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Merging BIM and GIS using ontologies application to urban facility management in ACTIVe3D

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ABSTRACT

This article presents the research work done in order to reduce the gap of heterogeneity between Geographic Information System and Building Information Models. The goal is to extend a platform dedicated to facility management called ACTIVe3D. We want to enlarge its scope to take into account the management of urban elements contained in the building environment, as well as other buildings. The particularity of the platform is that data can be accessed either by a semantic view or through a 3D interface. The SIGA3D project describes a set of processes that aims, for all the stakeholders of urban projects, to manage pieces of information through all the lifecycle of construction projects. To solve the heterogeneity problem between BIM and GIS, we developed a semantic extension to the BIM called UIM (Urban Information Modeling). This extension defines spatial, temporal and multi-representation concepts to build an extensible ontology. The knowledge database can be populated with information coming from standards like IFC and CityGML. This information system has been adapted and implemented into the existing platform and is today fully operational and used by thousands of users.

1. Introduction

From its design to its construction, a building requires coordination, understanding and a chain of numerous heterogeneous systems for every stakeholder involved in the project. The fields of construction and CAD (Computer Aided Design) had to adapt themselves over these past years to gain efficiency. An open standard has been proposed to model buildings. This standard is known as IFC (Industry Foundation Classes). From there, a discipline entitled BIM (Building Information Modeling) emerged. It consists in generating, storing, managing, exchanging and sharing building information in an interoperable and reusable way throughout all the lifecycle of a building.

BIM consists in treating the building as a fully-fledged information system. Even if the term BIM has existed for many years, today's meaning was democratized in the mid-2000s. Since then, more and more building stakeholders (architects, engineers, contractors, etc.) have chosen to use BIM for their activity [11]. The first semantic-oriented BIM solutions have emerged recently. The semantic BIM consists in modeling buildings with ontologies to obtain easily graphs easy to handle. Such BIM are based mainly on the IFC standard (ISO 16739:2013) as described in the works of Benner et al. and Vanlande et al. [4,19]. Today, perfectly operational and accomplished solutions are used in many countries by various legal entities (governments, administrations, private companies, etc.).

IFC is a standard created by an association known today as BuildingSmart.[1] The IFC file format aims to provide a structured and shared view of the objects that makes up the building. Several studies have been made over the past decade to build ontology from such a format, such as those of Benner et al. and Vanlande et al. [4,19]. The semantic modeling of the building brings many benefits, such as interoperability between different applications and the ability to contextualize the data in order to create specific views for specific core businesses.

This is the case, for example, of the ACTIVe3D platform (A3D) which is developed since 2005 [19]. This platform is currently used in France by several universities (Nice), regions (Burgundy), cities (Paris), and ministries (Defense). All data managed with ACTIVe3D

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[1] http://www.buildingsmart.org/.

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today represents over 100 M square meters with several tools dedicated to facility management.

However, if BIM has been developed in recent years, its needs and features also have. We can take the example of the regions in France. They have since recently to manage the waterways. These canals often extend over several hundred kilometers. To manage them effectively, we need to represent all bays, locks, houses, trees, benches and other comprising elements both geometrically and semantically. This model will then be used in expert facility management software to anticipate the inherent costs needed to maintain them. BIM quickly found its limits on this type of project for many reasons: accuracy in locating objects on large sites, linking different complex objects, information about the surrounding landscape, spatial queries, etc.

The BIM approach on which we rely must then be extended with GIS (Geographic Information System) mechanism. The use of GIS to manage facilities is not a solution since GIS has a limited management of semantic information on the components from the different layers of the information system. Indeed, GIS are designed to deal mainly with large scale and the needs of facility management remains strong at the building scale. We therefore wish to couple BIM and GIS approaches to standardize the representation of knowledge related to the building and geographic objects.

Thus, in our approach named SIGA3D, BIM is no longer limited to the description of a building, but also of the interactions with its environment. The modeling of this set is an emerging discipline that has been called Urban Facility Management (UFM) [13]. It describes a set of business processes revolving around construction and urban management. The heart of this system is based on the modeling of the urban information system, called Urban Information Model (UIM).

For this, we studied the approach made in GIS (geographic space management in the broadest sense of the term), and in particular in the urban modeling industry. According to M. Batty [2], graphical representations of functions and processes to generate urban spatial structures in terms of land use, population, employment and transport can be described as urban models. There are many heterogeneous file formats for representing geographic information. Associations and consortia such as the OGC (Open Geospatial Consortium[2]) and OSGeo (The Open Source Geospatial Foundation[3]) were created to standardize this domain. Thus, the development of new open and independent standards allows modeling geographic information. We may cite for example GML (Geography Markup Language) that describes geographic elements. GML is used for exchanging geographic information over the Internet. In particular there is a system based on GML which enriches the semantic dimension of the representation of cities, the CityGML format. As the IFC, this format allows to create knowledge databases according to the objects and relationships described in this format.

The idea of our research is to bring GIS and BIM closer by bridging the gap of heterogeneity between the two approaches. The identified kinds of heterogeneity are structural and semantic. The objective is to develop a platform for urban facility management that allows the emergence of new business disciplines by coupling these two fields of activity in a common environment. The goal is to manage urban facilities (including buildings and urban proxy elements) in an interoperable way. To achieve this, we use semantic graphs and ontologies defining concepts and relations to model all the required information. This article focuses on the semantic modeling of urban objects and describes the mechanisms set up to reach this goal.

Section 1 of this document is a brief state of art on the modeling of building information on the one hand, and urban information on the other hand. They are both axed on the semantic modeling approach. In the second section we discuss the limits of the urban model for the representation of building information and vice versa, the limits of BIM to manage urban and environmental information. The third section presents our semantic indexation method used to define a global ontology. This ontology is used to merge all data during the building lifecycle and its environment in order to create an urban information model. Section 4 presents the extension of the ACTIVe3D platform and the particular implementation of the SIGA3D ontology. The last section concludes this paper.

2. BIM and GIS

In this section, we present the work done in the BIM domain and especially the semantic BIM as designed in ACTIVe3D. Then we present the limits for the intended purpose. Urban modeling and GIS are then introduced.

2.1. From BIM to semantic BIM

In the paper of Vanlande and Nicolle [18], BIM is described as an intelligent representation of the building, made from CAD data, CAD objects, and parametric building modeling. The quality of the information strongly depends on the person who is inputting the data and the software used. Consequently, the models for data exchange and sharing are another main characteristic of BIM. There are several ways to share information, either in a centralized manner (database, web services, etc.), or by exchanging files by common services (e-mail, CD, USB flash drive, etc.).

The particularity of the semantic BIM is the use of ontologies to manage models. Ontologies unify the knowledge generated during each step of the building's lifecycle. For this purpose, the users describe real-world elements and their interactions with each other in the model. This is done on two levels: syntactic and structural. Users do not interact directly with the ontologies, they used CAD software that allow to design buildings in an object manner (that is to say users do not draw lines to represent a wall, but instantiate an object "wall" and its interactions with other objects). The ontology graph is then deduced from the user model.

The management of the building's lifecycle requires another management level. Indeed, the problem is that the elements and their interactions with the real-world are not the only things to model. Indeed, all the elements, their states and their interactions have to be validated. This means that, during the design time, the system retains more relevant information about the elements; the management system of the building lifecycle has to describe the components of a building project. These components are, for example, all the tangible elements (such as walls, stakeholders, and furniture), as well as immaterial elements (costs, projects, phases, actions, etc.). Moreover, the interactions between elements are modeled by links. For instance, when a wall which contains a window is moved, the window moves as well. Therefore, a wall and a window are connected by a containment relationship.

The ACTIVe3D BIM was built as an extension for the IFC model building lifecycle. This approach allows the characterization of objects that make up a building such as their classes, relations and properties throughout the entire building lifecycle and from diverse points of view [10]. The IFC standard uses files that are made of objects and connections between these objects. Attributes can be defined for objects, describing its "business semantic". The "relation elements" represent the connections between objects. The IFC model is an object model which uses the EXPRESS language (ISO standard 10303-P11, 1994). It describes more than 750 classes

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[2] www.opengeospatial.org.

[3] http://www.osgeo.org.

```
#111029 = IFCRELCONTAINEDINSPATIALSTRUCTURE (‘25wKeDex98fQp5Pukf_Ilc’,
#6, ‘BuildingStoryContainer’,‘BuildingStoryContainer for Building
Elements’, (#111007), #110989);

#111030 = IFCRELAGGREGATES (‘216Bv$dJj3tQjFeDohe6fQ’, #6,
‘BuildingContainer’, ‘BuildingContainer for BuildigStories’, #30, (#34,
#16235, #29699, #56800, #62027, #67346, #72533, #91602, #110939));

#111031 = IFCRELAGGREGATES (‘17XMUtGDr8FeFMtR6rOcy5’, #6,
‘SiteContainer’, ‘SiteContainer For Buildings’, #28, (#30));

#111032 = IFCRELAGGREGATES (‘0pVN8yq8vDRfwN_tnJREKC’, #6,
‘ProjectContainer’, ‘ProjectContainer for Sites’, #26, (#28));
```

Script 1. Extract of an IFC file in the EXPRESS format.

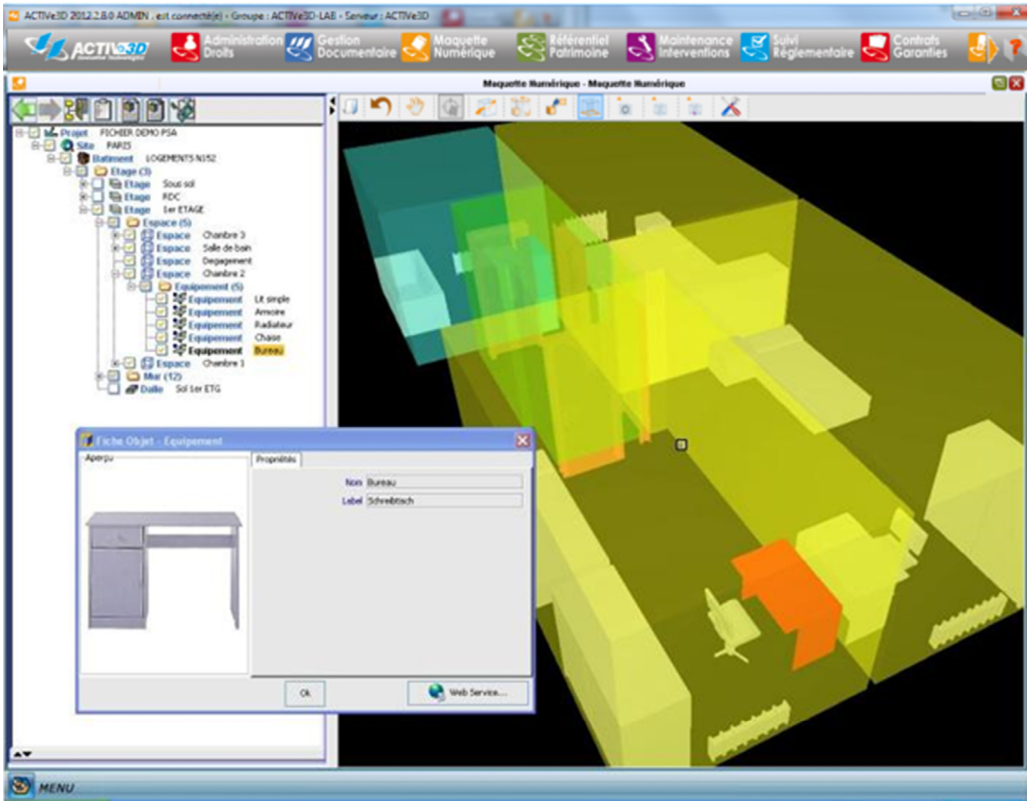
in its last release (IFC 4 in March 2013). An example of an IFC file in the EXPRESS language is shown in the Script 1. It shows that one line describes one element with reference to others lines.

There are three types of IFC classes: object classes, relationship classes and resource classes. The object classes consist of a triplet (GUID, OS, FU). The GUID defines a Globally Unique IDentifier for the IFC object. OS defines the OwnerShip features of this object. FU are the Functional Units that define the context of use of the classes (i.e. the geometrical model, its localization, its composition, etc.). The resource classes define a set of attributes used for the functional unit description. These resources are organized as a hierarchical graph. The relationship classes represent the various relations (capacity, aggregation, etc.) between the object classes and the functional units.

The A3D semantic extension allows new elements to be adding as well as relation elements and resources to the IFC management system. With the semantic graphs generated thanks to this architecture, it is possible to manage and handle IFC files in order to operate several operations: merging two files, extract partial data from one file, visualization and storing, etc. Moreover, the objects of a model can take with multiple semantic values, depending on the context of use. This is realized by defining a hierarchical structure of contexts called contextual view. The ACTIVe3D platform can display contextual building information, specific to a user or to a business activity for example. The generated interface shown in Fig. 1 is made up of a tree of containment (alphanumeric) on the left side, a 3D scene and a technical chart on a semantic element of the scene in the pop-up.

A set of tools has been included in this application, such as a query engine, a document generator, management of localized interventions in the building, a task planner, an IFC viewer, a report designer, etc.

All IFC objects can easily be handled by any process. It is possible to configure them to contain Web services links for electronic catalogs of furniture and equipment, documents, ad hoc data or rules. The whole information can be managed from a 3D



Nom Bureau
Label Schreibtisch

Fig. 1. Snapshot of the 3D scene management system.

graphical interface that has been certified IFC 2 × 3 compliant by the International Alliance for Interoperability.

If IFC and semantic BIM give a good answer to the problem of building management, the modeling of their environment is more difficult. Indeed, IFC focuses on the building and its immediate environment. The building environment is itself limited to the site of the building in the most used IFC version (2 × 3). An IFC site is a defined area of land on which the project is built. It is therefore quite possible to design a digital elevation model (IFC `IfcSite`) with attributes: perimeter, area, terrain points (x, y, z), designation, address, etc. and associated properties: description, building coverage, etc. However, this is optional and limited to the surface. At the moment, this model is not suitable for defining objects outside of the building. These limitations are also well known in the community as evidenced by work on IFG (IFC for GIS), designed to extend the standard for geo-referenced object modeling outside building. This work aims to facilitate the integration of BIM in GIS. In the very recent version of IFC (IFC 4), geographical elements can be defined (`IfcGeographicElement` and `IfcGeographicElementType`) to increase interoperability with GIS.

GIS seems to be a solution to extend the possibilities offered by the BIM. Moreover, they solve some of the obstacles met in the project to extend BIM to the management of urban elements: geocoding, scalability, connections between BIM and urban objects, etc. The following section presents the GIS, their semantic capacity, and usability for our objectives. The main problem to solve is the interoperability between the GIS world and BIM.

2.2. From GIS to urban modeling

GIS are older than the concept of BIM and the scope of operations is larger. They are becoming a part of mainstream business and management operations around the world in organizations, both in public and private sectors, as diverse as cities, state government, civil engineering, telecommunications, urban planning, petroleum exploration, land surveying, etc. GIS refer to any system that captures, stores, analyzes, manages, and presents data that are linked to at least one location. Over the past 20 years, geographic information has grown so anarchic that it has generated many problems of syntactic heterogeneity. To overcome this problem, the Geography Markup Language (GML) was quickly established for the exchange of geographic information. It is a standard of the OGC (ISO 19136).

BIM and GIS domains try to standardize architecture and processes but do not have the same objectives. BIM focuses on an expressive object oriented modeling of data with complete semantic (typically used for modeling new building and structure and cover physical and functional characteristics of a building) and 3D modeling (intensive use of 3D geometry such as CSG (Constructive Solid Geometry), BRep (Boundary Representation), etc.).

The GIS focus on a large-scale presentation and centralization of the data with geo-location using real world coordinates. GIS are strong in 2D geometry modeling and provide mechanisms of multi-representation, such as levels of detail (LoD).

In recent years, governments, cities and companies have shown great interest in the construction of virtual 3D city models for various uses, ranging from communication to management of urban facility through projects of urban planning, implementation and simulation (noise, pollution, etc.) [16]. If at the beginning, urban models were very different from GIS, they are now very close.

It is furthermore possible to combine the techniques of integration between GIS and urban models into four groups [17]: Integration of GIS in urban models, integration of urban models in GIS, the integration of the two systems through data exchange (weak coupling), and the integration of some models and functionality of a system in the other (strong coupling). The operation is similar to integrating BIM with GIS.

However, there are problems with the integration of these different models [12]: different organizations, different patterns, different geometric models, lack of semantics and lack of interoperability.

In order to achieve interoperability among BIM and GIS, the use of standards is unavoidable because of the size of existing communities in each field. For the geographic information, many standards have been proposed to address the problem of heterogeneity. Several organizations, industry consortia and communities are involved in the development of standards for urban modeling:

- ISO/TC 211 – geographic information/geomatics is in charge of standards for geospatial information;
- OGC focuses on standards for geographic services;

One result of the collaboration between ISO/TC 211 and OGC is the publication of a standard focusing on implementation aspects of 2D and 3D geospatial information: GML, for 2D and 3D. It is used to encode, manipulate, store and share geographic information, by the description of application schemas. GML is an XML encoding according to ISO 19118:2011 which specifies the requirements for the definition of encoding rules to be used for data exchange. One of the application schemas is dedicated to city modeling and is called CityGML.

Originally developed in Europe, the CityGML format has gradually established itself as the standard for the exchange of digital 3D city models. The objective of CityGML is to propose a common definition and understanding of basic entities, attributes and relationships in a 3D city model. CityGML is an international standard for the representation and exchange of semantic models of cities and landscapes in 3D. It was adopted by the OGC as one of their official standards in 2008.

The basic model of CityGML consists of two hierarchies of semantics and geographical features for which matching items are linked by relationships. The thematic model of CityGML consists in class definition for the most important types of objects in a virtual 3D city. The model covers a wide range of urban objects, including (but not limited to) buildings, transport networks, hydrography, vegetation, terrain, land cover, city proxy elements, etc.

CityGML has the advantage of clearly defining the concept of LoD (Level of Details) for geography application. This is an adaptation of the traditional multi-representation in GIS, focusing on the simplification of the geometry of the objects. This is needed for such application due to the amount of data to be displayed. The LoD will help decrease the complexity of object geometries by adapting their representation based on several geometrical parameters (distance from the camera or size of the object on screen, speed, etc.). CityGML defines five LoD as follows:

- Level 0 represents digital terrain model in 2.5D, possibly with the application of aerial photographs. The ground surface is not represented at this level. This level enables to represent large areas like regions, for example.
- Level 1 shows buildings which can be created by extrusion of their outline. The roofs are flat, and the walls are not textured. This representation is suitable for the display of scenes within the scale of a city.
- Level 2 adds details on some roofs and applies textures to buildings. These textures can be generic or derived from photos of the buildings' facades for a more realistic rendering. This level will be displayed at the scale of city neighborhoods. Level 3 represents the architectural features of buildings. Thus, roofs and

walls are detailed and shown on the buildings in 3D (rather than as a simple picture as the case in LoD2). Vegetation and urban objects are components of this LoD. This representation is used to display the outside of buildings.

- Level 4 complements the previous level with the modeling of the interior structure of buildings. This LoD is used to represent the internal architecture of buildings.

Although the building model is the most detailed thematic concept of CityGML, its semantic expressiveness is far from what is achieved by the IFC model. Moreover, if CityGML is used more and more, there is no business software that uses the CityGML model. This is also due to the way it represents the geometric elements, using only a boundary representation where, for instance, CAD software uses parametric modeling.

Though we saw that standards exist in our research domain, none allow modeling both a geographical environment with mechanisms from geographic representations, as CityGML does, and a digital model of a building semantically as rich as IFC. However, there are several approaches that aim at improving one or more dimensions we have identified to reach the solution. We discuss these in the following section.

3. From BIM to UIM through GIS

Following our previous work on ACTIVe3D, and the state of the art given in the previous section, we have identified three areas of research and development (as shown on Fig. 2) involved in the definition of an urban information model: the BIM axis corresponds to the modeling of building; the GIS axis represents geographic data and related tools; and finally, ontologies are treated through the contextual axis.

There are many solutions dedicated to the implementation of one or more fields that can be identified on this multi-axes system. For example, CAD software, which are used to draw buildings, can be positioned along the BIM axis. GIS-related applications, which can display 2D geo-referenced geometries, are located on the GIS axis. Then, semantic web languages, which are used to model the context, such as RDF (Resource Description Framework) or OWL (Web Ontology Language), can be placed on the third axis, namely the context axis.

Some approaches are positioned on two axes. The 3D GIS for example, improves the buildings' representation dimension of GIS. On the BIM/context dimension we can find the FM-CAD (facility management) from CAD editors that provide some FM in order to ease the contextualization of BIM information. Similarly, we have BIM-GIS approaches from GIS editors that help modeling building information in geographic systems. Then, on the figure, we can see a solution positioned on the context/geographic plan. MADS from [15] is a conceptual model that allows to model space, time and multiple representations. It defines types of complex objects, their attributes and their domains, the relationship between the types of objects, relationships between objects, such as aggregation, topological relations that constrain the geometry of related objects (disjunction, adjacency, crossing, overlapping, inclusion, and equality). We will use some concepts of MADS later in our approach. In particular, to formalize the semantic multi-representation issued of MADS, we use an extension of the logical description language ALCN with mechanisms coming from the representation of [3]. Then, A3D is the BIM semantic we have described in the previous section.

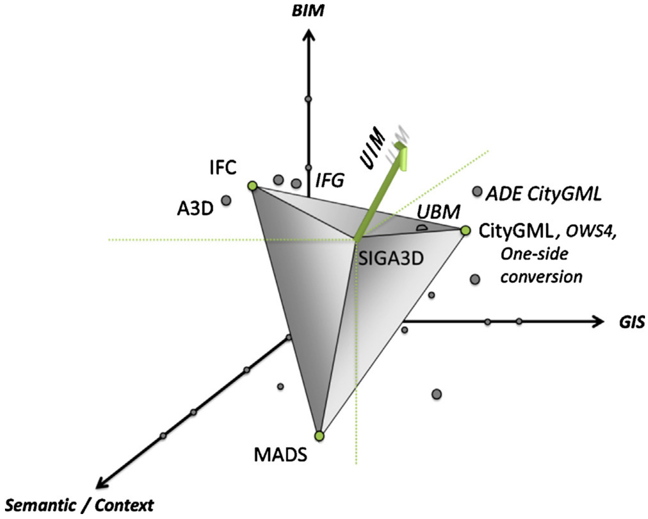


Fig. 2. Positioning of the UIM approach.

Also, we have solutions that allow more or less dealing with all three dimensions. Ideally, the UIM should be positioned in the center of the system, dealing with the three domains (as shown on Fig. 2). There are several approaches to achieve this: either the BIM domain is extended with others fields, either the GIS part is completed with BIM and context elements, etc. We can however describe the main feature of each domain and choose the approach that seems the best in our activity field. The next paragraph discusses the works that go in this direction.

One of the most common approaches to model building information and geographic data in a homogeneous system is to combine IFC and CityGML standards. Several works have been performed in this direction, with different approaches.

The main trend to solve this problem is an approach based on a one-way conversion between these two file formats. Isikdag and Zlatanova [8] provide the basis for a framework for automatic conversion of IFC into CityGML. This article argues that there are two steps in the conversion process: the transformation of semantic information and processing geometries. Most of the projects are focused on geometry, and usually on the transformation of IFC into CityGML, like explained in [9,14]. These projects aim at developing algorithms that allow a complete and automatic transformation of IFC building models into CityGML models. The research focused initially on the first two levels of details defined by CityGML. The objective of the proposed algorithms is to create a valid geometric and semantic representation for LOD1 which can also be applied to LOD2. IfcExplorer is a prototypic software that implements such algorithms for integration, analysis, three-dimensional visualization and conversion of spatially referenced data (Benner et al., 2009).

The transformation of a CityGML building into IFC format is more difficult, especially for the geometric part. The main difference between these two formats is the way the geometry is built. On the one hand, CityGML represents existing buildings as they look on the ground, by their surface. On the other hand, BIM, and CAD in a more general way, model the building as it is built, with the use of volumetric and parametric primitives. This situation leads to uncertainty in the representation of models.

A second approach to combine the two formats is the creation of CityGML extensions (known as Application Domain Extensions – ADE). It is a solution used to enrich the semantics of CityGML in order to facilitate the import of IFC. The most known project in this area is described in [5] and consists of an extension called GeoBIM. Only few IFC classes are required to be transformed in the extension to obtain a specific result, and some of them have a direct correspondence with classes in CityGML. Although the idea of improving the building model of CityGML by a semantic extension seems promising, the realization encountered several difficulties. We can say that without complete implementation of IFC into CityGML, software dedicated to specialized building functions will experience compatibility difficulties.

Finally, there are also proposals to develop frameworks that can be used to perform two-way communication between the two models. The Unified Building Model approach, detailed in [12], is one of them. It is based on the notion of a unified model which is defined, for the theoretical part, as a superset model, and extended to include all elements and objects from both IFC and CityGML. This model arises as an intermediate model for mapping objects between these two standards. Thus, this approach allows a bidirectional conversion between IFC and CityGML that goes further than previous models did. The unified model is based on the concept of reference ontologies.

All these proposals to combine IFC and CityGML in order to improve interoperability between these standards lead to the same goal: little semantic knowledge of the building, data loss in transformation processes, and a lack of overall management of building and geographical elements.

In addition, relationships between objects are often only geographical and topological. One approach that seems closer to our goals is the UBM. However, the project is still relatively new and there are several limitations. It deals only with buildings (only models of IFC and CityGML buildings are designed as a starting point). In addition, the model could gain in flexibility and capacity modeling and model checking (coherence and consistency) to be created from a common vocabulary and independent in terms of class hierarchy structuring, such as those from the semantic web tools and languages like OWL or C-DMF.

Fig. 2 summarizes the discussion by positioning the different approaches we studied. We can identify our objective which is to build an urban information model that uses the strengths of the three fields of study to overcome the obstacles: geo-localization of the BIM model, scalability of the architecture (number of objects and scope of scenes), relations between building and urban objects, adaptability and evolutivity.

In the next section, we describe how we pursued our work on the semantic aspect initiated with the BIM ACTIVe3D. In particular, we show how we integrate BIM and GIS through the definition of a context to define new business know-how specific to the UFM. This contextual modeling is useful for business relevance and optimization.

4. Ontology-based approach

There is several search works that have been done to provide inter-ontology mappings with a logical approach. We can cite for instance C-OWL [6] that extends the OWL language with capabilities of local context management. Although this approach is interesting, its main limit is the lack of reasoning on the ontology. The idea in SIGA3D is rather to use a combination of the works previously studied to create a solution that arises along the new axis in Fig. 2. Indeed, research that focuses on interoperability between GIS and BIM converges to a new research center. We identify this new axis as the UIM axis: it is intended to represent not only GIS knowledge but also information from BIM and context, in a homogeneous way. Homogeneity here means that we want a same level of knowledge for both semantic and geometric modeling dimensions. This approach consists in translating classes and relations into semantic graphs.

We explain this architecture in the following part. The global architecture of UFM is made up of several processes, from the data acquisition to their visualization. In this section we present the modeling process which built the ontology and define the context, and the mechanism of Contextual Levels of Details that aim at improving the management of data.

4.1. Data modeling process

The modeling process consists in building a dynamic ontology that can then be populated from diverse sources such IFC and CityGML format. The ontology is qualified of dynamic because the ontology model that describes a specific building and environment is built dynamically, depending of the data. Moreover, the model can evolve through time thanks to specific operators and the changes are logged. Thus, the whole lifecycle of the ontology can be followed, and so can be the evolution of the environment modeled by this ontology.

The ontology is based on C-DMF, the framework on which the BIM ACTIVe3D is built [18]. The architecture of SIGA3D extends C-DMF to define new semantic elements, new relational items and new resources for the geographic world. It is especially possible to define geo-referenced and temporal elements, what was not allowed in the original version. This process step is divided into two parts (see Fig. 3 below): modeling of data (Data Model Framework, DMF) and contextualization (Context Model Framework, CMF).

DMF aims to define a data model. It can model semantic information as well as geometric and spatio-temporal entities. It is done thanks to operators that model the structural part of the graph. These operators are defined in an RDF model and use the RDF/XML syntax. They are based on a combination of various operators, such as RDF, OWL, SWRL and Named Graph and allow

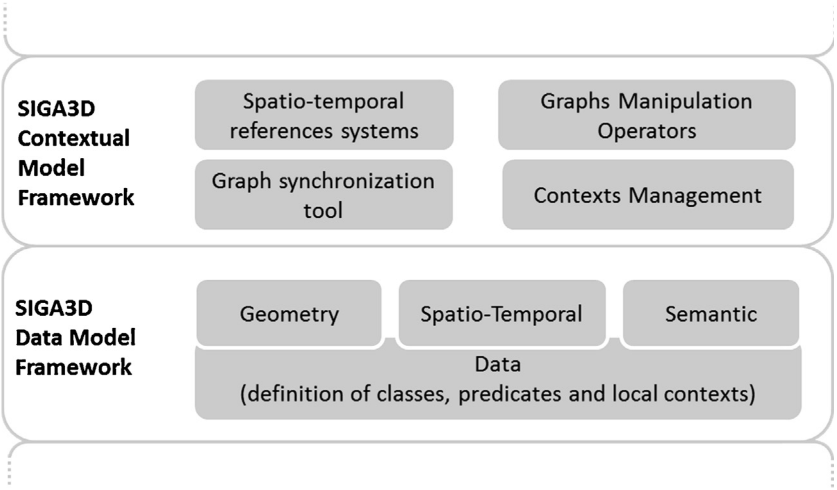


Fig. 3. Architecture of the modeling process.

the definition of classes, properties, variables, predicates, implication, intersection, union, etc.

Moreover, this framework can use special operators to define spatial and temporal entities. There are two levels of integration of such elements. The first part is to define spatial and temporal elements like point, line, instant, interval, etc. We based our modeling time approach on the work carried out for OWL-Time [7]. The spatial approach is based on the GML format. For example, it becomes possible to compute a bounding box for an object in the ontology, and to geocode it. The second part of spatio-temporal entities aims at defining relations between such elements. It is a part of the contextual modeling framework of our architecture we explain later.

The DMF layer includes a multi-representation model based on the MADS approach. We extended the eligible operators with the addition of local context. This local context can be the resolution, a point of view, intrinsic properties, etc. It can be defined as a concept of the ontology (`dmf:class` for example) as well as just a `rdfs:label`, for instance. This allows a given concept of the ontology to have several definitions pertaining to this local context. The combination of these concepts allows the optimization of the graphical scene, not only through traditional simplification of geometries (as it is the case in CityGML), but also through semantic criteria.

CMF is the second layer of the process and consists in defining a context for the DMF graphs. The context is defined as a special graph called `cdmf:SystemGraph`. The representation of context is derived from the Named Graph. This graph is built using special graph operators on the DMF graphs like the union, intersection or mapping. The goal of these operators is to simplify the management of the evolution of integrated information. The result of this part is, in addition to the definition of a general context (that is to say give one piece of information on an object such as author, language, rights, etc.), the possibility to associate the data of DMF with several contexts. Thus, we defined the concept of contextual views: depending on the user and its business, its rights, etc., the data graph is displayed differently.

The context describes also spatio-temporal relationship on graphs of DML. The goal is to define, for a given context, the validity of an element based on spatial or temporal properties. It also avoids creating incoherence where an element linked to another is modified in the ontology. The tangible area for the temporal aspect is based on time intervals and relations of Allen [1] (precedes, meets, overlaps, contains, starts, equals, during, finishes). The concrete spatial area is defined for the polygons by the use of base predicates of the topology Equals, Contains, Covers, CoveredBy, Crosses, Disjoint, Intersects, Overlaps, Touches and Within. These relations can be, for instance, the adjacency of two building models (typical topological spatial relationship), or the definition of the opening hours to access a public monument. As the objects we load in our urban facility management may come from different sources with different references system for space and time, we have to manage these spatio-temporal properties by storing a Coordinates References System and a TimeZone for each context. The coordinates are then converted.

Fig. 4 is an example of the graphs generated by this architecture. The `SystemGraph` *Sg0* models the context and the other graph, *DistrictModel*, represents the structure of a district model. This ontology can then be populated automatically from standard formats such as IFC or CityGML. The strength of this representation is that the ontology can easily evolve and be adapted to any standard.

4.2. Example of multi-representation and C-LOD

The local context introduced in the previous paragraph makes it possible to store several graphical representations of an object and display them depending on the context. It is an addition to the customizing of the interface in relation to the contextual views. The management of local contexts is done in this part by defining new local contexts (based on the mechanism described in the previous part). For example, we can define three local contexts: `designer`, `structureEngineer` and `March`, as follows (Script 2):

We can then define several properties and a spatial representation for a class `buildingPlan` which depends of the user. The contextual operators `dmf:[ c1,...,cn] Class`, `dmf:[ c1,...,cn] property` and `dmf:[ c1,...,cn] spatialEntity` are used (Script 3):

Script 2 describes an object, `BuildingPlan`, which has several properties. For a designer, the `BuildingPlan` is defined with a `line_thick` and a plan containing two representations. The same object is defined differently for a structure engineer, with wall

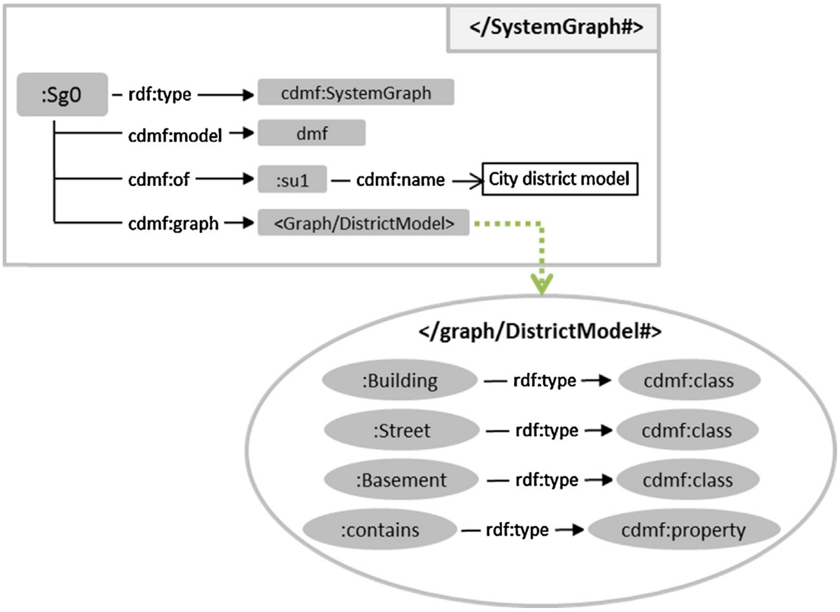


Fig. 4. Example of a city district modeling with CDMF.

```
<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 2. Example of local context definition.

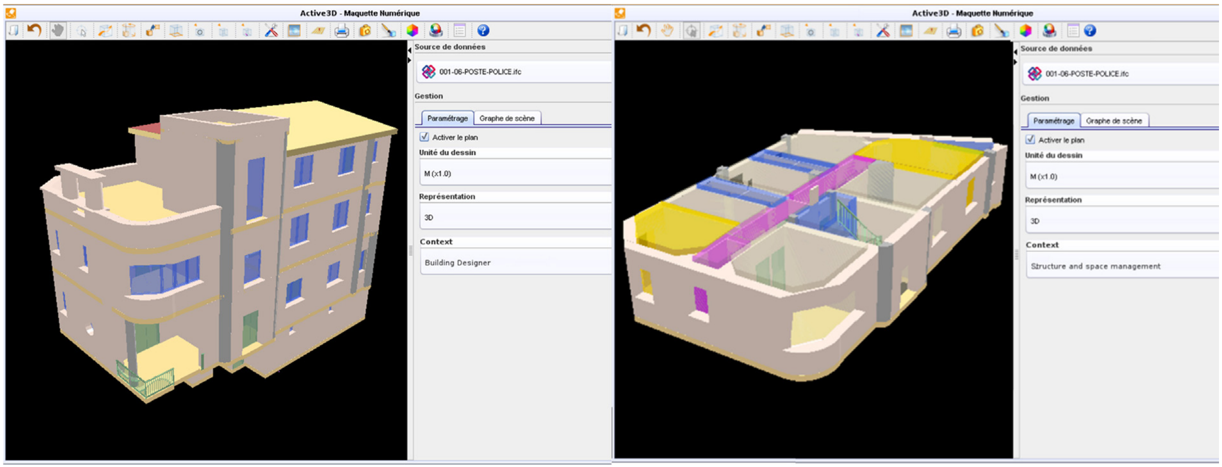
```
<dmf:Class rdf:ID='BuildingPlan'/>
<dmf:[designer]property rdf:ID='line_thick'/>
<dmf:[structureEngineer]property rdf:ID='wall_material'/>
<dmf:[designer]property rdf:ID='contains_plan'/>
<dmf:[designer,structureEngineer]property rdf:ID='contains_plan'/>
<dmf:spatialEntity rdf:ID='the_plan'/>
<dmf:[designer]property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

<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 3. Example of context definition for a `BuildingPlan`.

material, `wall_material`, and an attached plan with only one 2D representation. Fig. 5 shows an example of a building representation: on the first part we have a structural view of the entire building according to an architectural context, and on the right a spaces view of one of the building storeys according to the spaces management context. The representations of spaces are semantically different.

5. Industrial development

The concepts introduced in the previous sections have been implemented in the ACTIVe3D platform. The implementation has been done in three steps. The first one consists in defining the process used in the urban facility management. Fig. 6 presents the business processes involved in the management of urban heritage.



001-06-POSTE-POLICE.ifc
☑ Activer le plan
Unité du dessin: M (x1.0)
Représentation: 3D
Context: Building Designer

001-06-POSTE-POLICE.ifc
☑ Activer le plan
Unité du dessin: M (x1.0)
Représentation: 3D
Context: Structure and space management

a) Detailed view of the global building structure

b) View of a building storey in a space management optic

Fig. 5. Example of semantic multi-representation of a building.

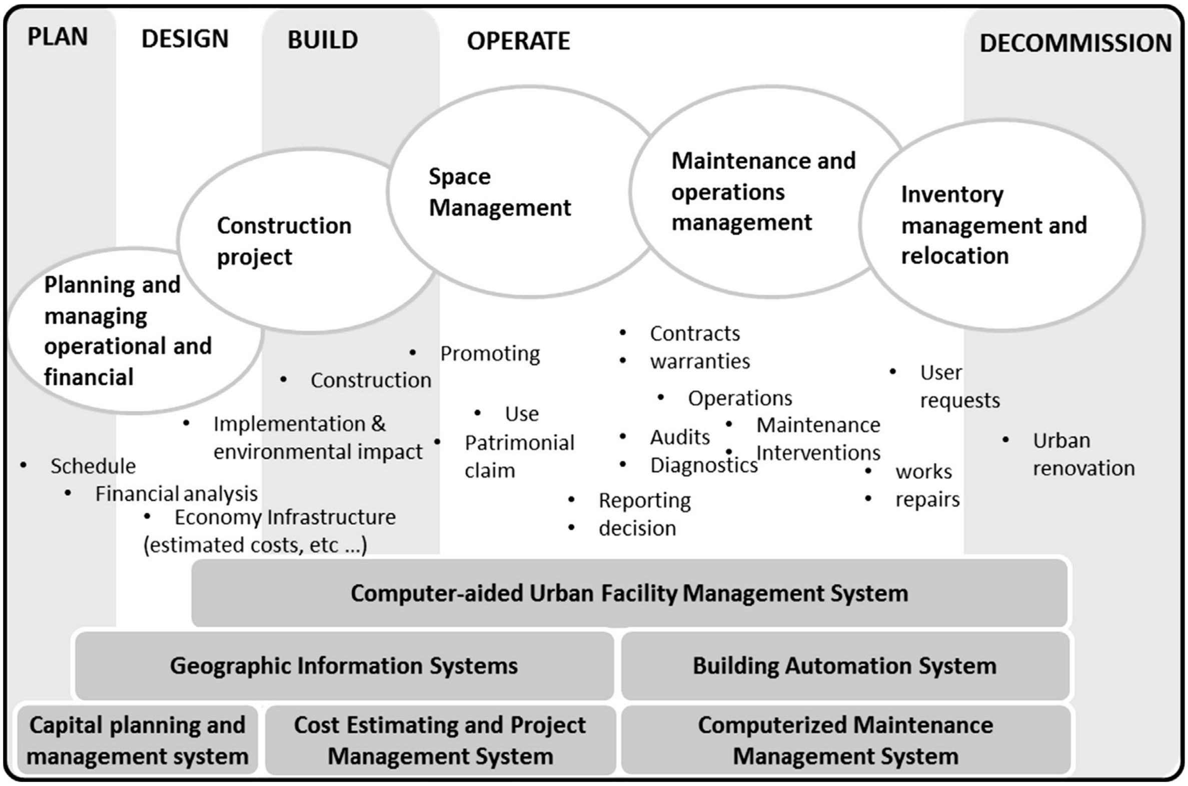


Fig. 6. Identified business process identified for the urban facility management.

It shows for each activity identified during the life cycle of an urban project the business processes, their associated skills and the tools used. That positions our approach on urban facility management system.

5.1. UFM, a set of processes

We can now describe processes specific to this domain. Fig. 7 is an architecture of processes that represents the set of procedures needed to complete the urban facility management. These processes go from the acquisition of data in the information system until their exploitation in the ACTIVe3D 3D engine. The modeling process uses the architecture we described in the previous section. Then, the streaming process helps to query the data, geometric and semantic, directly from the database to the client of the ACTIVe3D platform. The second step is the development of the software architecture of the system. It is composed of several layers including the two presented in the

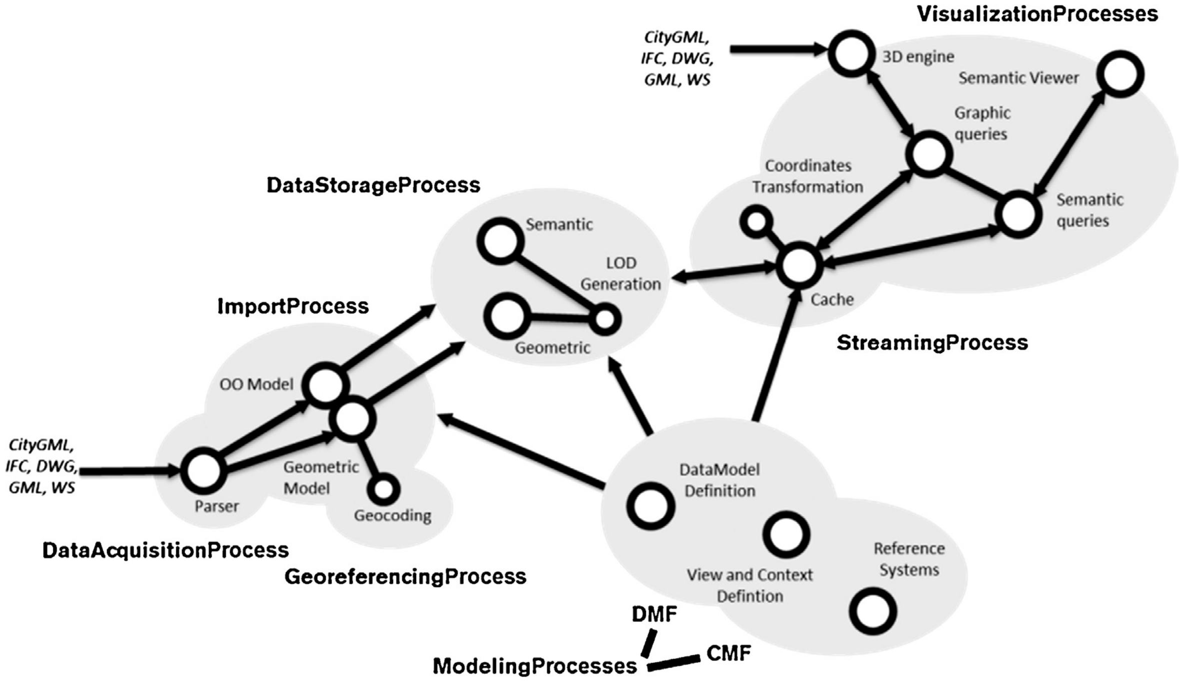


Fig. 7. Organizational view of the UFM processes.

previous section. The last part of the implementation is the industrial adaptation of the ontology mechanisms described in this document to the existing software architecture and constraints.

5.1.1. Data acquisition processes

The data can be extracted from standards as presented in our approach, but also from other formats as the CAD DWG format or the geographic Shapefile format. Web services can also be used. Two approaches for acquisition of data are used in SIGA3D. The first approach is common in the BIM world where processes are most of the time file sharing oriented. The second approach is mainly used in the GIS world where web service of type WMS and WFS are very common. We created a parser for each kind of data source model (IFC, DWG, DML and CityGML). The data acquired can be objects in the sense of the well-known oriented-object paradigm (for IFC or CityGML for instance), or geometrical objects like points or lines (for DWG format of AutoCAD or the GML format).

5.1.2. Import process

The import process aims to find and organize the objects described in the source for future use. This step is based on graph analysis to model complex objects that have business knowledge. For this, a memory model is built. It uses the graph structure of the data model in which we want to store objects required to populate the ontology. During this phase, all the objects and relationships are analyzed to construct an acyclic graph called contextual tree. It is built by the use of business rules such as “a door is opened into a wall space” that was defined in the modeling process.

The second part of the import process is dedicated to the 3D modeling. In this step, all the geometries defined in contextual trees are converted into a triangular surface model. During this conversion, the 3D objects are associated with a GID (Globally Identifier). The standard formats IFC and CityGML use GUID to identify each business object in the world. We use these identifiers to link the 3D visualization with the information stored in the database. The geometries are then stored as scene graphs.

5.1.3. Data storage

Generated objects are stored as acyclic graphs which defined XML contextual trees into a database. This step is done in two separate database schemes (one dedicated to semantic description and the other for geometric definition of objects). The geometric data can be exported without the complex graph structure of the semantic graph (contextual trees). It is stored as a scene graph to allow applications to load the data and display them as a streaming media. Indeed, under this form, the data require only few transformations from the client application to be displayed. In addition, the scene graph being structured on a hierarchical form, we can easily choose the level on the hierarchy to be displayed, and then optimize the network bandwidth and memory of the computer that displays the scene.

Each object of the 3D scene stored during this process part is made up of several representations. This allows the use of common geographic levels of details, that is to say several representations more or less detailed of the object, but also other geometric representations that can be chosen thanks to semantic criteria. These are part of the contextual levels of details. They can be used to enhance the scene by providing appropriate representations to users.

These representations are chosen for an object during the streaming mechanism process, according to the modeling process step (which defines the contexts).

5.1.4. Georeferencing process

One of the objectives of the SIGA3D project is the management of spatial objects. To get geographic objects, Earth coordinates need to be attached to geometric and semantic objects. Sometimes, designers of urban or real estate projects geocode their plans, in order to work on a GIS example. But most of the time, plans that we will recovered from architects are created in local coordinates systems, each system being unique to the software used for the design. This is the role of the georeferencing process to link object representations to geodetic coordinates.

For the SIGA3D project, the georeferencing management is done on two levels of the whole process that we described: (i) a geocoding phase during the import process, and (ii) a transformation phase of the coordinates when displaying data, if necessary. Indeed, the plans and models that we have to deal with in the application can be associated with different CRS (Coordinate Reference Systems). In addition, as it was detailed in the semantic approach of SIGA3D, the definition part of the context contains information on the CRS used by each user, according to their profile and selection criteria. However, data are stored with their original coordinate system. This allows an easier reuse of objects by their designers when necessary.

5.1.5. Modeling process

The modeling process part consists in building a dynamic ontology which references the data stored in the relational SQL database. It corresponds to the approach we introduced in the previous section.

5.1.6. Visualization process

This final step of our urban facility management global process is to display the information models in a form that corresponds to the preferences of the user. The viewing can be done in two ways: a 3D visualization of an urban environment, and semantic information displayed as text trees (as shown in Fig. 1, adapted to urban environment).

The information displayed and its form depend of the profile of each user. The information can be loaded dynamically upon request. This allows the application to be mobile and be used with light hardware and connection, the whole knowledge base being often very big (millions of objects). The streaming process consists in getting the part of the scene graph the user wants to access, e.g. an entire building site, only a room of a building, or an urban network like hydrant network. During this phase, the appropriate representation is loaded for each object, and the coordinates, spatial and temporal, are computed.

This set of processes has been implemented through an architecture we can see in Fig. 8. This makes the Urban Information Model part. The implementation of the layers has to be adapted to industrial constraints for the project. Each layer corresponds to one or part of one process explained before. We present the implementation we made of our ontology and the multi-representation mechanism in the next part.

5.2. UIM, an architecture to model the urban knowledge

The complete architecture of the ACTIVe3D platform is presented in Fig. 8. Each layer helps to achieve one or part of the UFM processes. We present the mechanisms established to implement the concepts of our approach in the application in this section.

The main mechanism is the representation and storage of our ontology in the database. As we said before, the semantic data and geometric data are stored distinctly. The diagram on Fig. 9 shows a part of the implementation of our architecture, which links the ontology of ACTIVe3D to the one operated by the 3D viewer and in which geometries are stored. That explains especially the mechanism of contextual LoD. Under a) is the ontology itself, with its concepts, relations and instances. The conceptual level is

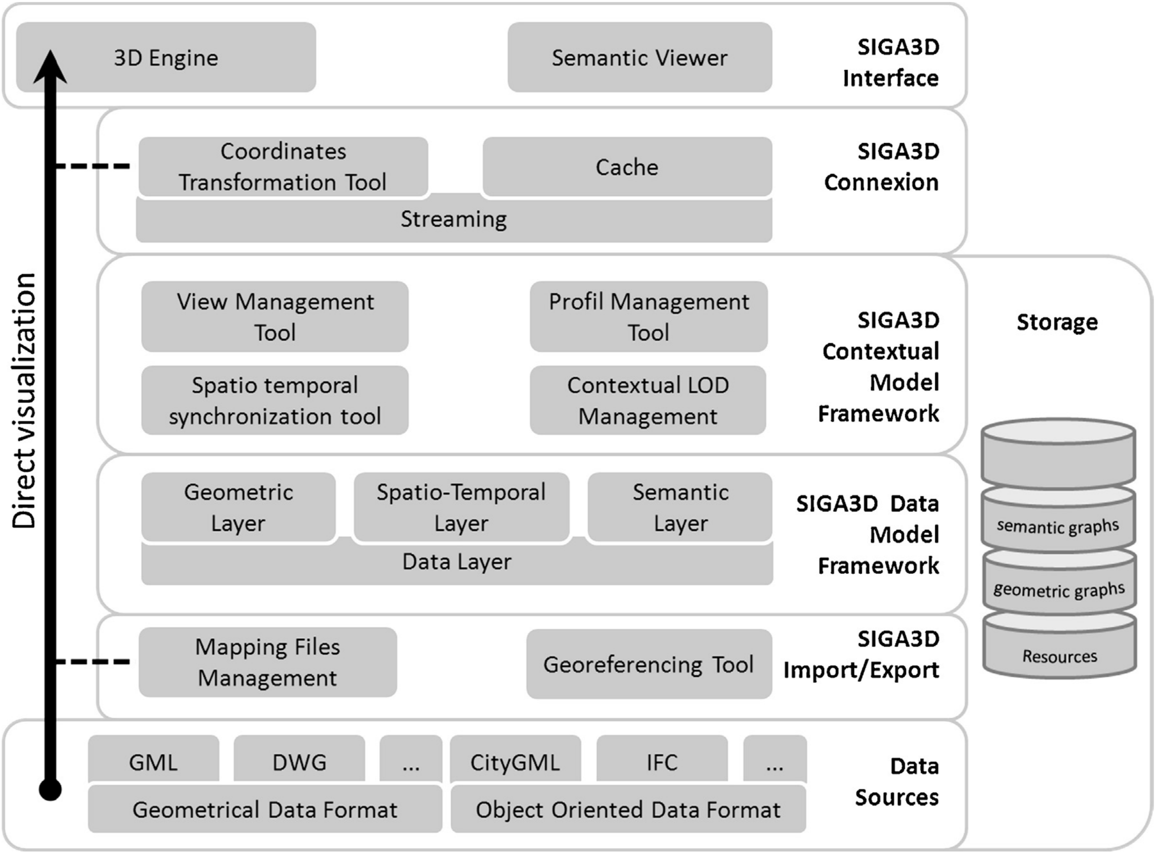
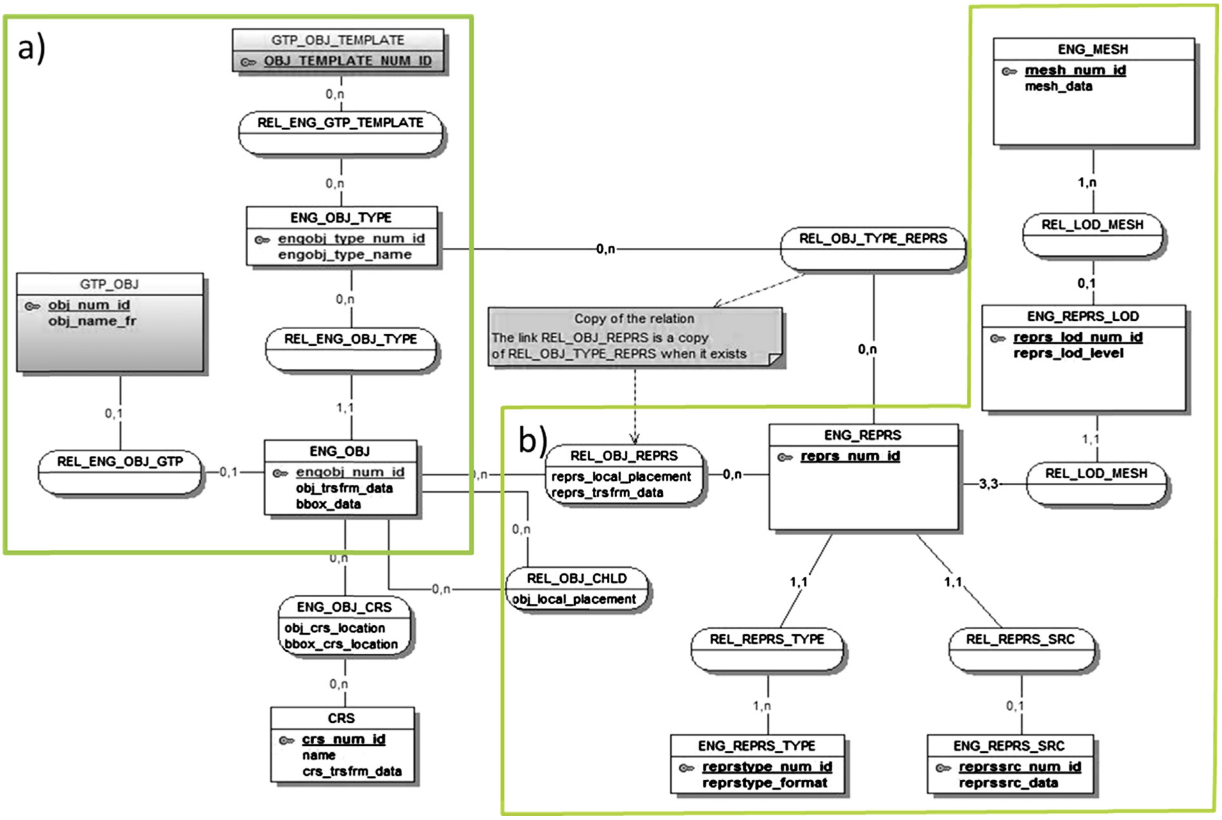


Fig. 8. Organizational view of the UFM processes.



Copy of the relation
The link REL_OBJ_REPRS is a copy
of REL_OBJ_TYPE_REPRS when it exists

Fig. 9. Conceptual model of the UIM.

made up of the objects `GTP_OBJ_TEMPLATE` and the relations to `ENG_OBJ_TEMPLATE`. It defines objects that can be instantiated thanks to the factual level made up of `GTP_OBJ` and its relation to `ENG_OBJ`.

To store this part of the ontology we used a relational model due to industrial constraints. Indeed, the platform is currently used by thousands users, so we had to make a first quick implementation, cost effective and compatible with the information system held by our customers. For this reason, we do not have any efficient implementation of the ontology in triplestores at the moment but the work is in progress.

The links between the semantic and geometric data are created in the database. The purpose of these links, one at the level of the data model and another at the level of data instances is to recover, from each object or concept in the ontology, its associated geometry. From this geometry we can find its representation or representations. The reverse is also true as we can see a scene from the geographic database and query the semantic data model for information on the objects displayed graphically.

These geometries are links to representations, highlighted in Fig. 9b. It consists of the relationship between the classes `ENG_REPRS` and `REL_OBJ_REPRS` that contain representations of each object (each object being linked to one or more representations). Geometries can be stored in two ways: either directly as mesh (explicit description of the geometries), or as primitive, like described in the source files most of the time. The way the geometries are stored in this part will affect the performance of dynamic load (streaming) directly. The choice will depend of the context of use. We can notice on this diagram that for each representation, levels of details are stored (`class ENG_REPRS_LOD`). These levels of details are automatically computed.

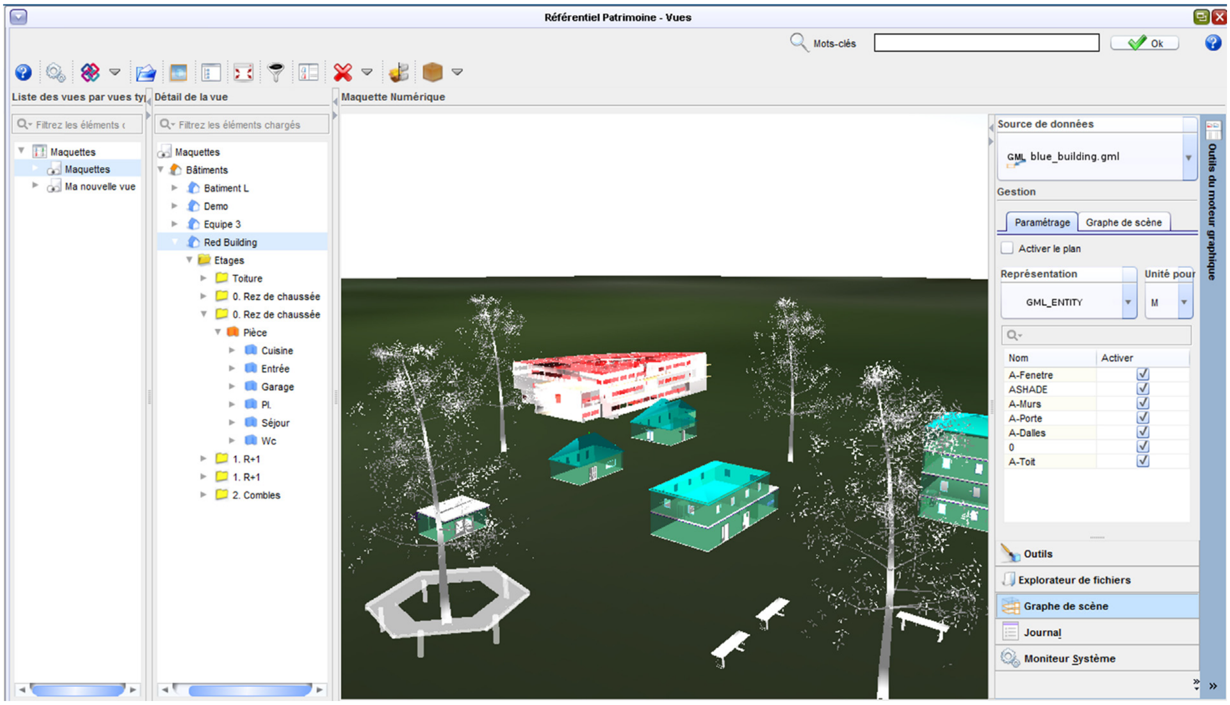
The contextual levels of details are the process to choose one of the representations depending on the context. The context graphs are stored in the factual part of this diagram. Others parameters can though be considered to choose the representation as external elements such as day and night and defined explicitly by the viewer.

5.3. *Results*

We now present briefly the results of the implementation we made in ACTIVe3D. The visualization of the ontology can be done from the 3D viewer as well as in the form of contextual alphanumeric trees. To do so, the process consists to load from the database some pieces of the information contained in the semantic graph. The data is then displayed in a contextual view created during the modeling process, and selected depending on the current context of the user. Similarly to the 3D part, only the displayed data are loaded into memory. The mechanism of streaming is possible thanks to the use of alphanumeric trees for which only displayed nodes are loaded into memory, without their subtrees. Fig. 10 is a screenshot of the ACTIVe3D platform where we can see an entire site appearing in both the 3D engine and the alphanumeric view. The objects shown on this screenshot come from different sources, mixing GML and IFC. The two views are related: selected and edited objects in one view are also in the other, thanks to the unique identifier mechanism we explained in the data import phase. It is possible to perform a geometric query from the semantics to have a 3D custom view of the selected object, or, on the contrary, make a semantic query from the 3D view to obtain additional information on the selected object.

To complete these results, we have built a complete scene composed of several buildings described in different formats. The next table (Table 1) shows the buildings composing this scene with their format, file size, the size of the cache memory once the building imported in the scene, if it is composed of 3D or 2D objects, the number of objects it contains, and the time it takes to import the building in the scene (i.e. read the file, compute the representations, populate the ontology, etc.). The tests have been made on Windows Seven on an Intel Core 2 Duo machine with 2GB of memory and an ATI Radeon HD 4670 graphic chipset.

To conclude this part, each element of the Fig. 10 can be related to elements of our architecture, as shown in Fig. 11. We can see the link between the simplified SIGA3D architecture and the elements of the user interface (scene graph on the right (2), lists of the data loaded from the database or files above (1), 3D engine at the center



Source de données: blue_building.gml

Représentation: GML_ENTITY

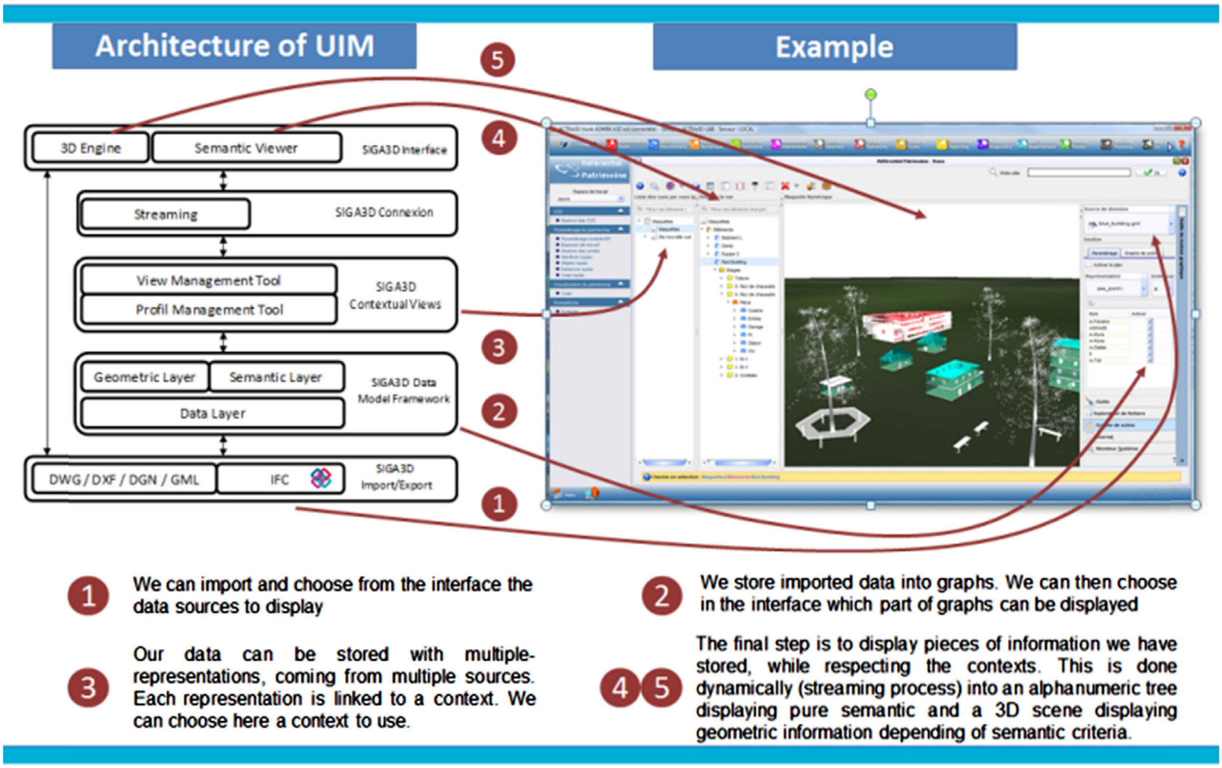
Unité pour: M

Nom	Activer
A-Fenetre	☑
ASHADE	☑
A-Murs	☑
A-Porte	☑
A-Dalles	☑
0	☑
A-Toit	☑

Fig. 10. Screenshot of the SIGA3D platform.

Table 1
Statistics of a composed scene.

File type	File name	File size (kB)	Cache size (kB)	2D/3D objects	Number of objects	Opening time (s)
DGN	FLOOR_PLAN	151		/		7
DGN	FLOOR_PLAN	43		/		6
DWG	PLAN-SURFACE	201		2D	170	9
DWG	plan park	566		2D	2564	8
DWG	plan masse	1760		2D	32131	9
DWG	Site_Full	676	4403	3D	131	7
DWG	10_11_01	1408	13,170	3D	2015	12
DWG	Nantes_long_10_10_00	1688	92,211	3D	569	26
DWG	1er_Etage_mairie_de_paris_2010_purge	3600		3D	85	16
DWG	1er_Etage_mairie_de_paris_2010	3767		3D	236	41
CityGML	Complex LoD3 objects	41,061		2D/3D	209	27
CityGML	LoD 4 house	139,500		3D	521	187
IFC	Building_storey.ifc	6100	8606	3D	907	40
IFC	Universite_Nantes_building.ifc	3872	6484	3D	1217	19
IFC	POSTE-POLICE-PARIS.ifc	7060	2872	3D	538	41
IFC	Dijon_toison_extension.ifc	23,823	76,757	3D	5743	379



① We can import and choose from the interface the data sources to display

② We store imported data into graphs. We can then choose in the interface which part of graphs can be displayed

③ Our data can be stored with multiple-representations, coming from multiple sources. Each representation is linked to a context. We can choose here a context to use.

④⑤ The final step is to display pieces of information we have stored, while respecting the contexts. This is done dynamically (streaming process) into an alphanumeric tree displaying pure semantic and a 3D scene displaying geometric information depending of semantic criteria.

Fig. 11. SIGa3D: links between the application and the architecture.

(5), lists of contextual views on the left (3), and hierarchical tree of patrimony depending on the selected contextual view between the two previous elements (4)).

6. Conclusion

The research presented in this paper defines a new approach for urban facility technical management. This includes the modeling and exploitation of buildings information, their environment, urban elements and networks. For this purpose, we defined a process of production and management of this information, throughout the entire lifecycle of the described objects. We have named this concept the urban facility management. In particular, we created an Urban Information Model (UIM by analogy to the Building Information Model), which allows us to model all the information of the city, including urban proxy elements, networks, buildings, etc. into an ontology. Our approach is the crossroads between building modeling and Geographic Information Systems.

We based our works on an existing platform dedicated to building facility management. It uses the semantic BIM to manage data and contexts. We extended this architecture to manage geographic elements. The idea is to use the semantic approach to bridge the gap of heterogeneity between BIM and GIS. By building an evolutive ontology that manages space, time and multi-representation, we are able to manage in a same structure and with the same tools data coming from BIM and GIS worlds. A mechanism of contextual levels of details allows us to optimize the 3D scene and information displayed to the users.

This approach allows facility managers to support the life cycle of an urban environment from the design to the recycling of the buildings in a collaborative context. Several actors provide and handle urban information. The feedback of end users can be transmitted through the platform to the facility managers in order to improve the quality of knowledge models. Our framework facilitates data maintenance (data migration, model evolution) during the lifecycle of an urban environment and reduces the volume of data with specific graph operators. It further presents data processed and stored into our databases into an ergonomically and friendly 3D Interface (improve by the feedbacks of our customers such as the city of Paris). In fine, if the concepts behind the interface are powerful (ontologies, reasoning, 3D representations, C-LoDs, etc.) and allow many actions, the different processes are transparent for the users since they use an interface dedicated to handle all the elements they have to manage.

The work we have conducted to get these results provides advancement in the interoperability between two fields. But there is still some works to achieve. The main limit in the development of the existing approach presented in this document is the use of a database to store the instances of the ontology. If the semantic mechanisms described in the project SIGA3D have been transposed to the relational model, the power of ontologies is not fully used. With the development of new powerful triplestores such OWLIM and Virtuso, we want to modify the existing architecture of SIGA3D to exploit them. We have already developed an ontology based on IFC 2X3 stored into the OWLIM triplestore. Our ongoing research is to develop several ontologies dedicated to specific domains of expertise, and linked them thanks to the architecture of SIGA3D. The goal is to make possible the use of specific tools to make logical reasoning and checking of inconsistency on model sets. This way, it will become possible to deal with the lifecycle of an ecosystem of ontologies.

7. Key terms

7.1. Building Information Modeling (BIM)

The term BIM has been presented recently as a demarcation of the next generation of Information Technologies (IT) and Computer-Aided Design (CAD) for buildings which focus on the production of drawings. BIM is the process of generating, storing, managing, exchanging, and sharing building information in an interoperable and reusable way.

7.2. CityGML

CityGML is an information model dedicated to the representation of sets of 3D urban objects. It is an open standard implemented as an application schema for the Geography Markup Language 3 (GML3), the extendible international standard for spatial data exchange issued by the Open Geospatial Consortium (OGC) and the ISO TC211.

7.3. Facility management

Facility management is a set of processes that aims at managing spaces, infrastructures, people and organizations. It is used to anticipate and reduce inherent costs to the management of a building for example, and to add value to the core business of the client organization where possible. The urban FM extends this concept to the management of specific city elements, including geographic objects, networks, etc.

7.4. Geographic Information Systems (GIS)

is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data. Geographical data are all kind of objects linked to a location. GIS are known to be effective in the management of large amounts of data on large surface areas.

7.5. IFC

The "Industrial Foundation Classes" (IFC) is an ISO standard that defines all components of a building in a civil engineering project. IFC includes object specifications, or classes, and provide a structure for data sharing among AEC applications.

7.6. Ontology

Literature now generally agrees on Gruber's terms to define an ontology: explicit specification of a shared conceptualization of a domain. The domain is the world that the ontology describes. It can be a general domain or a more specific one. This description uses a vocabulary of concepts which is understandable and agreed by people of the domain; here is the meaning of "shared conceptualization". The ontology can be implemented in several languages with a different level of formalization and expressivity, with no ambiguity that's why ontology is an "explicit specification".

7.7. Semantic web

The term was coined by Tim Berners–Lee who defines the semantic Web as a web of data that can be processed directly and indirectly by machines. In other words, semantic Web is a mesh of information linked up in such a way so as to be easily processable by machines, on a global scale.

7.8. Urban Information Modeling

It is a semantic modeling framework that aims at coupling GIS and BIM fields by the definition of contextual processes in order to integrate the business knowledge. It aims at modeling the knowledge of urban environment.

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References

[1] J. Allen, Maintaining knowledge about temporal intervals, Commun. ACM 26 (11) (1983) 832–843.

[2] M. Batty, Urban Modelling, in: R. Kitchin, N. Thrift (Eds.), International encyclopedia of human geography, 51–58, Elsevier, Oxford, 2009, , ISBN: 978-0-08-044910-4.

[3] C.D. Benslimane, C. Vangenot, A.C. Roussey, A. Arara, Multi-representation in ontologies, in: Proceedings of 7th East-European Conference on Advances in Databases and Information Systems, 2003.

[4] J. Benner, A. Geiger, K. Leinemann, Flexible generation of semantic 3D building models, in: G. Gröger, et al. (Eds.), Proceedings of the 1st International Workshop on Next Generation 3D City Models, Bonn, Germany, 2005.

[5] L. Van Berlo, R. de Laat, Integration of BIM and GIS: the development of the CityGML GeoBIM extension, in: Proceedings of the 5th International 3D GeoInfo Conference, Berlin, Germany, 2010.

[6] P. Bouquet, F. Giunchiglia, F. van Harmelen, L. Serafini, H. Stuckenschmidt, C-OWL: contextualizing ontologies, in: Proc. of the Second International Semantic Web Conference (ISWC 2003), 2003.

[7] J.R. Hobbs, F. Pan, An ontology of time for the semantic web, ACM Transactions on Asian Language Processing (TALIP): Special issue on Temporal Information Processing, vol. 3(1), 2004, March, pp. 66–85.

[8] U. Isikdag, S. Zlatanova, A SWOT analysis on the implementation of BIM within geospatial environment, in: A. Krek, M. Rumor, S. Zlatanova, E. Fendel (Eds.), Urban and Regional data Management, UDMS Annuals 2009, CRC Press, The Netherlands, 2009, pp. 15–30.

[9] T. Kolbe, K. Nagel, A. Stadler, CityGML – standard in photogrammetry? in: 52nd Photogrammetric Week in Stuttgart, September 7–11, 2009.

[10] Thomas Liebich, IAI/IFC – concept of the IFC standard and the relation ISO and XML (presentation), in: Presented at Interoperability in AEC&FM, October 29–30, Sydney, Australia, 2001.

[11] The Business Value of BIM in Europe, McGraw-Hill Construction, http://bim.construction.com/research/FreeReport/BIM_Europe/ (accessed March 2013).

[12] M. El-Mekawy, A. Östman, Semantic mapping: an ontology engineering method for integrating building models in IFC and CITYGML, in: Proceedings of the 3rd ISDE Digital Earth Summit, 12–14 June, 2010, Nessebar, Bulgaria, 2010.

[13] C. Mignard, C. Nicolle, SIGA3D: semantic combination of IFC and GIS to support urban facilities management, in: F. Dietter-Dorloff, I. Bedini, E. Kajan (Eds.), Handbook on Research of E-Business Standards and Protocols: Documents, Data and Advanced Web Technologies, Frank Dietter-Dorloff, Ivan Bedini and Ejub Kajan (Ed.), 2011.

[14] C. Nagel, A. Stadler, T. Kolbe, Conceptual requirements for the automatic reconstruction of building information models from uninterrupted 3D models, in: Academic Track of Geoweb 2009 Conference, Vancouver, 2009.

[15] S. Spaccapietra, C. Parent, E. Zimányi, The MurMur Project: Modeling and Querying Multi-representation Spatio-temporal Databases, 2002 (ScienceDirect).

[16] J. Stoter, H. Kluijver, V. Kurakula, 3D noise mapping in urban areas, Int. J. Geogr. Inform. Sci. (Elsevier) 22 (8) (2008) 907–924.

[17] D.Z. Sui, GIS-based urban modeling: practices, problems, and prospects, Int. J. Geogr. Inform. Sci. 12 (1998) 651–671.

[18] R. Vanlande, C. Nicolle, Context DataModel framework: semantic facilities management, Int. J. Prod. Lifecycle Manag. (2008) 165–177 (Inderscience Enterprises Ltd.).

[19] R. Vanlande, C. Nicolle, C. Cruz, IFC and buildings lifecycle management, J. Autom. Constr. (Elsevier) (2008) 70–78.

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