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Abstract

Compliance checking for building models, cities and territories involve formalizing a set of model schema knowledge and constraint. The objective of our study is to propose: an information model to federate heterogeneous data sources describing an urban area (building and building environment) along with a method for formally specifying of urban rules. The overall goal we pursue is to be able to query and to verify data against different regulations and/or requirements. The purpose of this article is to describe our approach for interoperability among different data sources (e.g. IFC, CityGML) thus creating a consistent description of an urban area.

Résumé

La vérification de conformité des modèles de bâtiments, villes et territoires passe par la formalisation d'un ensemble de connaissances, de schémas de modèles et de contraintes. L'objectif de notre étude est de proposer : un modèle d'information permettant de fédérer des sources de données hétérogènes décrivant une zone urbaine (bâtiment, quartier, etc.) et une méthode de formalisation des règles urbaines, afin de pouvoir effectuer l'interrogation et la vérification des données au regard de différentes exigences règlementaires. Le but de cet article est de proposer une approche qui permet d'implémenter une interopérabilité entre les différentes sources de données (ex. IFC, CityGML), dans le but de créer une description cohérente d'une zone urbaine.

Keywords

BIM, CIM, CityGML, IFC, GIS, Semantic interoperability, Federation.

Mots clefs

BIM, CIM, CityGML, IFC, SIG, Interopérabilité sémantique, Fédération.

1. Introduction

In the last years, a growing demand for modelling man-made, natural and built environment has been noticed. This is mainly drawn by the need for merging outdoor and indoor applications according to different use cases such as visualization or applications related to crises, planning, construction, 3D cadaster, etc. Several attempts have been observed lately to design methods and tools integrating GIS and BIM models [1] [2].

BIM stands for "Building Information Modelling". "Building" here is rather generic, going beyond what one would consider a building, including infrastructure elements such as roads, tunnels, bridges, etc. BIM is a combination of processes and methods along with a 3D parametric digital model. BIM aims at supporting sharing reliable information throughout the lifecycle of the considered built element, from design to demolition. Such digital model is a representation of the physical and functional characteristics of the built element (building or infrastructure). Thus, BIM allows specifying who does what, how and when, in the context of a construction project. The scale associated with such BIM projects and related specification of exchanges among actors usually corresponds to the built element itself, without necessarily including it into a bigger city, region or wide scale.

When considering a broader perspective, notably the city and the regional levels, additional approaches exist. We can mention CIM that stands for "City Information Modelling" and relies on a 3D urban model containing the various elements of a city such as buildings, roads and public spaces, streetlights, etc. Moving up to the level of a geographical area, one has LIM that stands for "Landscape Information Model". In another word by expanding the GIS coverage we can create a multiscale digital model that can cover a building, district, city, region, etc.

When considering an information model spanning over several of these perspectives (building, city, region), such model should allow representing the essential nature of the built and natural world as digital information models, which can then support various types of machine-driven computational processes to simulate, analyse, design, manage, understand, assess, test, evaluate the real world. The vision presented here of this digital twin for the environment (be it built or natural) poses several challenges to the existing BIM, CIM and GIS approaches, notably in terms of accuracy when loading objects on large sites, linking different complex objects, information about the surrounding landscape, spatial querying, etc. With respect to this, in the paper at hand, we present an approach for federating BIM and GIS worlds, with the aim to establish a consistent knowledge model of natural and built environment. The approach presented here answers the interoperability gap as identified by several factors such as international standardization organisations (e.g. ISO launching a Joint Working Group on BIM/GIS interoperability), industrial actors (e.g. Autodesk and ESRI collaboration around Project Information Modelling[1]), etc. Such interoperability problem is usually depicted between oriented object data formats (e.g. IFC) and geometrical data formats (e.g. CityGML). Following this separation, our article first introduces the data exchange approaches as done in BIM and in GIS. Section 3 further discusses concepts of interoperability and presents the standard approaches that can be used to implement it. Section 4 presents our proposal for implementing semantic interoperability among the BIM and GIS domains. We conclude this paper with a discussion about the advantages related to our approach, along with the future work needed.

