# Architectural Heritage Ontology
## *Concepts and Some Practical Issues*

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Abstract: Interoperability has become fundamental to the management and sharing of the data. For this reason, international standards are published and ontologies are proposed and used for structuring databases in order to assure information retrieval, improved analysis and correct interpretation of the data, besides the interoperability of compliant databases. For thematic data about cultural heritage, standards vocabularies and ontologies EXIST, but are not fully suitable to represent some aspects of architectural heritage. In fact, complex spatial data have to be equally managed using these technologies, for enabling analysis empowered by the inclusion of the spatial and geographical dimension. This could undoubtedly enrich the documentation of architectural heritage. However, few spatial ontologies exist, which are able to correctly represent the complexity and richness of such data. In the paper, an existing ontological model for cartographic urban themes, OGC CityGML, is extended, in order to propose a data schema for the management of architectural heritage multi-scale, multi-temporal and articulated data. The extended parts of the model are explained in the paper. Moreover, some implementation aspects are considered both for the definition of the ontological schema extension and for the management of the data using it.



## 1 INTRODUCTION

The management of spatial and geographic knowledge is becoming more and more discussed, since informatics technologies permit new advanced analysis and possibilities in information sharing. Contextually, some connected principles and concepts are highlighting new requirements for the knowledge and new needs for the data management. In particular, interoperability is a key issue, on which the idea of the Semantic web, smart cities and international standards are built (Barnaghi et al., 2012, Chourabi et al., 2012, Schaffers et al., 2011).

A unique frame is therefore needed in order to make the conceptualisations unambiguous. This can be solved through the use of ontologies (Guarino, 2009, Laurini, 2015) in order to reduce the risk of misinterpretation and possible consequent damages or loss of information (Guizzardi, 2005). Moreover, the definition of an explicit and shared data model permits to produce and share open data, with all the connected advantages (Janssen et al., 2012).

Therefore, the world of spatial knowledge management and geographical intelligence is developing tools for the realization of an effective "geoweb" (Laurini, 2014). We can see the effort in the directives of some national and international institutions dealing with cartography or environmental management: for example, the INSPIRE (INfrastructure for SPatial InfoRmation in Europe) European Directive is developed by the European Parliament and the Council of 14th March 2007 (Directive 2007/2/EC) (http://inspire.ec.europa.eu/). Equally, some consortiums of major stakeholders and actors of the sector are developing international industry standards, becoming the base for interoperability and open data. In this framework the OGC (Open Geospatial Consortium) (www.opengeospatial.org/) standards (among which the model for urban data CityGML) are conceived.

CityGML (http://www.opengeospatial.org/standards/citygml) is an open data model, an application schema (XSD) for GML files aimed at the representation, storage and exchange of 3D urban objects. The original aim (its history begins in 2007) was to foster the reusability of 3D city models. Its semantic definition can be equally useful to manage the semantics of the data with the tools offered by informatics and artificial intelligence.



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Some more examples can be seen in the opposite direction, that is, the effort of the world of semantic thematic data to include geographic information. For this reason, GeoSPARQL (http://www.opengeospatial.org/standards/geosparql) is developed by OGC as an extension of the W3C (World Wide Web Consortium) (www.w3.org/) SPARQL (SPARQL Protocol and RDF Query Language) (http://www.w3.org/TR/rdf-sparql-query/), which is the designed language to query RDF-structured data. It is considered for the inclusion of spatial data in RDF-OWL information.

These languages are defined by the cited organizations, and represent the crucial technology for the application of the theories of open-data and interoperability. Among these, markup languages allow to write content and provide information about which role the content plays using a both human and machine-readable format. In particular, XML (eXtensible Markup Language) (www.w3.org/XML/) is used as a metalanguage for markup: it provides a uniform framework, and tools for the interchange of data and metadata among applications. This is why XML is the base of most of languages born to structure open and application-independent data and exchange them through application or through the web. Some of relevant XML – based languages are for example RDF (Resource Description Framework) (www.w3.org/RDF/), which permits to manage semantic data (through a triple mechanism), OGC GML (Geographic Markup Language) (www.opengeospatial.org/standards/gml) to archive geographical objects, COLLADA (Collaborative Design Activity) (https://it.wikipedia.org/wiki/COLLADA**)**, which is an interchange format for 3D models, and so on. The structure of the XML-based files is defined in equally XML-based formats, such as simple XML Schema Definition (XSD), which is the one used by GML format, or extended ones such as RDFS (RDF Schema) - OWL (Ontology Web Language) (www.w3.org/2004/OWL/).

An example of geographic issues managed on the web using the described technologies is GeoNames (http://www.geonames.org/) which is a database including toponyms gazetteers and information related to the included named places.

Looking at the Cultural Heritage field, database interoperability and information retrieval have always been crucial aims for its documentation (http://www.icomos.org/en/charters-and-texts). It is indispensable the data to be unambiguous for permitting correct interpretation, and to be contextualized with metainformation.

The CIDOC (International Committee for Documentation) conceptual reference model (CRM), developed by the Commettee of the ICOM (International Council of Monuments) is considered the core ontology for Cultural Heritage (Doerr, et al., 2007). It uses RDF-OWL for the management of thematic data. It became standard ISO 21127.

A further existing database exploiting the described theories and technologies are a set of vocabularies developed by the Getty Institute (http://vocab.getty.edu/). These are oriented to structure Cultural Heritage related terms and items, and are divided in four vocabularies. Art and Architecture Thesaurus (AAT), structures hierarchically the terms linked to the description of the works of art and architectures. The Getty Thesaurus of Geographic Names (TGN) differently from GeoNames, includes also historical denominations. The Union List of Artist Names (ULAN) contains the names and synthetic information about the cultural heritage authors; and the Cultural Objects Name Authority (CONA), describes the different denominations of a cultural item over the time. In them the spatial component is not present, but they can be the reference for the denomination of parts which unequivocally have a spatial connotation (e.g. all the architectural parts or toponyms), or for related information (such as authors or object names).

