From a CityGML to an ontology-based approach to support preventive conservation of built cultural heritage

Olga Zalamea
KULeuven/SADL
Celestijnenlaan 200E
Leuven, Belgium
olga.zalameapatino@sadl.kuleuven.be

Jos Van Orshoven
KULeuven/SADL
Division Forest, Nature, Landscape
Celestijnenlaan 200E
Leuven, Belgium
jos.vanorshoven@sadl.kuleuven.be

Thérèse Steenberghen
KULeuven/SADL
Celestijnenlaan 200E
Leuven, Belgium
therese.steenberghen@sadl.kuleuven.be

Abstract

Built Cultural Heritage (BCH) management requires information from several domains and sources. The integration of this information is complicated because multiple scales and dimension levels are involved, along with different data models. Therefore, sources rarely share the same information structure and/or the terminology is syntactically and semantically different. In BCH-management there is a focus on the representation of 3D features in a spatially explicit way and one of the mains standards used to create this representation is the City Geography Markup Language (CityGML) standard. However, the CityGML standard does not provide sufficient semantics as required for a proper BCH-management, even after extending the definition of the standard with particular classes for the BCH-domain. An ontological model could fill these semantic gaps and provide some improvements to the original model. Through the application of a use case we converted the CityGML preventive conservation model to a taxonomy, which can be used later to identify current ontologies, which partially or completely matches the classes represented in the taxonomy.

Keywords: Built Cultural Heritage, Ontology, CityGML, Linked Data.

1 Introduction

Conservation of BCH is recognized by several international heritage soft-laws, “International Charters” and guidelines for multidisciplinary approaches [10, 11, 5]. Also, UNESCO recommends applying a preventive conservation approach for BCH through continuous monitoring and regular maintenance [12].

However, the concomitant nature of the preventive conservation approach and the BCH assets increases the difficulty of the conservation tasks. The management of BCH assets requires the involvement of multiple disciplines, actors, related data sources and systems. In addition, several hierarchical spatial scales such as city, zone, site, building and building element are needed. For example, inventories are typically performed at the building level while tactical decisions such as those required on fire safety infrastructure are taken at city or at a geographical sector level. Regarding to data analysis, two-dimensional models cannot cover the essential geometrical, topological and semantical scopes of heritage objects [3].

All these problems generate a significant amount of data and information but also result in a complex schema integration problem of associating complementary information [15].

In order to remediate some of these issues several standards for 3D data modelling have emerged, of which the most prominent are the Industry Foundation Classes (IFC) and the City Geography Markup Language (CityGML) [13]. The IFC standard is intended for modelling building and construction industry data. CityGML is a data model capable of representing information referring to the building elements. Its multiscale approach (Levels of Detail, LoD), makes CityGML a better candidate for the domain since the management of BCH also operates at various hierarchical spatial scales [9].

However, CityGML also has a number of limitations for its application in the BCH domain. First, there is the incompleteness in the representation of specific BCH-components like pilasters, cornices, friezes, etc. Second, CityGML does not make sufficient provision for the representation of thematic information for the heritage domain, e.g. condition status, or vulnerability issues.

The hypothesis is that the limitations of CityGML, and the schema integration problem of the BCH domain *can be overcome through the extension of CityGML with an ontology-based model*.

