SIGA3D: A Semantic BIM Extension to Represent Urban Environnement

An ontology-based management of level of details

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Abstract— **This paper presents a new architecture dedicated to the management of buildings and urban objects through a 3D digital mockup. We focus on the ontology-based framework of this architecture, and the semantic LoD (Level of Detail) mechanism defined to build dynamically the 3D scene from a set of heterogeneous information systems. This project is developed into an industrial web platform which manages more than 100 million square meters of buildings.**

Keywords- Interoperability; Semantic Heteogeneity; ontology; used profil; Building Information Modelling; Geographic Information Systems

I. Introduction

Today, at a time when environmental issues are becoming more insistent, ways to control costs in the management and development of a territory are increasingly sought. This may involve the facility management of a set of buildings that one wishes to identify and observe to limit the costs of maintenance or the creation of new entities to anticipate the ecological and economic impacts. These goals require a lot of heterogeneous information on assets to manage, at several moments of their life cycle. This unification is an expensive process which is not always adapted to the trends of the trade or the market. The global information system becomes quickly obsolete and unsuited regarding the data model evolutions and improvements. In order to unify and centralize the management of real estate, urban and extra urban, it is necessary to develop a new form of collaborative architecture. This architecture makes it possible to combine in a homogeneous environment a set of heterogeneous information from diverse information systems such as those from the Building Information Modeling (BIM) domain and the Geographical Information Systems (GIS) domain.

The term BIM has been coined recently to demarcate the next generation of Information Technologies (IT) and Computer-Aided Design (CAD) for buildings, which focus on drawing production. BIM is the process of generating, storing, managing, exchanging and sharing building information in an interoperable and reusable way. A BIM system is a tool that enables users to integrate and reuse building information and domain knowledge throughout the building life cycle [2].

GIS are becoming a part of mainstream business and management operations around the world in organizations both in public and private sectors. The term GIS refers to any system that captures, stores, analyzes, manages, and presents data that are linked to at least one location.

Since 2008, we develop a collaborative web platform dedicated to urban facility management. This approach is based on a semantic architecture using ontology evolution mechanisms. The content of this ontology can be displayed in a real time 3D viewer we have developed. This one allows the management of a large number of objects in scenes and the management of geocoding objects by implementing a mechanism of geometric Levels of Details (LoD). In our architecture, we introduced also a semantic multi-representation mechanism (i.e. several semantic definitions of a concept depending of local contexts).

This approach of multi-representation adds to the traditional principle of LoD the notion of Contextual LoD (C-LoD). A C-LoD is a geometric representation of an object which is selected according to semantic criteria and not only displayed depending on the distance between the view point and the object as it is usually the case for LoD. The criteria may depend on user (we defined a profile in which we can find various information like the business process to which he is attached), external criteria as day/night or weather, or even of the object itself (intrinsic properties such as material, temperature, etc.). The semantic management drives streaming processes, which extract the knowledge and 3D representation of urban objects from a relational database. Moreover, all the technologies used to build our framework architecture attempt to be as compatible as possible with the standards in use in the semantic, geospatial and BIM worlds. This allows us to bridge the gap of interoperability meet at different levels when working with several data sources coming from several domains.

II. Semantic Representation of Urban Environment

Our proposal is based on a semantic architecture articulated in 6 levels (Fig. 1). The import/export level is dedicated to the parsing of various file formats required to model a complete urban environment from different sources (GIS/BIM). This can be done from local files or Web Services. The Data Model Framework (DMF) level makes it possible the combination of geometrical data and semantics.

The level "Contextual View" associates user profiles and business rules to build C-LoDs. The connection level is mainly dedicated to the streaming process between the databases and the interface. The interface level displays the urban environment into a 3D digital mockup coupled with a semantic tree of urban elements.