Recently some effort has been done also to include geographic information in cultural heritage descriptions. Some localisation data is tried to be included in semantic structures: the Getty project ARCHES (http://archesproject.org, Myers et al., 2013), based on CIDOC-CRM structure integrates some WebGIS function; the CRMgeo project (Doerr et al., 2013) includes spatio-temporal representation potentiality in CIDOC-CRM.

However, these geographic references are often bi-dimensional and have little defined geometry (points, lines or approximate polygons), since the aim is not the analysis and reading of the artefact geometry, but its localisation for a territorial reading. Recently, another extension of the CIDOC CRM was realized: the CRMBA. It is expressly realized for the documentation of standing buildings (Ronzino et al., 2015). However, the gap in this research could be found in the management of complex 3D models in connection with other parts of the city and the landscape, which is a topic treated by CityGML.

For the particular needs of architectural heritage information management, 2D (often small-scale) data are not sufficient. 3D dense data have to be exploited with higher levels of detail (high measurements and georeferencing accuracies) and complex semantic definition (object-oriented structures) (Laurini, Thompson, 1992).

The availability of the 3D dense models is a reached aim of survey and geomatic discipline (Chiabrando, Spanò, 2013). However, the potentiality of management, analysis and editing typical of traditional GIS (Geographical Information Systems) are at present moment reduced for this kind of data. The development of new software structure or user interfaces are needed, based on adapted or new theoretical framework (Brahim et al., 2015, Solovyov, 2012), which again permit the usability of the systems in a real effective way.

### 1.1 Proposal Aims

In this research, a solution to the need of a data model for architectural heritage 3D high-level-of-detail data is proposed, by extending the existing structure OGC CityGML using its ADE (application domain extension) procedure.

CityGML was chosen as a base since it is a standardized model already dealing with buildings in their double dimensions: as a part of the city and as a higher detailed 3D object. It is important to consider this double nature also in architectural heritage emergences, because they are often both meaningful to the definition of the cultural values of the considered buildings. Moreover, CityGML includes the possibility to have multi-scale representations. The integration of the monument in wider maps of the city or the landscape, permits to perform strategic analysis in a broader context.

CityGML is shared as a data model, already in a potentially implementation-ready format. The UML (Unified Modelling Language) diagrams are published in the OGC encoding standard (OGC, 2012). They are already in an advanced phase of the data modelling process, since the database design details are specified as in a logic-level model (e.g. an object-oriented approach is envisaged and types of data and code-lists are defined). Moreover, the XSD files are shared and available for the direct use for implementation. However, for its generality in representing urban models, it can be considered an ontology (Métral et al., 2009, Kolbe et al., 2008). It is in fact independent from the specific applications for which it can be used and aims at representing a common frame for urban 3D maps data.

Therefore, for extending CityGML including structures for the management of spatial data complexity of architecture and monuments, some preliminary general reflections are reported, which can be valid as ontological-level thinking. However, the extension is then realized in accordance with the formats and structures used in CityGML (implementation-oriented), to be coherent with the extended model and for permitting the test also in the implementation.

However, some considerations and necessities of representation remain at present unimplemented, about more evolved constrains to be imposed to the model.

In a second part, the procedure followed for the implementation of the model is presented, highlighting some possibilities of use of the schemes for data archiving.

In the end, some part dealing with the kind of data to be managed is presented, taking in consideration the processing phases to be followed (from the processing of the 3D model to its semantic visualisation).

## 2 CITYGML CHADE (CULTURAL HERITAGE APPLICATION DOMAIN EXTENSION)

CityGML model can be extended in order to model further aspects linked to specific application domains. The so-composed extensions use specific characteristics and procedures of CityGML, being defined as ADE (Application Domain Extension). Some official ADEs exist (http://www.citygmlwiki.org/index.php/CityGML-ADEs). They regard especially some urban-scale themes, such as the noise, or the inclusive routing. Some of these are specific on buildings, for example GeoBIM integrates some classes derived from IFC (Industry Foundation Classes) (https://en.wikipedia.org/wiki/Industry_Foundation_Classes) standard used in BIM (Building Information Modelling) (de Laat, van Berlo, 2011). However, even if in the future probably the field of BIM (born to project new buildings) will meet GML models, at present it's too rigid for describing Cultural Heritage buildings, which need more flexibility.

A further research has been performed for the extension of CityGML model in order to include some information about the CH (cultural heritage) nature of the building and some surface characteristics, such as the deterioration (Costamagna, Spanò, 2013). In the model proposed in this paper, the characteristics of surface complexity are tried to be included. Moreover, some attention is drawn to the traceability of the stored information, in order to include in the data the elements useful to technicians for interpreting the stored information and evaluating the degree of fuzziness of the data.

In Figure 1 the CityGML Cultural Heritage Application Domain Extension (CHADE) for the building module of CityGML is summarized. It is then analysed in detail in the following subsection. The extension has been developed and will be tested on the building module; anyway, once its validity will be proved, its concepts and classes can be applied also to the other CityGML modules.

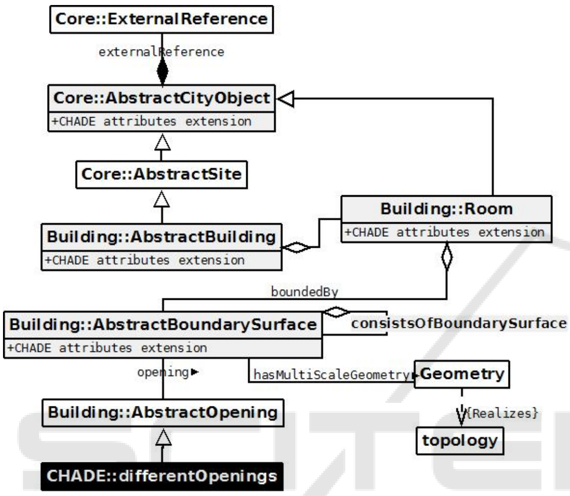


Figure 1: Synthesis of the CityGML CHADE in UML diagram. In white the CityGML classes, in grey (black for the whole class) the CHADE extensions and the inserted relations.