[1] http://www.infrastructure-reimagined.com/bim-and-gis-transformation/

2. Modelling Language Concept

When considering GIS, information modelling is done according to the ISO 19100 series of standards, defining the so-called General Feature Model [3] with respect to the UML (ISO 19505) approach for modelling. On the other hand, when considering IFC, the information model is object-oriented and based on the EXPRESS approach (ISO 10303-11). As there are several fundamental differences between information modelling in ISO 191xx standard family and in ISO 10303, this section focuses on highlighting them.

2.1. Information modelling with in BIM

IFC is an object-oriented open standard initiated by buildingSMART in 1994. It has now become a formally registered international standard as ISO 16739:2013, and represents the BIM data exchange standard. According to [4] IFC (ISO 16739-1), data is structured according to the EXPRESS specification (see figure 1). Thus the structure of IFC comprises four different schema levels, as illustrated by Figure 2. These four layers define the overall EXPRESS Schema and are fully described in the IFC standard. While the lower layer contains abstract schemas for resources as involved in BIM projects (e.g. date and time, topology, geometry, costs), the core layer is limited to the definition of IFC basic concepts namely the IfcKernel schema and the core extensions schemas (e.g. IfcControlExtension[2], IfcProductExtension[3] and IfcProcessExtension[4]). Elements defined according to the core layer schemas can be further extended and referenced by schemas from the shared element layer, which contains elements as required for interoperability with additional services or domains (e.g. facility management, building services). Finally, the top layer contains domain specific data schemas representing entities as specialized according to industry discipline. These entities are "self-contained and cannot be referenced by any other layer[5]".

[2] http://www.buildingsmart-tech.org/ifc/IFC2x4/rc2/html/schema/ifccontrolextension/content.htm

[3] http://www.buildingsmart-tech.org/ifc/IFC2x4/rc2/html/schema/ifcproductextension/content.htm

[4] http://www.buildingsmart-tech.org/ifc/IFC2x4/rc2/html/schema/ifcprocessextension/content.htm