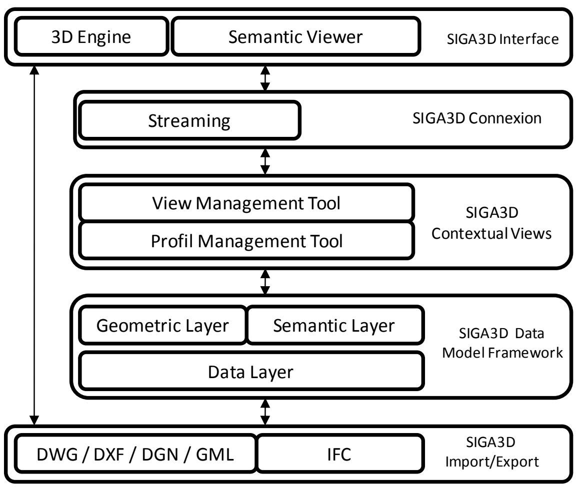

Fig. 1. SIGA3D Architecture**.**

The innovative feature of this architecture is mainly contained in the DMF level and Contextual Views level. These levels are the base of our semantic C-LoD proposal. The DMF level is made of graphs representing the ontology, allowing the context management and versioning of the data (through CMF for Context Model Framework which matches with the Contextual Views layer of the Figure 1). Graphs operators are defined to facilitate the implementation of changes in conceptualization. Information about reference systems for space and time (Coordinate Reference System (CRS) and TimeZone) are also managed in this part. The other part, DMF, defines a unified syntax-based knowledge representation based on the languages OWL, RDFS, and rules RuleML, SWRL and described in this document in an expressive way with description logic. DMF also contains operators for the management of space and time and the definition of local contexts that allow us to conduct a multi-representation of data. The goal of this part is to provide models used in an inference engine to infer and to check the data modeled by the C-DMF (Context-Data Model Framework which include CMF and DMF) modeling operators.

III. SIGA3D DATA MODEL FRAMEWORK

The Data Model Framework is made of operators to construct urban data models. These operators allow the description of classes and properties that can be used to define complex concepts using operators of intersection, union, involvement, etc.

dmf:Class defines a class.
dmf:Property defines a property.
dmf:Var defines variables used in the logical formulas.
dmf:Predu defines unary predicates.
dmf:Predb defines binary predicates.
dmf:Equiv defines two predicates as equivalent.
dmf:And defines the intersection.
dmf:Not defines the negation.
dmf:Or defines the union.
dmf:OrX defines the exclusive disjunction.
dmf:Diff defines the difference.
dmf:Imp defines the implication. It is used to represent various operators like sub-property, restriction, transitivity, symmetry, functional property, etc.
dmf:spatialEntity defines a geometric representation. This operator refers to a geometrical representation of the object with IFC or CityGML standard.
dmf:temporalEntity defines an instant or an interval of time.

The spatial data and especially georeferenced coordinates do not make sense without the knowledge of the coordinate reference system. This information appears in the upper layer of our architecture that manages the context of model graph, to unify the management of coordinates. The same kind of information is provided for time, with the management of Time zones.

The management of local contexts, which allows multi-representation, is done in this part by defining new stamped operators (based on the mechanism described in the part V of this article), corresponding to the DMF operators defined above. For example, the script 1 defines three local contexts, *designer*, *structureEngineer* and *March*.

```
<dmf:Class rdf:ID='Profession'/>
  <Profession rdf:ID='designer'/>
  <Profession rdf:ID='structureEngineer'/>
<dmf:temporalEntity rdf:ID='achievementDate'/>
<dmf:property rdf:ID='unitType'/>
  <Day rdf:ID='March'>
    <unitType rdf:resource='#unitMonth/>
   </Day>
```

Script 1. Definition of local contexts.

We can then define several properties and a spatial representation for a class '*buildingPlan*' which depends of the user. In the script 2, the contextual operators *dmf:[*c_1*, …,*c_n *]Class*, *dmf:[*c_1*, …,*c_n *]property* and *dmf:[* c_1*, …,*c_n*] spatialEntity* are used.

```
<dmf:Class rdf:ID='BuildingPlan'/>
<dmf:[designer]property rdf:ID='line_thick'/>
<dmf:[structureEngineer]property
       rdf:ID='wall_material'/>
<dmf:[designer]property rdf:ID='contains_plan'/>
<dmf:[designer,structureEngineer]property
             rdf:ID='contains_plan'/>
<dmf:spatialEntity rdf:ID='the_plan'/>
<dmf:[designer]property rdf:ID='3D_plan'/>
```