## 2.1 The CHADE Components: Research of Granularity, Flexibility and Traceability

From the general to the particular, the first problem was to include some attributes useful for the identification of the monument and some related information (if a CH declaration exists, what are the related documents, who are the owners and what is the preservation authority). Some of these have been borrowed from previous researches (Costamagna, Spanò, 2012), and extend the Core class "AbstractCityObject". It is possible to include this kind of extensions by means of composite attributes also in following phases, that is, the implementation of the model, since the XSD format permits to include complex attributes in the form of DataType, composed by a series of further attributes. Another interesting possibility for this case is the "ExternalReference" class, already in CityGML, which permits to relate the model with further databases managing data about the same object. For example, considering the management of the Versailles castle, the reference can be realized to the instance having ID:700000350 of the CONA vocabulary of the Getty Institute which describes it (http://www.getty.edu/cona/CONAFullSubject.aspx?subid=700000350).

The second issue is the extension of the attribute list for the "AbstractBuilding" class. In particular, its function and its denomination. Both these values are complex when regarding a historical item, since both can change over the time, and must be archived as a reference for researches and as an element for understanding the history of the building. Therefore, in implementation phase, for both a DataType is included. The BLDG_Function data type includes at first the function name (at present in English, specific future works with historians could further evaluate if considering different languages in order not to lose meaning nuances). The reference to the URI of the Getty Institute vocabulary AAT (Art and Architecture Thesaurus) follows, which includes the terms linked to the buildings function as subclasses of "single built works by function". The last two attributes are present almost everywhere in the detailed added data types, because they are of fundamental importance for historical data connotation. The time attribute is defined as a time object defined in the same GML general schema. It also could be defined as a TM_Object (time object) as stated in ISO TC211 ISO 19108:2006 Temporal Schema, but some incompatibilities among some ISO TC211 definitions and GML requirements persist (https://en.wikipedia.org/wiki/Geography_Markup_Language). Anyway, both schemas have issues for detailing the time considered, as a date, as a period, with different degree of fuzziness and with the possibility to establish a sort of topology for temporal data, in a temporal reference system. It is of obvious importance for managing historical data. The second attribute is "Source", which is detailed, in turn, in a data type, including metadata, reference to the source, codes for its identification and retrieval and the same attribute "time".

Similarly, the attributes of the class "Room" are extended, adding "RoomClass", "RoomFunction" and "RoomUsage", all with reference to the Getty AAT vocabulary URI. The "RoomUsage", which can change over the time, is detailed in a dedicated data type.

The, may be, more interesting part of the model is the extension of the CityGML class "AbstractBoundarySurface". In the original model it has no attributes, and can be specialized as belonging to the main parts of the buildings (e.g. RoofSurface, CeilingSurface, WallSurface…). The change of this class can permit to follow with a major flexibility the description of the parts of the buildings, which are stratified and articulated and even small portions can have different meanings. With "portions" also "fiat parts" (without "bona fide", that is defined, boundaries) are intended. Therefore, a recursive mereological "part of" relation is added from AbstractBoundarySurface to the same AbstractBoundarySurface. This permits to articulate the surfaces in hierarchical, semantically well-defined, multiscale and possibly topologically defined parts. Several attributes are added and defined following the already explained criteria. Among these, the "LevelOfSpecialisation" (LOS) attribute deserves an explication. The 3D models are usually considered for the geometric accuracy, which mainly derives from the production methods and measurements systems. This characteristic is stored in GML models as LOD (Level of Detail) associated to each geometry. Even if it implies some consequence on the level of semantic definition, it's mainly linked to the possibilities of representation offered by the available data, and thus to the accuracy and data density. The Level of Specialisation, in inserted in order to manage the possibility to define parts and subparts which can be recognisable on the same model (with homogeneous accuracy and LOD) but need to be separately specified because of the different meaning they assume if considered in the whole or as a singular part (Figure 2).

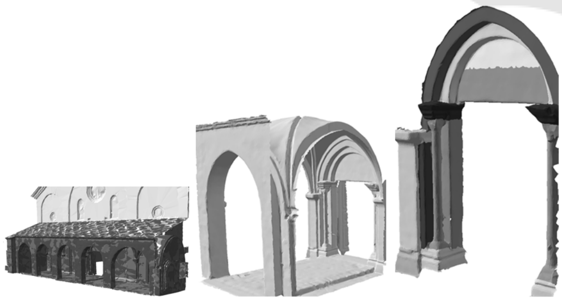

Figure 2: Examples of consecutive LOS specified on parts of a homogeneous-LOD 3D model. The colours represent the parts in which the object is divided.

A further extension of this class regards the associated geometric levels of detail: two more LODs are added, a LOD5, for approximately 1:50 scale and a LOD6 for bigger ones. The associated geometry class must be defined as a "Geometric complex::GM_CompositeSurface", since it is structured and hierarchical, in the same way as the boundary surfaces must be also semantically defined. Moreover, it has to be related to a "Topological Complex::TP_Complex", deriving from the "Topology" part of the standard ISO TC211 – ISO 19107:2003 Spatial Schema or the GML specification (they should be harmonised for the same issues regarding time objects). This last described part is complex to be used with current software and requests some more efforts. Anyway, the inclusion of the topological relations as schematized in Figure 3 should be useful for correctly set the models.

OGC has processed some topological and mereotopological structure for helping to correctly store the data, but they are already oriented to linked open data formats, without regarding GML (http://ows10.usersmarts.com/ows10/ontologies/).

