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Architectural heritage knowledge modelling: An ontology-based framework for conservation process

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ABSTRACT

This paper presents an ontology-based model to support the representation and management of information and knowledge during investigation activities for the conservation of architectural heritage. Despite the significant impact of information and communications technology (ICT) on architectural heritage, current approaches to its use in this context are often conceived only to provide flexible and reusable tools and methodologies, thus proposing oversimplified procedures that are ultimately insufficient for a truly accurate conservation project. A few experiences recently have focused much attention on the specifics of conservation. Although they have generally been concerned with the specific activities and knowledge domains related to conservation processes (such as cataloguing or monument damage), the importance of dealing with them in an integrated way is often neglected. Hence, each step of the process – such as the preliminary phase of knowledge acquisition, the summaries, which facilitate the assessment of value, diagnostics, design, the construction phase, and maintenance – is treated in isolation from all the other activities. This lack of synergy often compromises the final result. In order to deal with the complexity of representing historical architecture, and its conservation process, this proposed model defines four main knowledge domains (artefact – lifecycle – architectural heritage investigation process – actors), in which all the knowledge related to each artefact is formalized through semantic networks, in terms of entities, properties and relationships. Specific reasoning and inference rules allow checking of the model for coherence, in order to reduce information discrepancies, inconsistencies and errors. The proposed model offers a high level of accuracy in its capacity for description and, at the same time, a broad versatility within representation modelling, allowing such a reliable representation of multiple issues that eventually it may be required for every historical building, depending on its features and state of conservation. Moreover, the versatility of the model provides a suitable representation even for the different nature of the investigation activities results – whether analytical or hermeneutical. Finally, the knowledgebase has been connected with a building information modelling environment, providing an effective integration between geometrical and non-geometrical information.

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1. Research aims

This piece of research aims to conceptualise and develop a knowledge-based model for the representation of architectural heritage, in order to support both the investigation and design phases of the conservation process. The aim of the investigation phase is to define a representation of knowledge that suits the richness and specificity of information relating to historical architecture. The design phase has the goal of creating a model that is able to provide and manage investigation results that can be used for conservation planning, and to act as a support for design decision-making. The proposed model has at its core a knowledge base developed through information ontologies and oriented around the formalization and computability of all knowledge necessary for the full comprehension of the object of architectural heritage.

Rather than forcing modelling approaches from other fields into built heritage practice, the research presented in this paper focuses on the development of an approach towards the representation of ad-hoc knowledge, methodology, and tools, in order to fit the

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requirements of historical architecture conservation, according to its specificity and unique qualities.

2. Introduction

All endeavours towards representing and managing knowledge within the field of architectural heritage conservation should necessarily consider complexity and specificity of conservation activities. Every heritage intervention is developed on the knowledge of the fabric of the building and, to achieve full comprehension, the investigation process is articulated around two processes: an examination of the building, and its critical appraisal. The first relies on a specialized and mainly analytic approach (developed by multiple professionals such as historians, physicists, chemists and biologists), while the second is built on interpretative and critical activities (performed by a conservation architect). These activities, gathering all the information provided by the investigation process, lead to an assessment that gives purpose and direction to the conservation design. This synthesis should consider each individual clue, avoid inner contradictions and merge materials and shapes, history and function, buildings and meaning in a coherent and organic framework.

While information and communication technology (ICT) have proved their efficacy in controlling particular aspects of representing historical architecture (such as the accuracy of 3D representation of artefacts, or the ability to digitally archive documentation), some limits and criticisms have arisen in terms of their actual suitability to architectural heritage conservation projects. One initial limit is the excessive standardization of current ICT-aided modelling approaches, and tools that clash with the uniqueness and unrepeatability of historical architecture; a second is related to interdisciplinary features of the investigation and conservation process, in which many different specialists operate together. Each uses their own set of models, methods, tools and jargon, and it is difficult to find an ICT framework that effectively supports such diverse information, knowledge sharing, and collaboration.