[5] http://www.buildingsmart-tech.org/ifc/IFC2x4/rc2/html/schema/chapter-7.htm

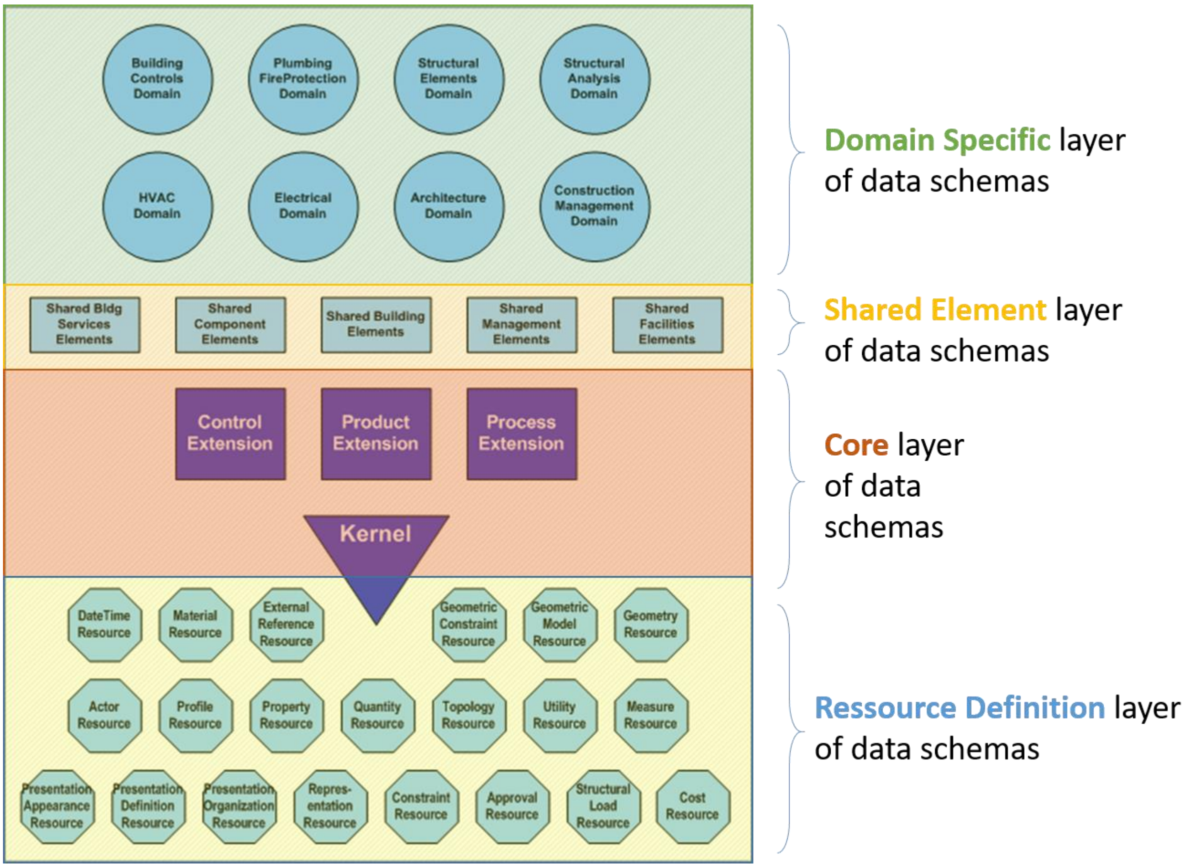

Figure 1: The four layers of data schemas as described in the IFC standard (ISO 16739-1) [4] and modelled in the EXPRESS Schema (ISO 10303-11) [5]

IFC supports a wide range of geometric representations [6] (Boundary Representation (BRep) (figure 2 a), Swept Solid (figure 2 b), and Constructive Solid Geometry (CSG) (figure 2 c)) as well as rich semantic information: such as owner information, modification history of model, and cost and schedule of building components. BIM models based on IFC could be used in various phases of the construction, such as in feasibility studies, tendering [7], code checking [8], and operation management [9]. In addition, IFC file have several format: .ifc, .ifcXML, .ifcZIP, .ifcSTEP, .ifcOWL. For example, an .ifc file can use the STEP serialization, as specified by ISO 10303-21 [10]. This is the most common exchange format used is illustrated in (figure 2 d).