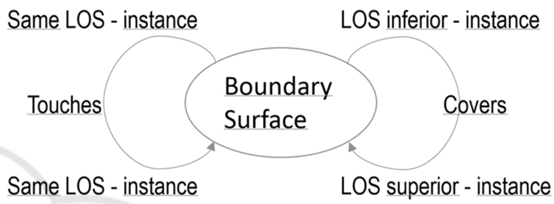


Figure 3: Schema of Egenhofer Topological Relations to be included in the model and verified. Some exception can exist (for example, a pillar can be considered only for one half as a component of a bay, admitted that they belong to the same classification), these must be so analysed in order to confirm or not the validity of this model. Egenhofer relations are considered even if they deal with 2D geometry, since an only reference surface is considered, although being a 3D surface.

## 2.2 Implementation Issues

Ontologies exploit object-oriented structures and systems, which are unusual in current and known GIS management systems: some of the most spread ones (PostgreSQL-PostGIS, ArcGIS Geodatabase tool, Oracle) implement object-relational systems, which are hybrid systems including some constructs of object-oriented databases, but not the whole potentiality. Some studies about the development of some semantic GIS have been performed, beginning in the mid-1990s (Mennis, 2003, Fonseca et al., 2002). In these studies, an object-oriented approach was used as an effective solution for expressing and storing the data meanings (Scholl, Voisard, 1992). In this way, even more powerful systems could be built with significant data interoperability and a reduction of any potential ambiguity. Anyway, at present moment few similar systems are available, preferring to use SQL-based implementations (Belussi et al., 2011). This is due to the necessity to adapt the exigencies to the available platforms and software systems and to the necessity to change the storing methods to permit the production and management of computationally heavy files. In next years probably the object-oriented GIS will be developed again or, some different interface from the GIS we know will be improved to include spatial analysis and query functionalities.

The described model has been implemented using the method defined as best practise by OGC (van den Brink et al., 2012). UML schemas are modified, which use stereotypes defined by a GML UML profile, so that their meaning can be understood by the machine and the performed transformation can be coherent and correct. In particular, for building the system the proprietary commercial software Sparx Systems – Enterprise Architect is used. Contrary to the indications of using open source software for managing public (and open) data, it is recommended also in some official occasions (for example for the management of INSPIRE schemas). The software permits to import existing models (in this case, obviously CityGML building module and some general schemas such as GML are used; also ISO 19108 for temporal objects and ISO 19107 for spatial issues could be considered). The classes, selected and imported in the new extension model, maintain all their characteristics and relations with the other parts of the model they belong to. This is crucial for not to create an isolated new model, but to be inserted in a complex existing framework.

From this basis, new classes can be added, the attributes can be defined and new relations can be established.

In particular, following the OGC best practise, for extending an existing class with further attributes, a subclass having the same name of the class to be extended and stereotype “ADEElement” should be created. The specialisation relation is marked with stereotype “ADE”. For adding a new class, a simple subclass having stereotype “featureType” must be added.

The so-formed model (Figure 4) can then be exported in different formats, including XSD for being used as a GML application schema. Other interesting formats are OWL, ArcGIS workspace and similar. From the XSD file also SQL (Simple Query Language) relational or object-relational database schemas could be generated, by passing through different software, such as Altova XMLSpy, which permits to manage XML documents. However, the passage from an object-oriented model to a relational one often requires some adapting transformations.

Contrary to what it seems, the passages are not so easy, or, better, they have to be controlled and corrected, since they need correct information or reference files describing, in the specific software-understandable language, how the transformation must be done. Some specific applications and proper UML profile exist for this aim, but they are not always easily available and compatible in any situation. Waiting for this progress, possibly planned as future work, the resulting files have to be corrected manually by editing the XML text following the rules for the ADEs realization.

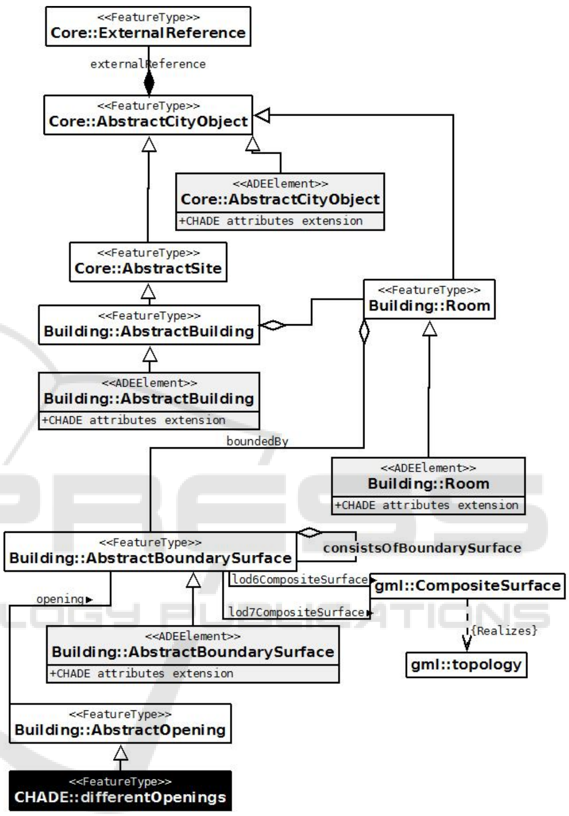


Figure 4: Synthesis of the UML model modified for extending CityGML – Building module in the CHADE, following the OGC best practise indication (Van den Brink et al., 2012).

## 3 PREPARING THE 3D DATA

For processing and interchanging the data about the paper case study, which is the medieval Staffarda abbey church (in the north-west of Italy) some of the previously described technologies are used. The main problems along the whole workflow are often linked to the inability of the software to manage some functionalities and algorithms and/or formats at the same time. For this reason, several passages in specific software are needed.

In this research, existing and available software are used, being not the implementation of new applications among the objectives. In particular, open source solutions are preferred, when possible, for interoperability and replicability issues.

When the schemas are ready, the dense high-level-of-detail 3D models have to be prepared. Since the managed surfaces are complex, being composed by miles of triangles (stored in form of rings composing a multiple composite surface), it's obviously not possible to store manually the singular points, but they have to pass through a series of phases which permit to export them in a GML format.