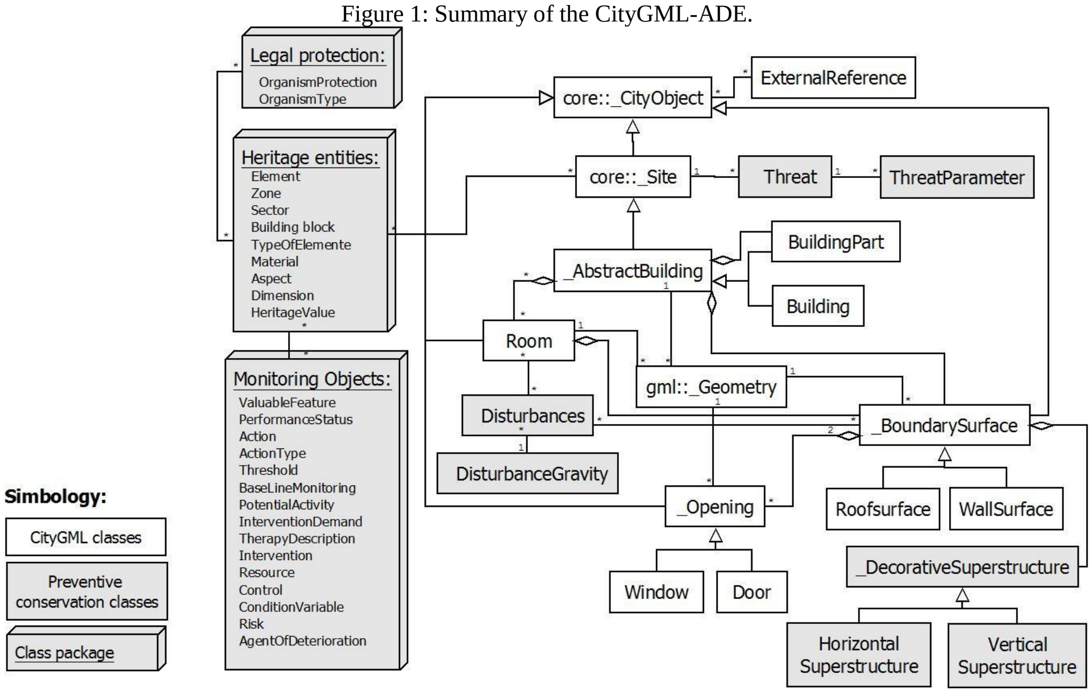
This paper presents the advantages of an ontological approach for BCH-management and the initial steps to move from a CityGML-based data model supporting the preventive conservation of BCH towards a BCH-ontology. This transition is tested in the context of the UNESCO world cultural heritage site management in the city of Cuenca, Ecuador.

2 Problem statement

The main manager actors of the World Heritage City of Cuenca are the *Cultural Heritage National Institute* (INPC), the *Municipality of Cuenca* and the *World Heritage City Preservation Management* (VlirCPM) research project at the University of Cuenca, which operates under the UNESCO PRECOM3OS Chair. Having all these organizations involved in the BCH-management creates an integration problem since there are no agreements on the standardization, exchanging or sharing of the generated information.

As a first step in filling this gap, the VlirCPM project has developed a CityGML-based data model through a dedicated Application Domain Extension (ADE) [9]. This CityGML-

Figure 1: Summary of the CityGML-ADE.



Source: Heras 2013.

ADE is based on the preventive conservation approach. In order to apply it, a preventive conservation cycle (PCC) has to be implemented. Analysis, diagnosis, therapy and control are the phases of the PCC. In each phase data are collected and/or computed which are passed on to the following phase. If the data are insufficient to complete a particular phase, iteration between phases is possible. Since monitoring is a continuous process, the cycle is also continuously reiterated. Figure 1, is a summary of the CityGML-ADE for BCH-management as proposed by Heras et al. [9]. Basically, the model merges the main classes from the CityGML-Building module with classes required for implementing a preventive conservation approach.

This model provides an adequate spatial representation of the BCH-domain but a number of shortcomings still need to be addressed. A discussion on how to overcome these shortcomings is presented in the following section.

3 Methodology

Ontologies encompass "Formal, explicit specifications of a shared conceptualization" [17]. For Antoniou et al. [1] an ontology consists of a finite list of terms and the relationships between these. Axioms are used to represent the relationships between the terms and to add a logic layer to the conceptual model. Among the practitioners in the field there is not a clear division between what is referred to as "vocabularies" and "ontologies". The trend is to use the term "ontology" for more complex, and possibly quite formal collections of terms [19]. Taxonomies being classification schemes arranged in a hierarchical structure are considered as a basic starting point for the construction of an ontology. In this research the concepts in Table 1 are adopted.

Table 1: Adopted concepts for the intended research

Formal representation	Scope	Example
Taxonomy	Hierarchical structure of classes and subclasses representing terms of interest in a particular domain	In Figure 1, the following hierarchical structures, among others, are stated: An *AbstractBuilding* can be a *Building* or a *BuildingPart.* A *BoundarySurface* can be a *CellingSurface* or a *WallSurface*.
Vocabulary	Taxonomy + Axioms representing relationships among the terms.	A *Room* is part of a *Building*. A *WallSurface* is part of a *Room*. The relationship "PartOf" has a different meaning that the hierarchical relationship "Is-a" represented in the previous example.
Ontology	Vocabulary + Axioms representing additional restrictions allowing complex logical inferences	If *WallSurface* is part of two *Buildings*, it can be inferred that those Buildings are 'neighbours'.

Source: Author.

Table 2: On-To-knowledge methodology description.