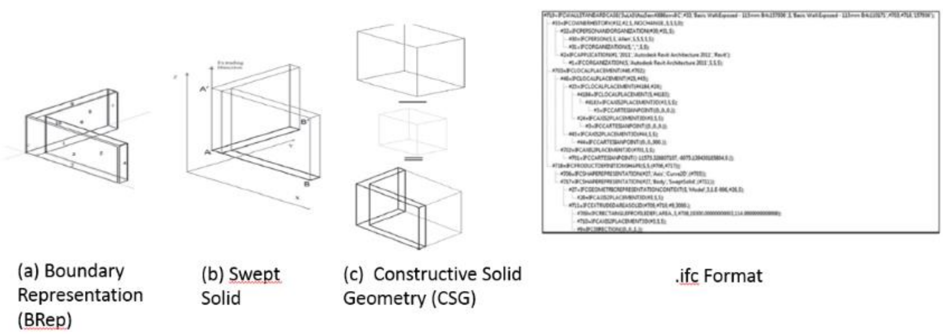

Figure 2: IFC geometrical representation and STEP .ifc serialization

2.2. Information modelling in GIS

A “geographic information system” (GIS) is a computer-based tool that allows you to create, manipulate, analyze, store and display information based on its location. GIS makes it possible to integrate different types of geographic information, such as digital maps, aerial photographs, satellite images and global positioning system data (GPS), along with associated tabular data base information (e.g. attributes). For example, GIS can help in answering questions such as: What exists at a given location? Where does some event occur? GIS allows one to examine and analyze geographic information at different levels of detail or from different perspectives. Then, it enables you to customize the display of your maps and analyses for presentation to particular audiences [11] (figure 3 a). In addition, Geographical features are often stored in Raster or in Vector format. There are numerous formats available for both raster and vector data. It is necessary to consider the file format of GIS data because software programs rarely support all file types. Example of Raster GIS file format: ADRG, binary file, digital raster graphic (DRG), etc. Example of vector GIS file format: GeoJSON, DGN, Keyhole Markup Language (KML), MapInfo TAB format, Shapefile (figure 3 b) [12]. One of the most GIS used tools is City Geography Markup Language (CityGML). It defines basic entities, attributes, and relations present in a 3D city model. It is an open data model based on XML for storage and exchange of 3D city models. A CityGML model thus contains a description of urban elements and components [33].

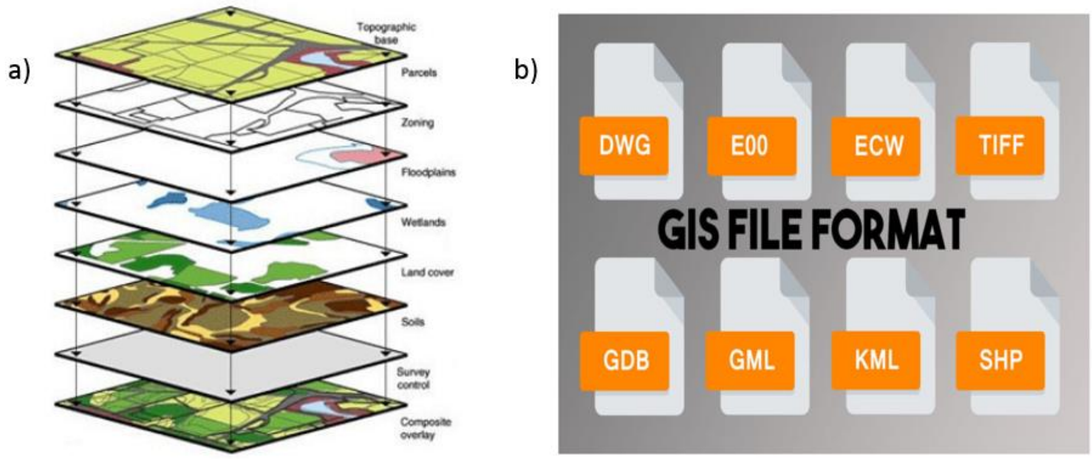

Figure 3: GIS information (a) and format (b)

When considering geographic information, the ISO 191xx standard family is concerned. Based on model-driven architecture (see figure 4), each ISO standard in this family specifies a different level of abstraction. The ISO 19103 UML (Unified Modelling Language) [13] profile along with the ISO 19109 GFM (General Feature Model) [14] represent the two meta-models. Thus, while in the BIM domain, information is modelled according to the EXPRESS schema, in GIS information is modelled according to UML and GFM, following four main levels of abstraction as depicted in Figure 4.