We will not describe here the acquisition and processing phases, which exploit a series of techniques for georeferencing the model in a known reference system (Chiabrando et al., 2013, Dabove et al., 2014), measuring points with various methods and variable accuracy and density (Bryan, Blake, 2000), processing the models for finally obtaining an integrated, correct, georeferenced and optimized 3D model (Figure 5) (Bastonero et al., 2014). We suppose then to start the process from this point.

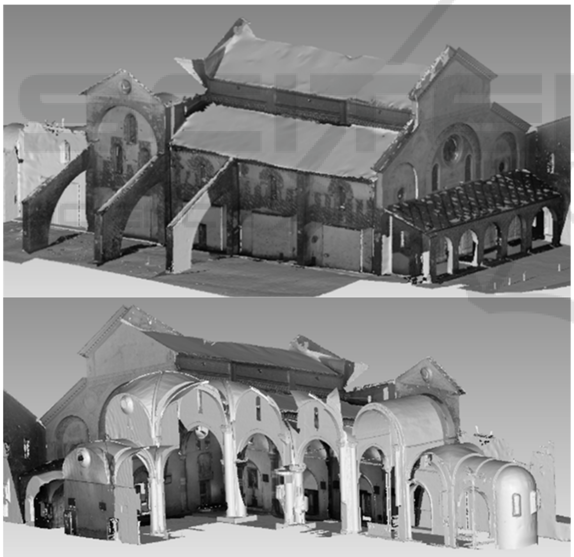

Figure 5: Views of the 3D model (textured mesh) of the Staffarda abbey church, processed using LIDAR acquisitions integrated with photogrammetric data acquired from UAV (Unmanned Aerial Vehicle) (Bastonero et al., 2014).

The first editing phases to be performed on the models regard on the one hand the reduction of its points, caring the conservation of the original definition (Figure 6). This process can be performed using different algorithms, not always known in proprietary software. Anyway, the topic should be further analysed in order to establish the methods and the limits of this practise.

On the other hand, the model must be segmented, so that every part must be isolated from the other for being suitably managed geometrically and semantically (Figure 7); moreover, the temporal connotation must be considered in the segmentation, since it is essential for historical objects (Donadio, Spanò, 2015). A surface can be eventually repeated if it is part of more than one instance having different LOS as attributes. Also this field can offer a quantity of techniques which should be analysed for finding the most suitable one.

Figure 6: 3D models of the church façade before (first image) and after (second image) reduction.

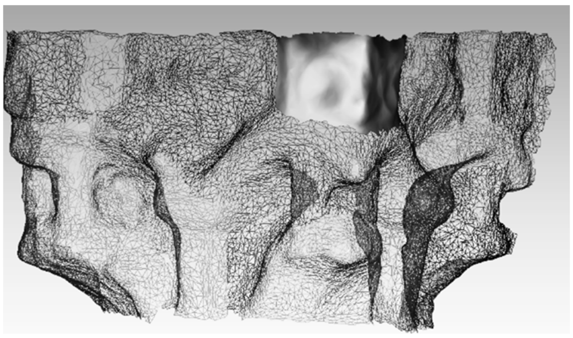

Figure 7: 3D model of one segmented capital (a segmented part is highlighted with textured representation).

These phases can be performed in 3D model processing and editing software, such as Hexagon 3D Reshaper (proprietary software), which has the advantage of managing coordinates, which have high values such as cartographic ones, therefore georeferenced models can be directly managed. Moreover advanced editing tools are integrated in it.

At this point, two main alternatives are available for translating the 3D model into a CityGML-compliant format. The first one is the use of Safe Software FME (again a proprietary software), which is expressly dedicated to these operations. The second option is the use of ESRI ArcGIS, which is equally a proprietary software, but being widely spread, its formats and procedures are often considered as de-facto standards. This last one is used in this case for this reason, even if the passage from an ESRI shapefile format, which is based on a relational model, doesn't give the possibility to directly specify the final structure of the data. Anyway, also the ESRI processing integrates the FME algorithms in the ArcGIS "Data Interoperability Toolbox" extension.

For using the processing integrated in ESRI ArcGIS, some more passages are necessary. The processed 3D model must be exported in COLLADA format for the following transformation. This open exchange format is not managed by some proprietary software, therefore the model must be exported in 3D model format (such as OBJ or PLY) and reimported in further software able to do the exportation. For example, the open source software MeshLab can do that. The problem is that it has difficulties in managing high coordinate values, so that the whole model must be translated near the origin for this passage. The exported COLLADA files can be then reimported in ESRI ArcGIS, as multipatch shapefiles (ESRI, 2008). Here they have to be retranslated to their original position in georeferenced coordinates, and can be exported, through the "Data Interoperability" toolbox to a generic CityGML file. The result is the inclusion of the geometry and the attributes of the single parts of models in files structured as CityGML and semantically classified as "GenericCityObjects". The GML file (readable as XML structured text) has to be manually modified for including in the description schema the CHADE and to correctly define the semantics of each part.

In particular, the reference to the extension namespace must be added in the heading of the file, since there is no way of modifying the FME libraries (used directly or through ArcGIS toolbox) for including the extensions. Moreover, each segmented part of the multipatch is exported as a distinct object having a geometry attribute (in form of gml::MultiSurface), but they are not hierarchically structured and they haven't a specific semantic yet (being all "GenericCityObjects"). Therefore, the hierarchy must be set and the correct labels must be applied following the CityGML file format. Moreover, all the textual attributes must be manually filled in. In this phase it is obviously considered the extended model CityGML+CHADE. Another important issue is to add suitable identifiers, in order to uniquely identify the objects for query performing and information retrieval and for realizing some connections, for which for example Xlink syntax (which requires IDs for linking to specific objects) are used. It is preferable if the IDs are composed in form of URIs (Unique Resource Identifiers), following the rules used in best practises also in linked data environment (van den Brink et al., 2014). In this way, the produced information could be more easily translated to linked data for the effective sharing and processing through the Semantic Web.