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```
<dmf:[designer,structureEngineer]property
rdf:ID='2D_plan'/>
  <the_plan rdf:ID='plan_of_building_1'>
   <url_2D_plan
      rdf:resource='/building/1/plan/plan2D.dwg'/>
   <url_3D_plan
      rdf:resource='/building/1/plan/plan3D.ifc'/>
  </the_plan>
<dmf:[designer,March]Class
       rdf:ID='Plan_availability'/>
    <BuildingPlan rdf:ID='building_plan_1'>
    <line_thick rdf:dataType='&xsd;float'>10
    </line_thick>
    <wall_material rdf:dataType='&xsd;float'>wood
    </wall_material>
    <contains_plan rdf:resource='the_plan'/>
  </BuildingPlan>
```

Script 2. Use of contextual operators.

This example describes an object, *BuildingPlan*, which has several properties. For a designer, the *BuildingPlan* is defined with a *line_thick* and a *plan* contains two representations. The same object is defined differently for a structure engineer, with the material of walls, *wall_material*, and an attached plan with only one 2D representation. The figure 2 shows another example of multi-representation on a building storey. On the left part we have a structural view of the building according to the bricklayer context, and on the other side we can see a woodwork view (flooring, windows, doors and stairs) according to the joiner context (right part).

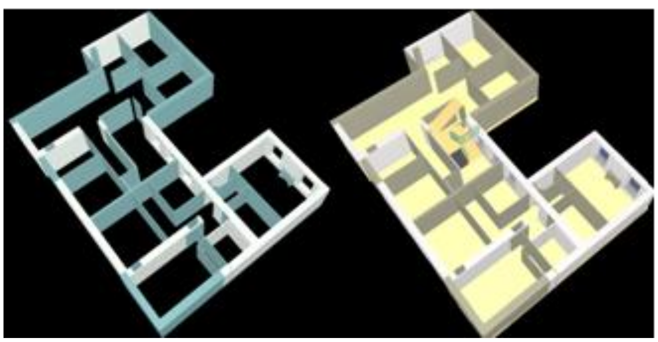

Fig. 2. Example of semantic multi-representation of a building.

IV. SIGA3D CONTEXT MODEL FRAMEWORK

This part of our architecture is composed of three main blocks. The first block sets the context for each graph of DMF. The second block defines a set of graph operators to facilitate the writing of information and limit the redundancy of data in the context management. Then the third block defines a set of operators on graphs to describe more accurately the geographical information by defining spatio-temporal relations between different data models of DMF. Context management in this architecture is done by defining a special graph called *SystemGraph*. A *SystemGraph* defined the context for a graph or a set of graphs using operators. These operators can be applied on graphs defined in the second block of the CMF. The use of these operators can simplify the management of the evolution of knowledge of the model. Indeed, rather than storing for each modification of the model a new version of the complete graph, the CMF layer stores the modification as operations on graphs. The *SystemGraph* can be described using the following operators:

- *cdmf:graph* connects graph and data. These data are described according to the data model. They can be a combination between other graphs using the CMF graph operators *AddGraph* (union of graphs), *RemoveGraph*, *InterGraph*, *CompInterGraph* and *MapGraph*. These operators allow us to improve the modification tracking of the ontology by limiting the size of the graphs and their reusability.
- *cdmf:of* represents the context. This property defines a list of resources representing the access context.
- *cdmf:model* refers to the data model which is used. This data model defines elements which will appear in the graph.
- *cdmf:action* defines user's rights to access the data (read/write/remove). If no action is defined in the system Graph, which means that only the visualization of the data is allowed.
- *cdmf:synchronizationGraph* defines a list of graphs linked with the element *cdmf:graph* by all kind of spatial and temporal relationship.
- *cdmf:reference_frame* defines the TimeZone and the CRS used for the data model associated to the *SystemGraph*. These values are valid for all data of associated graphs. This means that if original data sources are not defined in the same CRS, a transformation of coordinates has to be done before using the data.

The spatio-temporal synchronization is not a common graph operator and is very specific to the description of geographical information. It allows defining the validity of a model by describing relationships with other models. It can be used in case of model evolution to assure the consistency of the global model. For instance, if we define a building model and an electric power network model, it is possible to describe a topological relation between the two models to say they are spatially connected. Then, if one of the models is modified, for example, to move the building in the case of a bad georeferencing, the other model has to be modified to keep the spatial connection relation consistent.

V. PRINCIPLE OF SEMANTIC MULTI-REPRESENTATION

The principle of multi-representation can consist to display different maps of different scales for a same place, or to simplify the geometry of an object depending of geometric criteria such as distance or size. This is the well-known mechanism of LoD in GIS. To this geometric

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definition of multi-representation, we propose to add a semantic dimension. This semantic multi-representation allows a user to display information in a form that suit him (contextual view), or to make a control on access of the modeling data. The combination of these two types of multi-representation is an innovative aspect of our approach. It gives the new concept of C-LoD, representations that would be displayed according to semantic criteria.