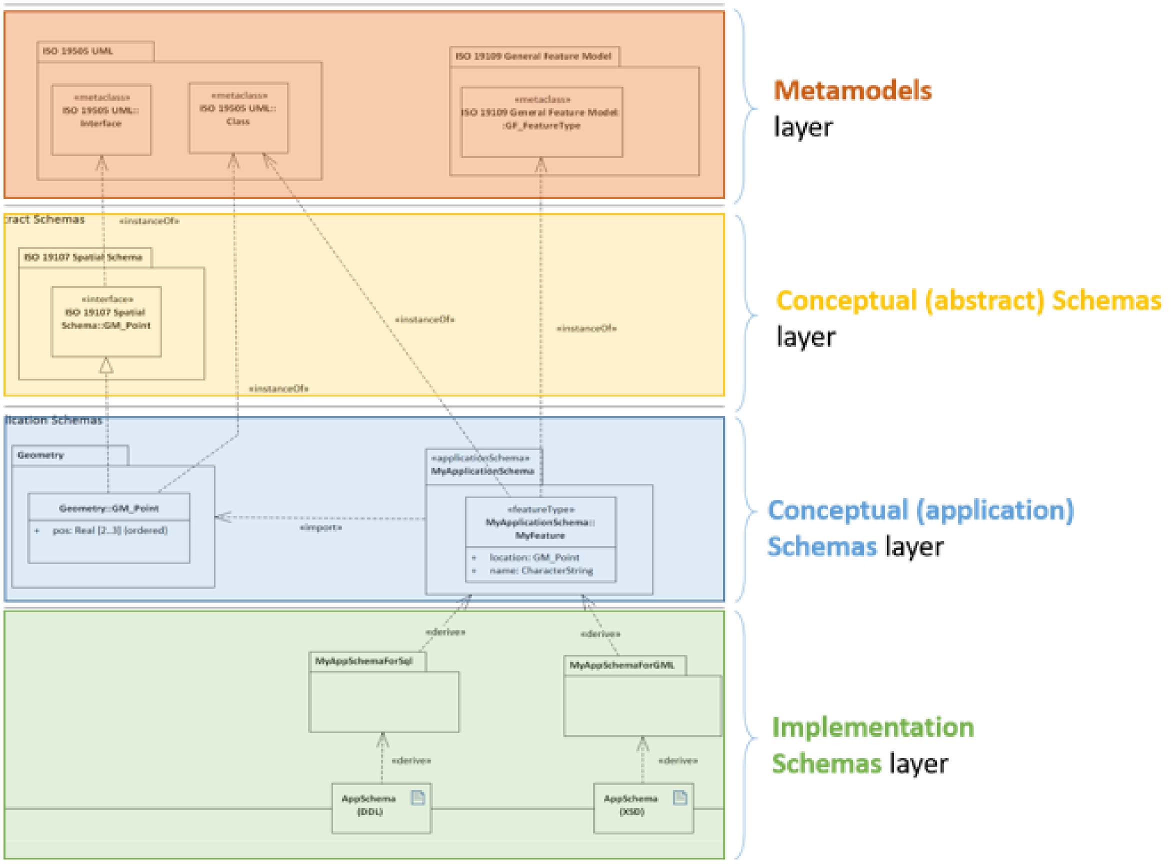

Figure 4: Layers of abstraction as defined by ISO/TC 211 (ISO 19103)

2.3. Comparison of the two modelling approaches

Given the above considerations about modelling approaches as standardized for BIM and GIS, a consistent modelling of BIM&GIS information would require defining rules and constraints aligning the concepts and models used in each domain. Notably, the IFC Core data schemas layer could be aligned with the Meta model layer in ISO 19103, while the Conceptual (abstract) schemas layer in ISO 19103 could be aligned with IFC Resource Definition data schemas layer (see figure 5). According to these remarks, when aiming at BIM/GIS interoperability, modelling approaches as used in the BIM and in the GIS domain could be somehow linked or connected, notably by means of semantic vocabularies such as ontologies. Next section discusses standard approaches and levels existing for achieving interoperability.