The Xlink syntax can also be considered and used for the establishment of mereo - topological relations among the parts.

XML processing softwares (some used alternatives can be, for example, the proprietary software ALTOVA XMLSpy or the open source software Xpad) can validate the obtained GML file.

## 4 RESULTS: THE ARCHIVE IN A GRAPHICAL INTERFACE

At this point, the GML file could be shared through the web and read by several applications or interfaces for being consulted and analysed.

In this case, an open source software was used and tested in order to read the GML archive based on CityGML CHADE. An open source software was chosen for two main reasons: first, for the already cited goals of interoperability and replicability of the procedures; secondly, because the open source software often permit to access the source code of the libraries they use, and possibly modify them. This is useful in order to include the CHADE schema for the correct interpretation of objects that refer to it.

The FZK software (http://www.iai.fzk.de/www-extern/index.php?id=2315) was used, which is one of the more developed available CityGML viewers. It includes the schemas of some versions of CityGML, and also some official CityGML ADE (e.g. the Noise ADE). Furthermore, it has an open structure, which can be customized by adding, for example, other CityGML schemas to be used. For this research the

CHADE schema (in XSD) was added in the directory of the reference files of the software for the described data to be interpreted. This is unequivocally an advantage of the open structure of the software.

At this point the software can read the processed GML archive (Figure 8).

In the visualization platform the object inserted in the archive can be read, including the relationships among them (Figure 9), some measurements can be directly made on the 3D model (Figure 10) and some thematic visualization can be generated similarly to GIS management software environments (Figure 11). Moreover, statistics about the data are computed.

However, the application should be developed in order to include the possibility to effectively manage some elements introduced by the extension, for example the inclusion of different addresses (referred to the building but also to the owners, the authority, etc.) gives sometimes problems in their visualization. In the same way the links inserted in the GML file for cross-referring the objects or for inserting references to external resources (for example the Getty vocabularies) don't function in the software, because probably some change in the reading of such components should be done.

Equally, the levels of detail that can be visualized are limited to the ones envisaged by CityGML. For including the more detailed ones added in the CHADE, the application should be modified not only by adding the schemas but even in its tools and interface code.

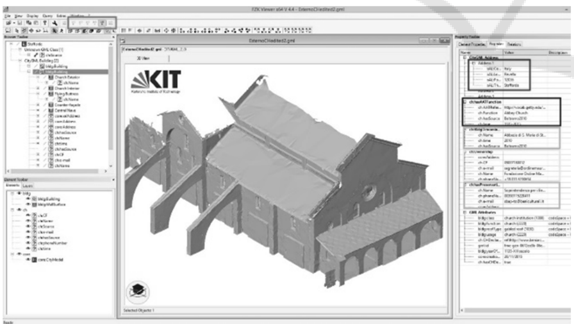

Figure 8: GML model structured using the CityGML CHADE in the FZK software interface: on the left, the objects in the model are listed, in the centre the 3D model is visualized and, on the right, the properties can be read. The attributes, which are, in turn, objects themselves or data types (and are therefore composed by a set of attributes) are highlighted by the frames. The level of detail to be visualized can be chosen, since the data are multi-scale (in the left part of the toolbar, framed in the figure).

Also the possible thematic visualizations are limited to some attribute of CityGML and don't consider the ones introduced by the extension. The same is for the statistics and analysis that can be performed, which are limited to some pre-set parameters and it would be interesting to enhance them.

However, these limits are connected to the visualization platform, while the previously structured GML file is independent from them.

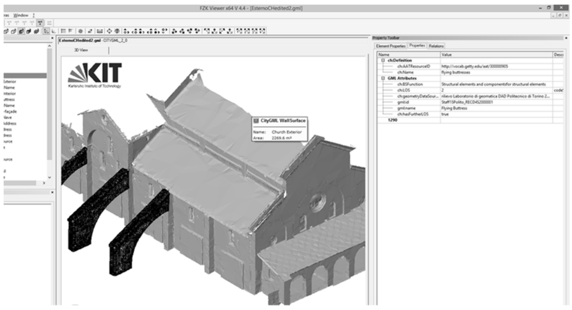

Figure 9: On the right box ("relations" window) it is possible to select and visualize related objects (geometry and thematic attributes). In the image, the result of the relation of the whole object to one of its parts (the flying buttress). They are selected in the representation and the attributes are listed in the right part.

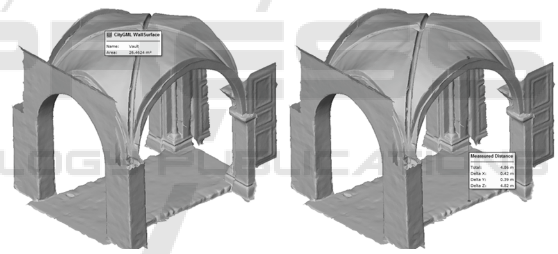

Figure 10: Example of direct measurements possibilities on the 3D model: areas and distances. This can be extremely useful for architectural heritage researchers and operators.

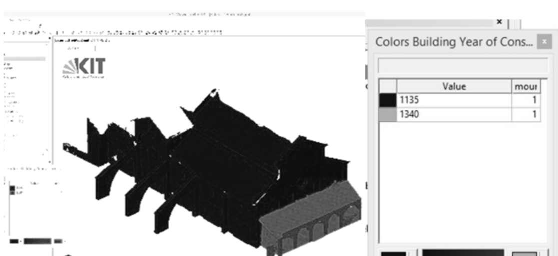


Figure 11: Example of thematic visualization (based on the attribute "year of construction").

# 5 DISCUSSION AND PERSPECTIVES

In the framework of interoperability established by the Semantic web theories and the world of standards, the establishment of reference domain ontologies become critical. Since a model for architectural heritage lacked, several standards dealing with building, landscape or city representation and cultural heritage management were considered as starting point for an extension or for their reciprocal integration. Finally, the OGC CityGML model was chosen as ontology for representing buildings. It is considered an ontology for being specific application – independent, even if implementation issues are proposed in the published standard.

An extension of the CityGML model has been proposed and tested in order to manage complex and multi-scale 3D models. This considers some important aspects of the architectural heritage both from the spatial and thematic points of view.

The conceptual definition was implemented using some existing tools, proposed as standard best practise. However, some passages result still difficult and the products need to be refined manually by editing the resulting XML file for obtaining a valid XSD. Future improvements will deal with the major control and automatization of the processes.

Similar considerations can be done for the management of the 3D models, which requires complex steps, possibly through different software for being prepared. In the end, a final manual editing of the GML file is equally necessary. This could be generally due to the closed source of proprietary software, which does not permit to modify the used libraries for inserting the extension of the model. In the meantime, there is little alternative to their use.

The fact that the editing of results is possible using XML language is beyond doubt an advantage, because it requires basic tools (even a simple text-editor could be effective), on the other hand, the required skills are not within everyone's reach.

However, a solution is proposed for managing the complex and multifaceted data about architectural heritage. Important aspects are cared, regarding the granularity of the information, its traceability, which is essential when dealing with historical items, the flexibility of the model, to adapt to the representation of such unique artefacts as monuments are, and the inclusion of thematic data with eventual reference to external databases and vocabularies.

The realization of standardized datasets using ontologies permits to perform automated reasoning on the information, in particular if shared on the web. Furthermore, the use of ontologies enables the interoperability of databases and the information retrieval through the semantic web. This represents obviously a great opportunity for research and preservation issues, but also for management, tourism, risk analysis and further connected activities.

The archive at present can be used in applications similar to the known GIS, for surfing the archive, realizing queries, applying symbols, measuring the model. However, also the available platforms should be modified and improved in order to permit a wider range of analysis and statistics and to include enhanced visualisation options.

Future work will be aimed first at including the real management of topology and mereo-topological constraints in the models and in the data, for enhancing the analysis potentialities and transversal information retrieval.

A further improvement will affect the connection with external reference to vocabularies (possibly using methods similar to the use of gazetteers for toponyms) and the inclusion or link to further data models and ontologies: for example, the connection to the CIDOC CRM is of primary importance.

Moreover, the translation of the model and of the dataset as linked open data will be essential to better exploit the Semantic Web technologies and to connect to similar information. This also will be a future development of the proposal.

When these aspects will be solved, it will be a further step towards the world-wide management of the architectural heritage data in an effective framework for their preservation, retrieval and analysis.

# REFERENCES

Barnaghi, P., Wang, W., Henson, C., Taylor, K., 2012. Semantics for the Internet of Things: early progress and back to the future. In *International Journal on Semantic Web and Information Systems (IJSWIS)*. 8 (1). p.1-21.

Bastonero, P., Donadio, E., Chiabrando, F., Spanò, A., 2014. Fusion of 3D models derived from TLS and image-based techniques for CH enhanced documentation. In *ISPRS Annals of the photogrammetry, remote sensing and spatial information sciences.* 2. p.73-80.

Belussi, A., Liguori, F., Marca, J., Migliorini, S., Negri, M., Pelagatti, G., Visentini, P., 2011. Validation of geographical datasets against spatial constraints at conceptual level. In *UDMS 2011: 28th Urban Data Management Symposium, Delft, The Netherlands, September 28-30, 2011.* Urban Data Management Society, OTB Research Institute for the Built Environment, Delft University of Technology.

Brahim, L., Okba, K., Robert, L., 2015. Mathematical framework for topological relationships between ribbons and regions. In *Journal of Visual Languages & Computing.* 26. p.66-81.

Bryan, P., Blake, B., 2000. *Metric survey specifications for English Heritage*. English Heritage.

Chiabrando, F., Lingua, A., Piras M., 2013. Direct photogrammetry using UAV: tests and first results, In: *ISPRS International Archives of the photogrammetry, remote sensing and spatial information sciences*. XL-1/W2. ISSN: 2194-9034. p.81-86.

Chiabrando, F., Spanò, A., 2013. Points clouds generation using TLS and dense-matching techniques. A test on approachable accuracies of different tools. In *ISPRS Annals Of The Photogrammetry, Remote Sensing And Spatial Information Sciences.* 5. p.67-72.

Chourabi, H., Nam, T., Walker, S., Gil-Garcia, J. R., Mellouli, S., Nahon, K., Scholl, H. J., 2012. Understanding smart cities: An integrative framework. In *System Science (HICSS), 2012 45th Hawaii International Conference* on. IEEE. p.2289-2297.

Costamagna, E., Spanò, A., 2013. CityGML for Architectural Heritage. In *Developments in Multidimensional Spatial Data Models*. Springer Berlin Heidelberg. p.219-237.

Costamagna, E., Spanò, A., 2012. Semantic models for Architectural Heritage documentation. In *Lecture Notes in Computer Science.* Springer. p.241-250.

Dabove, P., Manzino, A. M., Taglioretti, C., 2014. GNSS network products for post-processing positioning: limitations and peculiarities. In *Applied Geomatics*. 6(1). p.27-36.

De Laat, R., Van Berlo, L., 2011 Integration of BIM and GIS: The Development of the CityGML GeoBIM Extension. In *Advances in 3D Geo-Information Sciences*. LNG&C. p.211-225.

Doerr, M., Hiebel, G., Eide, Ø., 2013. CRMgeo: Linking the CIDOC CRM to geoSPARQL through a spatiotemporal refinement. In *Institute of Computer Science, Tech. Rep. GR70013*.

Doerr, M., Ore, Ch.E., Stead, S., 2007. In The CIDOC Conceptual Reference Model - A New Standard for Knowledge Sharing. In *Tutorials, posters, panels and industrial contributions at the 26th International Conference on Conceptual Modeling.* ACS. 83. p.51-56.

