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Original article

An ontological model for the reality-based 3D annotation of heritage building conservation state

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ABSTRACT

The conservation and restoration of historical monuments require a diagnostic analysis carried out by a multidisciplinary team. The results of the diagnosis include data produced by different techniques and protocols, which are used by conservation scientists to assess the built heritage. Nowadays, together with the aforementioned data, a great deal of heterogeneous information is also available, including descriptive and contextual information, as well as 2D/3D geometrical restitution of the studied object. However, the integration of these diverse data into a unique information model capable of fully describing the building conservation state, as well as integrating future data, is still an open issue within the Cultural Heritage community. It is of paramount importance to correlate these data and spatialize them in order to provide scientists in charge of our heritage with a practical and easy means to explore the information used during their assessment, as well as a way to record their scientific observation and share them within their community of practice. In order to resolve this issue, we developed a correlation pipeline for the integration of the semantic, spatial and morphological dimension of a built heritage. The pipeline uses an ontological model for recording and integrating multidisciplinary observations of the conservation state into structural data spatialized into a semantic-aware 3D representation. The pipeline was successfully tested on the Saint Maurice church of Caromb in the south of France, integrating into a unique spatial representation information about material and alteration phenomena, providing users with a means to correlate, and more importantly retrieve several types of information.

1. Introduction and objectives

In the field of cultural heritage, building conservation state monitoring poses an important challenge today. A major question is how to structure, connect and provide access to complex data interpretation in the field of conservation? The description and analysis of the architectural heritage is carried out using a large and very diverse number of resources such as documentary sources (text, graphics, voice) and analytical data (from the sample analysis, data from various sensors, map data from different imaging radiation, etc.). The data generation and process are conventional according to the expertise domain (architecture, mechanics, computer sciences, etc.) and all of them comprise the whole historical, archeological and constructive information required to understand the heritage structure and its evolution over time. Despite their complementarity, analytic data sources are often separated from one another. Therefore, the attempt to structure, share and link these data has a real meaning in the field of conservation. In addition, given the major advances in terms of technology development for 2D and 3D digitization of heritage buildings, the main issue encountered by the Cultural Heritage community today involves the possibility to correlate these heterogeneous data in order to produce relevant information (related to consolidated knowledge) for describing the building conservation state. Another important point relates to the spatial referencing gap. Data generated by different experts through graphic (or textual) materials or other processes are generally not spatialized: even though all these data refer to a common physical object (e.g. a heritage building) or to specific spatial regions of this object (e.g. a degradation pattern on a wall), the link between these data is only based on a conceptual description of the building (without any references to their reciprocal spatial position).

Designing an ontological model for the multidisciplinary observation for conservation state purposes seems to be a promising way to structure semantic-aware 3D representations of heritage

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buildings today. This paper introduces a domain ontology model for the reality-based 3D semantic annotations of the building conservation state. By combining qualitative and quantitative descriptors of interconnected 3D annotations, this dedicated ontology integrates data, information and knowledge that describe and monitor stone degradation phenomena in order to assist Cultural Heritage experts within the decision-making process.

This article is divided into five parts. Section 2 sets out several relevant principles in order to better understand the notions that are being used. The next step is to suggest a state of the art of existing systems that can either manage a huge amount of data thanks to a domain ontology or spatialize scientific observation around 3D representation. Our approach regarding the domain ontology design dedicated to 3D semantic annotation is developed in Section 3. The correlation engine discussed in Section 4 particularly underlines the merging of specific dimensions. In Section 5, the chosen implementation strategy intended to build the overall information system is presented. Finally, Section 6 concludes this article and suggests some related perspectives.

2. State of the art: literature review

This section comprises two parts. The first one provides some basic definitions in order to better understand the manipulated concepts used in the conservation monitoring issues. The second one gathers the most relevant related work suggesting solutions for addressing as efficiently as possible the given problem: works from which we can draw benefits for the approach presented in the next section.

2.1. Basic definitions

Many approaches are used today in order to objectively reproduce and represent with objectivity the current state of a heritage building, according to its morphological and conceptual complexity. In this section, we analyze the scientific literature related to the three major domains, which constitute the main dimensions of our approach: the domain ontology, the semantic annotation, and the reality-based 3D reconstruction.

2.1.1. Domain ontology definition

An ontology is used to describe, share and reuse knowledge and data between software and humans. This conceptual model is used in many information systems relying on semantic web technology. However, the name has been borrowed from the philosophic domain and is defined as the "study of being as being" [1]. Particularly in the computer sciences domain and knowledge-based engineering, the ontology is characterized as the "explicit and formal specification of a shared conceptualization". This definition shows and links a large number of specific concepts: Conceptualization means that a specific expert group of the same domain wants to describe and model an abstract phenomenon existing in the world. "Explicit" refers to the concepts and constraints that need to be clearly defined in relation to the domain. An ontology is "formal" because it is understandable and readable by a computer allowing it to produce some reasoning between concepts thanks to defined rules. Finally, it can be "shared", meaning that it gathers consensual knowledge agreed by a scientific community expert group. Therefore, a domain ontology is defined as a shared knowledge formalization dedicated to a specific domain.

2.1.2. Semantic annotation

Annotation principle is based on the linking between one entity and complementary information. Semantic annotation is the process that associates a tag aiming to argue advanced research on a particular analysis. Furthermore, an annotation is used to convert syntactical framework to knowledge structuration. Defined annotations subsequently enable the creation of complex information structuration. Indeed, this structuration has a meaningful impact on data displayable by the user. There are four models of semantic enrichment: by tags (keywords), by attributes (object features), by relationships (between provided resources) and then by ontologies ("an explicit specification of a shared conceptualization") [2].

In the domain of cultural heritage, the process of annotation on iconographic sources, more specifically on photographs, helps the comprehension of a building by providing semantic information. Three main methods are currently available to annotate a 2D source: manual (annotation related to a tag or a term from an ontology), automatic (by shape recognition), or semi-automatic (validation of a keyword suggested by the system). However, these three methods only use 2D information. Regarding 3D models annotations, information can be attached to points, segments, surfaces or objects in the digital mock-up. Recently, researchers have shown an increased interest in the use of 3D information in the image semantic annotation process.

2.1.3. Reality-based 3D reconstruction

Reality-based 3D is the technique used to create a three-dimensional representation of a real object. In recent decades, there has been an important demand for computer graphics triggering a great interest and change for the requirements. The creation of 3D models of heritage, as well as archeological objects and sites in their current state, requires a powerful methodology that can capture and digitally model the fine geometric and appearance details of such sites. The most commonly used methodology involves an image-based and laser-based approach that is nowadays well known. Several attempts have been conducted particularly by using image manual adjustment technique. Nevertheless, these attempts have not succeeded in offering a fairly accurate solution. That is why several research groups have developed a technique named automated image-based 3D reconstruction, including tools for orientation and image calibration [3]. Thanks to this technique, it is possible to perform a huge number of studies (metrical, morphological, spatial analysis and so on).

2.2. Related works

Two aspects can be highlighted in the conservation domain. On the one hand, several Information Systems suggest managing a large amount of data types so that the qualitative aspect is the most exposed. One the other hand, few systems are based on the quantitative aspect. And there are generally few studies relating to these two main aspects within an integrated approach.

2.2.1. Documenting cultural heritage objects by a domain ontology

The research group SeCo (Semantic Computing) has designed an ontology named MAO (Museolan Ontologia). The latter has been created for the content description such as tangible and intangible object. MAO structures data used by an application located on "the semantic portal for Finnish Culture Kulttuurisampo". One of the first public releases contains data from twenty-odd sources such as museums, libraries, archives, and so on. This application integrates contents produced by a large domain panel such as painting, sculpture, arts of drawing fields, and from web pages, data related to places, historical events, cultural sites, etc. Those data are related to one another thanks to a domain ontology [4]. The intrinsic information and images metadata are directly linked to location data displayed on a cartographic website such as Google maps. It is only possible through the use of an ontology, as these data are complex to manage with just a relational database. To conclude on this first example, the research group has designed an ontology that allows

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