To implement this new mechanism, it is needed to have a formalization of the multi-representation system in a semantic way. The works based on the MADS approach by [8] and later by [1] define a multi-representation formalism in ontologies. This approach is based on a stamping mechanism of the representations. In our architecture, stamps can be defined with any element of the DMF layer and especially spatial and temporal elements. Moreover, stamps can be applied on every element and operators of the DMF layer, such as data, instance of types and values of attributes, meta-data, and definition of a type or an attribute of the schema. The local context mechanism of the building and urban modeling architecture is based on this formal approach. Associating to the concept of local context, it is used to define contextual operators to model these contexts. A part of these operators is already defined in the BIM part with the possibility to build contextual view.

The next step required is the definition of operators for GIS domain. Thus, the local context can be also defined with spatiotemporal operators to describe the objects depending on space and time, an important dimension of GIS.

VI. DISCUSSION

Interoperability may be defined as "the ability of two or more systems or components to exchange information and to use the information that has been exchanged" [4]. Systems that can exchange data are syntactically interoperable: they share a common structure, with agreed-upon data formats and communication protocol. Syntactical interoperability is a prerequisite for further interoperability. The ability for systems to interpret automatically the exchanged information is known as semantic interoperability. The same meaning can be derived from the data at both ends. This implies that the systems share a common information model, where each element of the model is precisely defined. In a world where software vendors have implemented products tailored to the needs of specific communities and/or customers, standardization is the most efficient and global solution to interoperability problems [10]. Several organizations, industry consortiums and communities are involved in standards development activities related to urban matters:

- ISO/TC 211 (International Organisation for Standardization / Technical Committee 211, http://www.isotc211.org/) - Geographic Information and Geomatics is responsible of standards for geospatial information;
- Open Geospatial Consortium (OGC, http://opengeospatial.org/) focuses on standards for geospatial services;
- The buildingSMART alliance (formerly IAI for International Alliance for Interoperability, http://www.buildingsmartalliance.org) focuses on developing standards for the construction and facility management industries;
- Web3D Consortium (http://www.web3d.org/) is concerned with standards for 3D data exchanged over the Internet;
- Khronos Group (http://www.khronos.org/) creates open standards for the authoring and acceleration of parallel computing and graphics media;
- ISO/TC 204 – Intelligent transport systems standardizes information, communication and control systems in the field of surface transportation.

The use of standards that allow joint exploitation and combination of various geospatial and CAD data is a requirement for developing interoperable systems and is an increasing demand from user communities. In our case, to build the Contextual LoD, we have to share 3D models and its relationship with semantics. User communities can take advantage of this framework of standards to develop application schemas that follow the rules and reuse the components defined in the abstract standards. An XML Schema encoding following the GML grammar can then be derived from the application schema and serve as the basis for data exchange. This approach was followed during the development of CityGML and INSPIRES data specifications.

ISO/TC 211 has started to standardize different thematic aspects of geospatial information. Several standardized conceptual schemas have been defined, in accordance with ISO 19109. The following standards are relevant to urban space modelling:

- ISO 19144-2 - Classification systems - Part 2: Land Cover Meta Language (LCML) defines a meta language for expressing land cover classifications. Land cover classifications can be used to distinguish built-up areas from non-urban zones.
- ISO 19152 – Land Administration Domain Model (LADM) is a standardized conceptual schema for cadastre data. Land administration data can also play an important role in urban models.
- ISO/TC 204 has developed ISO 14825 - Geographic Data Files (GDF) as a conceptual and logical data model and exchange format for geographic databases for transportation applications. GDF has a strong focus on road transportation information.

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Other organizations have developed and maintain standards for urban and building models. The Industry Foundation Classes (IFC), defined by buildingSMART, is a BIM data schema covering a wide range of information elements required by software applications throughout the life cycle of a building. IFC now contains more than 700 classes enabling the exchange of building design, construction and maintenance data [7]. IFC 2.3 was adopted as ISO/PAS 16739 in 2005. The next release of IFC, IFC4, will be published as the ISO standard ISO/IS16739 at the end of year 2011 and will feature an improved modeling of external spaces and better support for geographic coordinate reference systems.

OGC published CityGML 1.0 in 2008. CityGML specifies a standardized application schema for 3D city models, from which a GML 3.1.1 encoding is derived. CityGML is therefore, both a conceptual model and an encoding, enabling syntactic and semantic interoperability. Its key features [5] are:

1. Thematic modeling: the model covers a wide range of city objects, including but not limited to buildings, transportation facilities, water bodies, vegetation…
2. Modularization: each thematic model is packaged in a separate UML module.
3. Multi-scale modeling: CityGML supports five levels of details (LoD). This mechanism facilitates the integration of 2D (at LoD0) and 3D datasets at distinct scales representing the same real-world entities. The same feature can be represented with different geometries at each scale. CityGML also provides an aggregation and decomposition association between objects that can be used to indicate that an object at a lower LoD has been decomposed into two or more objects at a higher LoD. They are defined as follows:
   - LoD0: regional view. An ortho-image or a map may be draped over a Digital Terrain Model, together with regional LandUse, water bodies and transportation information;
   - LoD1: city view. Buildings are modeled as flat-roofed blocks;
   - LoD2: city district, project view. Buildings are modeled with distinct roof structures and semantically-classified boundary surfaces. Vegetation objects, city furniture and more detailed transportation objects may also be modeled.
   - LoD3: architectural models (outside), landmark. Detailed wall and roof structures, balconies, bay and projection structures are modeled, as well as high-resolution textures, complex vegetation and transportation objects.
   - LoD4: architectural models (inside). Interior structures are modeled.
4. External references: objects in external databases may be referenced from the building or city object to which they correspond. They can be used to propagate updates from the source database to the 3D city object. They also help in linking different information models, while keeping them separate, as each has its own purpose.
5. Application Domain Extension (ADE) is a key mechanism of CityGML. Users can formally extend the base UML model with domain-specific information, e.g. an extension for utility networks or describing noise rates on city objects, and encode it in a XML Schema. Several ADEs have been developed for topics such as Noise (in relation with the European Noise Directive), Tunnels or Bridges. An ADE extending CityGML with more detailed semantics from the IFC standard is also being developed as the GeoBIM ADE [3].

CityGML's modularity, thematic structure, extensibility and external referencing mechanism sustain richer urban models integrating data from a variety of sources and enabling links with other application domains.

Semantic information must be taken into account according to 3D models. Transferring only geometry with the scene graph is not sufficient [6]. Transferring information between a server and a client application is not so easy. Using standards would be a good way. However, in our project, interactive exchange is needed and requires a semantic modeling of heterogeneous information using ontology [9].

VII. CONCLUSION

This paper presents an ongoing research on the definition of an Urban and Building Modeling Architecture. This paper focus on a new mechanism of LoD called Contextual LoD. It is the merge of classical geometric approach to define LoDs and two semantic multi-representations formalisms: the first part is based on contextual trees to define user profiles and business rules at the DMF level. The second part defines local contexts to allow multi-representation at a lower level, i.e. for each object of the model. The concept of C-LoD is designed to be integrated in an Urban Facilities Management (UFM) platform. It is an extension of the BIM concept for the management of urban objects. Our framework facilitates data maintenance (data migration, model evolution) during the life cycle of an urban environment and reduces the volume of data with specific graph operators. The urban approach also implies to manage precisely the spatial and temporal dimensions that have been considered in the definition of the C-LoD part. This approach is based on the CityGML 1.0 and IFC 2x3 standards. The implementation of the BIM part, including the making of data model and contextual views and profiles, as well as the 3D representation of building and urban objects with a LoD

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management is already done. Our future works will be to achieve the implementation of our framework for the UFM platform, including the C-LoD management. These works are based on our previous works on Active3d and designed to be fully compatible with both standards: the one for geographic information (e.g. ISO/TC 211) and the second for the construction world (e.g. ISO16739).

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