Donadio E. and Spanò A. (2015). Data Collection and Management for Stratigraphic Analysis of Upstanding Structures. In *Proceedings of the 1st International Conference on Geographical Information Systems Theory, Applications and Management*. ISBN 978-989-758-099-4. p.34-39. DOI: 10.5220/0005470200340039.

ESRI, 2008. *The Multipatch Geometry Type*. ESRI White Paper. Available from: https://www.esri.com/library/whitepapers/pdfs/multipatch-geometry-type.pdf [Accessed on 12/11/2015.

Fonseca, F., Egenhofer, M., Davis, C., Camara, G., 2002. Semantic granularity. In *Ontology-driven geographic information systems.* AMAI Annals of Mathematics and Artificial Intelligence, 36 (1-2). p.121-151.

Guizzardi, G., 2005. *Ontological foundations for structural conceptual models*. CTIT, Centre for Telematics and Information Technology.

Guarino, N., Oberle, D., Staab, S., 2009. What is an Ontology?. In *Handbook on ontologies,* Springer Berlin Heidelberg. p.1-17.

Janssen, M., Charalabidis, Y., Zuiderwijk, A., 2012. Benefits, adoption barriers and myths of open data and open government. In *Information Systems Management*, 29(4). p.258-268.

Kolbe, T. H., Gröger, G., Plümer, L., 2008. CityGML–3D city models and their potential for emergency response. In Zlatanova, S., Li, J. (eds.). *Geospatial information technology for emergency response*. CRC Press.

Laurini, R., 2015. Geographic Ontologies, Gazetteers and Multilingualism. In *Future Internet.* 7(1). p.1-23.

Laurini, R., 2014. A conceptual framework for geographic knowledge engineering. In *Journal of Visual Languages & Computing.* 25(1). p.2-19.

Laurini, R., Thompson, D., 1992*. Fundamentals of spatial information systems*. Academic Press.

Mennis J.L., 2003. Derivation and implementation of a semantic GIS data model informed by principles of cognition. In *Computers, Environment and Urban Systems.* 27. p.455-479.

Métral, C., Falquet, G., Cutting-Decelle, A. F., 2009. Towards semantically enriched 3D city models: an ontology-based approach. In *Academic track of geoweb.*

Myers D., Avramides Y., Dalgity A., 2013. Changing the Heritage inventory paradigm, The ARCHES Open Source System. In *Conservation Perspectives, The GCI newsletter.* 28(2).

OGC, 2012. *CityGML UML diagrams as contained in CityGML Encoding Standard Version 2.0,* OGC Doc. No. 12-019.

Ronzino, P., Niccolucci, F., Felicetti, A., Doerr, M., 2015. CRMba a CRM extension for the documentation of standing buildings. In *International Journal on Digital Libraries.* p.1-8.

Schaffers, H., Komninos, N., Pallot, M., Trousse, B., Nilsson, M., Oliveira, A., 2011. Smart Cities and the Future Internet: Towards Cooperation Frameworks for Open Innovation. In *Future Internet Assembly*. 6656. pp.431-446.

Scholl, M., Voisard, A., 1992. Object-oriented database systems for geographic applications: an experiment with O2. In *Proc. Int. Workshop on Database Management Systems for Geographical Applications.* Springer.

Solovyov, S. A., 2012. Categorical foundations of variety-based topology and topological systems. In *Fuzzy Sets and Systems*. 192. p.176-200.

Van den Brink, L., Janssen, P., Quak, W., & Stoter, J. E. (2014). Linking spatial data: automated conversion of geo-information models and GML data to RDF. In *International Journal of Spatial Data Infrastructures Research.* 9, 2014.

Van den Brink, L., Stoter, J. E., Zlatanova, S., 2012. Modelling an application domain extension of CityGML in UML. In *ISPRS Conference 7th International Conference on 3D Geoinformation, The International Archives on the Photogrammetry, Remote Sensing and Spatial Information Sciences.* XXXVIII-4, part C26, 16–17 May 2012, Québec, Canada. ISPRS.
http://inspire.ec.europa.eu/ [Accessed on 11/11/2015]
www.opengeospatial.org/ [Accessed on 11/11/2015]
http://www.opengeospatial.org/standards/geosparql [Accessed on 12/11/2015].
www.w3.org [Accessed on 09/11/2015].
http://www.w3.org/TR/rdf-sparql-query/ [Accessed on 12/11/2015].
www.w3.org/XML/ [Accessed on 09/11/2015].
www.w3.org/RDF/ [Accessed on 10/11/2015].
www.opengeospatial.org/standards/gml [Accessed on 12/11/2015].
https://it.wikipedia.org/wiki/COLLADA [Accessed on 12/11/2015].
www.w3.org/2004/OWL/ [Accessed on 11/11/2015].
https://it.wikipedia.org/wiki/COLLADA [Accessed on 11/11/2015]
http://www.geonames.org/ [Accessed on 12/11/2015].
http://www.icomos.org/en/charters-and-texts [Accessed on 11/11/2015].
http://vocab.getty.edu/ [Accessed on 12/11/2015].
http://archesproject.org [Accessed on 09/11/2015].
http://www.opengeospatial.org/standards/citygml [Accessed on 10/11/2015].
https://en.wikipedia.org/wiki/Industry_Foundation_Classes [Accessed on 09/11/2015].
http://ows10.usersmarts.com/ows10/ontologies/ [Accessed on 11/11/2015].
https://en.wikipedia.org/wiki/Geography_Markup_Language [Accessed on 16/11/2015].
http://www.citygmlwiki.org/index.php/CityGML-ADEs [Accessed on 17/11/2015]
https://en.wikipedia.org/wiki/Industry_Foundation_Classes [Accessed on 17/11/2015]
http://www.getty.edu/cona/CONAFullSubject.aspx?subid=700000350 [Accessed on 15/02/2016].
http://www.iai.fzk.de/www-extern/index.php?id=2315 [Accessed on 15/02/2016].