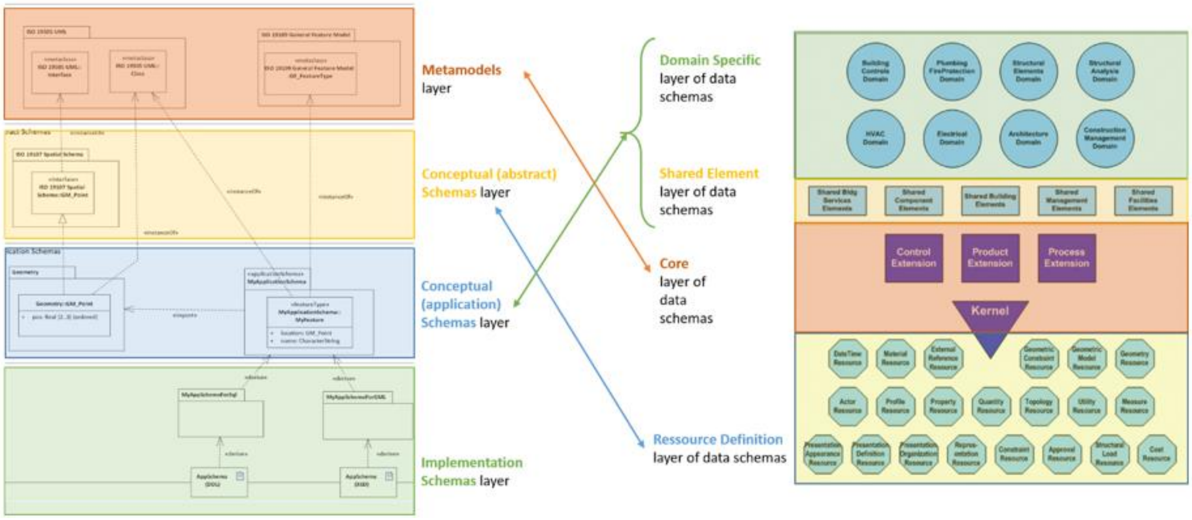

Figure 5: Potential links among the layers of the information models considered

3. Information Interoperability

Enterprise interoperability as an engineering discipline is not yet well defined; interoperability is still a vague concept that has many definitions and connotations in different sectors and domains. Thus, we need to define the concept of interoperability as relevant to our research problem. Interoperability barriers are numerous, and ISO 11354-1:2011 identifies three categories of interoperability barriers, namely: conceptual, technological and organizational. Interoperability barriers need to be categorized in standard ways and existing interoperability knowledge and solutions need to be related to these barriers in order to facilitate interoperability in design and implementation for industry. In computer science, we have 3 levels of interoperability as defined by IEEE 610.12-1990 [15] [16]:

- Physical interoperability level: is related to physical interoperability. The solution to establish such interoperability, is to use basic protocols, such as computer network protocols (e.g. TCP, IP, Ethernet, etc.)
- Syntactic interoperability: can be developed using syntactic formats, to exchange data such level of interoperability is achieved in the context of BIM through the IFC data exchange standard and in the context of GIS with the GML (Geography Markup language) approach
- Semantic - semantic interoperability can be achieved at 3 different levels: minimal (RDF), extended (RDFS) and full (OWL family)

When considering implementing full semantic interoperability, ontologies alone do not allow reaching it and they augment heterogeneity. Thus we have to consider coupling/linking/mapping existing ontology models. The issue thus becomes how to do so. Well, ISO 14258 defines 3 ways: federation, integration, unification [17] [18] (see figure 6).

3.1. Integrated approach

Developing interoperability through an Integrated Approach means that there exists a common format for all models. Diverse models are built and interpreted using/against the common template. This format must be as detailed as the models themselves. The common format is not necessarily an international standard but must be agreed by all parties to elaborate models and build systems. This approach is suitable when designing and implementing new systems rather than reengineering existing systems for interoperability. To some extent, the reengineering approach is more adapted to developing intra enterprise interoperability rather than inter enterprise one. Standardization at system level (not at Meta level) is a key issue to develop interoperability through integrated approach. However, in some areas such as for example enterprise model, mature standards are still missing. The integrated approach ensures the global consistency and coherence of the system. Various components of the system are designed and implemented using a common format (or standard) so that interoperability is seen as designed-in quality. Interoperation between various parts can be obtained 'a priori' without any interfacing effort [19].