Looking at the complexity of information required to fully represent and comprehend an architectural heritage artefact, this research has assumed as a hypothesis that a model for knowledge representation and management, guided in its conception and development by heritage conservation professionals, may arise from the use of information ontologies. Ontologies in information technology have been developed to provide a computable knowledge base consisting of a primitive system of representation through which it is possible to model a domain of knowledge. The primitives for representation are 'classes', 'properties' and 'relationships'. Therefore, an ontology is a definition of concepts that belong to a particular knowledge domain which includes the meanings, description, and the relationships between them [1,2], thus a formalization of contents within a logical network that can be managed by all the experts who are involved.

Indeed ontologies may well be able to describe all the information gathered to realize the conservation project, and in the meantime corroborate how the knowledge represented is interpreted. The structure of the ontology, to be properly processed, needs to be worked on jointly by knowledge engineers and domain experts. The former, informatics experts especially skilled in ontology representation language [ontology web language (OWL)] write the programs and manage logical coherence. The domain experts, cultural heritage professionals, are all those who contribute to the knowledge necessary to allow the conservation of a historical building from the commencement of the conservation project, to its eventual use and maintenance. They have a duty of care about the structure, and they verify its representativeness and responsiveness of its contents.

Formalizing such knowledge requires a highly accurate procedure in the definition of the concepts' semantics, and particular attention paid to describing the logical structure in which the semantics have to be represented. The purpose of checking both the description of a single item and the relationships, physical and conceptual, that involve it, works towards a deeper and wider comprehension of the heritage domain. In addition, such a dynamic approach is able to cope with the abiding dialectic between analysis and interpretation that typifies the approach to knowledge in a conservation project [3].

On this basis, the present model, apart from concerning the figurative, constructive and material features of a building (provided by the architectural survey, decay survey, chemical, biological or physical investigations, etc.) also aims to incorporate the indirect knowledge made up of the heterogeneous and critical assumptions provided by studies that are carried out within a conservation project [4].

3. Current state of the art

In architectural heritage, one of the main results of the pervasive use of ICT technologies, in addition to the creation of applications of this kind, has been the generation of a large amount of digital data, often produced by different actors through completely non-interoperable methods and systems. At present, the main feature of this data is the vast heterogeneity relating to the types of media and transmission formats, the accessibility level, the logical and structural models used for their definition, and the consistency of the information represented [5].

As mentioned above, one of the most recent solutions for creating a formal, shared and explicit description of information, even in the field of cultural heritage, is the use of special schemes called ontologies. In a cultural heritage context, the main ontological reference model that can be classified as core ontology is the CIDOC Conceptual Reference Model (CIDOC CRM) [6]. This ontology became the ISO standard in 2006 and to date allows the formal and highly specific representation of information about cultural heritage, together with a representation of the concepts of space and time, thus supporting operations of reasoning and inference.

While the CIDOC CRM model was developed mainly to manage the cataloguing of cultural heritage documentation, other domain-specific ontologies have been progressively introduced to represent other aspects of the heritage conservation process. As an example, Cacciotti et al. [7] proposed the Monument Damage Information System (MONDIS) that focuses on an ontological framework that can coordinate a systematic approach to the documentation of damaged historical structures, their diagnosis, and possible interventions.

While the literature on ontologies for cultural heritage is sufficiently wide, few attempts have been made to apply ontology-based modelling approaches to architectural heritage. Agathos and Kapidakis [8] used the CIDOC CRM template to derive the Architecture Metadata Object Schema (ARMOS) for the cataloguing of architectural heritage, focusing in particular on the formal aspects of architectural design. In terms of the investigation process, Mecca et al. [9] proposed a very specific ontology for a diagnostics workflow regarding earthen architecture, in order to formalize various collections of information guidelines.

Recently, there have been experiments regarding the application of ICT approaches to cultural heritage, derived from the architecture, engineering and construction (AEC) fields – such as building information modelling (BIM) and industry foundation classes (IFC) – to overcome these limits [10–12]. Along these lines,

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