Process-Step	Description
Knowledge Meta	
Feasibility study	Identifies the problem, the opportunity areas and the potential solutions.
Kickoff	Captures requirement specifications, looks for already developed ontologies and creates a semi-formal description of the ontology.
Refinement	The semi-formal ontology description is refined by adding concepts and describing relations and a target-ontology is formalized.
Evaluation	The target-ontology is evaluated to ensure it will satisfy the requirement specifications.
Application & evolution	The ontology is built and the management of the ontology evolution is set.
Knowledge	
Creation/Import	Contents are created or converted to fit the needs and conventions of the stakeholders.
Capture	Interlinkage is performed.
Retrieval / Access	Information that satisfies users' needs is retrieved, e.g. access to data about the condition and risks of BCH-objects.
Use	Process of knowledge retrieval for further use in a specific context, e.g. condition and risks analysis of BCH-objects performed by a specific stakeholder.

Source: Author.

In the field of ontological engineering several methodologies have been proposed to specify the ontology development process. In Casellas et al. [3] a comparison of methodologies can be found. The On-to-Knowledge methodology [15] has been chosen for its clarity and well elaborated definitions. The methodology consists of two processes closely related: The Knowledge Meta and the Knowledge processes.

Every step in the Knowledge process (Table 2) can be linked to steps in the Knowledge Meta process, e.g. creating or importing content can lead to a refinement of the current developed ontology. The methodology is iterative and incremental allowing a basic ontology to be refined and improved on additional iterations.

4 Application of the On-To-Knowledge methodology for the BCH-domain

4.1 Feasibility study

The CityGML-ADE presented in Figure 1. remediates the lack of representation of BCH components and thematic information. However, some shortcomings still exist: i) relationships have no expression ii) static model with fixed number of classes iii) model based on a single standard.

Relationships in the model have meanings that need to be interpreted and coded in a higher application level. For example 'Threats' increase the chances of potential affections whilst 'Damages' are current affections in building components. The implicit relation between these two needs to be explicitly coded in the applications built based on the model. Some relationships as generalization or composition have explicit meaning. In generalization, for example, a subclass inherits all the properties of a more general class. e.g. 'Abstract buildings'-'Sites' but even in this case the properties of the class 'Site' have to be codified in an application to be shared by the class 'Abstract buildings'.

The model presents fixed classes for all the stakeholders but it does not consider that the source models can be different. The INPC and the Municipality could record damages and threats in different way and all of them should be able to coexist together. Moreover, the model is static, any change in the model will imply a rebuilding of the applications based on the model. Thus, addition or modification of features is problematic and challenging.

The model is founded on the CityGML standard and representations based on other standards are not included.

These limitations present opportunities where the general characteristics of ontologies can be applied to improve the model.

First of all, relationships in an ontological approach are also formally defined. The range and domain are explicitly described. Therefore, applications can interpret different of relationships types.

Ontologies are based on the representation of triplets: subject-predicate-object. E.g. Building-has condition status-ConditionStatus. Since the model is represented as a set of triplets no specific structures are preconceived. This allows the model to be dynamically adapted to the particular necessities of each stakeholder or adding/modifying features. Therefore, several representations of the same data could coexist as the spatial representation using different standards as CityGML and IFC. In these cases additional rules need to be added to define when each representation is used.

4.2 Kickoff

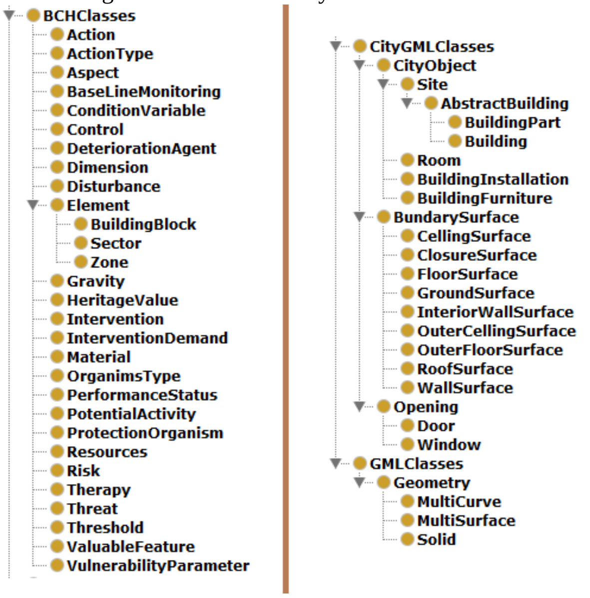
A taxonomy was derived CityGML-ADE model (Figure 2). This model is the result of a thorough specification of requirements, after several interviews and workshops with representatives of the INPC, the Municipality of Cuenca, the VlirCPM project, citizens, tourists and researchers. It has already been tested in the study area showing to provide a suitable representation of the Historical Buildings [9].

Table 3: Evaluation criteria for ontology seleccion.

Criteria	Description
Accessibility	The ontology is accessible through a server or the ontology can be downloaded
Completeness	Degree at which classes are not missing
Provenance	Metadata available to identify the creator of the ontology
Reputation	The creator of the ontology is reliable. Eg. Governmental organization, research lab, etc
Understandability	The classes in the ontology have labels that can be interpreted

Source: Author.

Figure 2: Basic taxonomy for BCH-domain.



Source: Author.

Basically the classes from the preventive conservation model were mapped as taxonomy classes. Following the hierarchical structure of the taxonomies the generalization associations were converted into ontology classes and subclasses. In order to distinguish the dedicated preventive conservation classes from the CityGML classes two super classes were created: the BCH-Classes and the CityGML-Classes. The taxonomy was created using Protégé, a free open-source suite of tools to construct domain models and knowledge-based applications with ontologies [16].

This research pays special attention to the physical representation of 'Buildings' as the main entity in the BCH-domain. Therefore, ontologies representing the CityGML classes were selected first. Already developed ontologies were searched in the literature review process, catalogues and search engines recommended by the World Wide Web Consortium (W3C): Linked Open Vocabularies [2], Swoogle [6] and Falcons [4]. The search revealed few ontologies proposed to represent the CityGML standard: the ontology of urban planning process (OUPP) used to integrate air quality models [7], an intermediate ontology aligned the representation of 3D standards as CityGML, IFC and Open Green Building XML Schema [8], and an ontological model for emergency response integrating topographic, cadastral and hydrology data [14].

4.3 Refinement

In this activity the ontologies found previously have to be evaluated. Several methods for ontology evaluation are described in literature [15, 18]. Table 3 explains the evaluation criteria. Accessibility is checked first. If the ontology is available then the degree of completeness is computed so priority can be given to the most complete ones. Then provenance is checked with the purpose of contacting the creators and checking their reputation. Finally, Understandability ensures that further work can be performed using the ontology.

After the evaluation all but one of the ontologies listed at the end of section 4.2 were discarded since they are not publicly accessible. All of them are reported to be in an initial development stage while the ontology itself is not available yet. The exception is the CityGML ontology used in combination with the OUPP ontology developed by the University of Geneva in Switzerland which can be accessed through http://cui.unige.ch/isi/onto/2010/citygml.owl.

The completeness of this ontology versus the developed taxonomy was found by us to be 100% since all the CityGML classes described in the source taxonomy were mapped into this ontological model. The authors of the ontology were contacted in order to verify its provenance and to request authorization to use the ontology in our research, the approval was granted. After studying the ontology and based in our own experience we judge the CityGML ontology as very understandable for those being familiar with the CityGML-standard. Based on these assessments we selected the University of Geneva CityGML ontology for further work on the phases of Evaluation, Refinement Application & Evolution.

5 Conclusion and Future work

We selected the On-To-Knowledge methodology to shift from a CityGML-ADE-based preventive conservation model towards an ontological approach to remedy the shortcomings of the CityGML-ADE, i.e. its static nature and the lack of expressivity in the relationship meanings. The main findings of performing the first activities in the Knowledge Meta-process are: the creation of a semi-formal representation of the CityGML-ADE model and the finding of the University of Geneva CityGML-ontology. The CityGML-ontology published by the University of Geneva can be considered to be an ontological equivalent of the CityGML standard and is an appropriate starting point for expansion with the dedicated preventive conservation classes. The University of Geneva ontology has been used in the urban planning domain. Another ontological representation of the CityGML standard reported in the emergency response domain is not available. A complete solution BCH has not been produced yet.

The CityGML-ADE model can be used to represent the particular case of the UNESCO world heritage city of Cuenca in Ecuador. To extend this solution several international models for BCH-management have to be gathered and compared in order to select the most suitable as the point of entry for the whole process.

Future work will include the completion of the identification of available ontologies to represent the preventive conservation classes, and the application of the On-To-Knowledge methodology to build an ontological model of the IFC standard that is also widely use in the BCH-field.

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