3.2. Unified approach

It means there is a common format but it only exists at the meta-model level. This format is not an executable entity as it is the case in integrated approach. Instead it provides a mean for semantic equivalence to allow mapping between models and applications. Using the Meta-model, a translation between the constituent models is possible even though they might encounter loss of some semantics or information. Most of research results developed in the domain of interoperability adopted the unified approach. For example, UEML (Unified Enterprise Modelling Language) aims at defining a neutral format at meta-model level to allow mapping between enterprise models and tools. The STEP initiative elaborated in ISO TC184 SC4 also defined a neutral product data format at meta-model level to allow various product data models exchanging product information. The unified approach is particularly suitable for developing interoperability for collaborative or networked enterprises. To be interoperable with networked partners, a new company just needs to map its own model/system to the neutral meta-format without the necessity to make changes on its own model/system. This approach presents the advantage to the integrated approach because of reduced efforts, time and cost in implementation [19].

3.3. Federated approach

Using the federated approach implies that no partner imposes their models, languages, and methods of work. This means that they must share an ontology. The federated approach can also make use of meta-models for mapping between diverse models/ systems. The difference to unified approach is that this meta-model is not a pre-defined one but established 'dynamically' through negotiation. Consequently, this approach is more suitable to 'Peer-to-Peer' situations rather than the cases mentioned in the unified approach. It is particularly adapted to Virtual Enterprises where diverse companies joint their resources and knowledge to manufacture a product with a limited duration. Using the federated approach to develop enterprise interoperability is most challenging and little activity has been performed in this direction. The main research area is the development of a "mapping factory" which can generate on-demand customized AAA (Anybody-Anywhere-Anytime) mapping agents among existing systems. It is worth noting that specific support for the federated approach is seen in entity profiles, which identify particular entity characteristics and properties relevant for interoperation [19] .

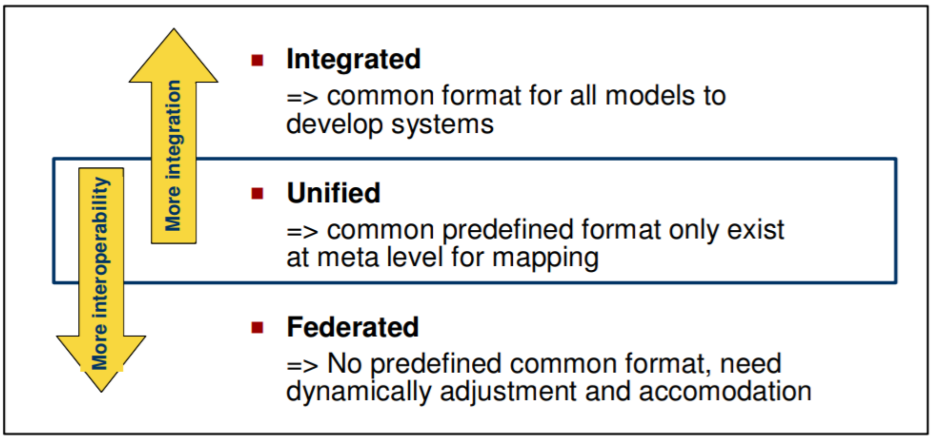

Figure 6: Standard approaches to achieve interoperability [19]

3.4. Conclusion

The choice depends on the context and requirements. If the need for interoperability comes from a merger of enterprises, the integrated approach seems to be the most adapted one. In this case, there is only one common format for all partners, and all models are built and interpreted according to this one. If the need for interoperability concerns a long term based collaboration, the unified approach seems a possible solution. For that, a common meta-model across partners' models provides a means for establishing semantic equivalence allowing mapping between diverse models. Finally, for a need of interoperability originated from the short-term collaboration project, the federated approach can be used. To interoperate partners must dynamically adapt to achieve an agreement. All the three approaches allow developing interoperability between enterprises systems. In [20] federation itself can be further strong-coupled (links are explicitly and formally defined at the level of the ontologies themselves, and the sum of all links is an integrated ontology) or light-coupled (no global ontology defined, higher degree of adaptability - problem: today's approaches do not take into consideration schema heterogeneity, and only define concept level mappings). