assessing interventions is aimed at assisting a technical-profile user in the tasks of retrieving an intervention or evaluating a solution by means of a dialogue with an expert system, as pointed out in section 2, implemented as a *web service*.

Such *web service*, implemented according to *SOAP* protocol (see Fig. 1), is the ultimate layer of an engine that navigates through the lexicon looking for successors or predecessors of a keyword (provided by the user) according to user's domain.
We use *SOAP* protocol because any other module of our architecture may use this assistant as it has been designed towards extendability as most of the complexity lies in the underlying hyper-graph data structure (implemented in *Java*).

Our lexicon is superimposed to different domains, which are shared by a unique ontology. Our formal model of the taxonomical ontology for the lexicon allows us to keep all keywords in one model and differentiate the domain of each classification because the hyper-graph model that we use is labelled. This solution is being applied to indoor and outdoor CH scenarios such as *Maritime Museum of Barcelona* and *Historic Centre of Segovia* for assessing accessibility issues for technical-profile experts (technicians).

5. CONCLUSIONS AND FUTURE WORK

In this work, we have developed a friendly smart interface capable of managing, by means of hyper-graphs, an assisted dialogue with a remote server where an expert system is in charge of different functionalities such as: a) storing new information, b) data accessing on different multimedia supports, c) suggesting similar examples and d) evaluating solutions. The developed solution provides a support for including and managing the knowledge linked to *Non-Destructive* (NDT) and *Semi-Destructive Techniques* (SDT) that are being used in conservation and restoration tasks of damaged Cultural Heritage buildings.

At the current state of implementation, there is not an automatic process for path finding; that is, user decisions drive the path step by step. This is an intended approach as the goal is assisting the user when navigating across the lexicon; that said, at the end of the process there will be a valid path (semantically correct). We could easily provide a verification service because there are traversal algorithms (Gallo et al., 1993) for such tasks on hyper-graphs, but we would not be helping the user navigate through the taxonomy (although it is in our current future work to develop algorithms to semi-automatically traverse the taxonomy).

We have developed a collaborative environment support where activities related to information insertions and carried out by technical-profile experts, are assisted with the developed tool.
Following steps to be addressed are concerned with the insertion of contents relative to NDT and SDT, in conjunction with the corresponding protocols for interventions.

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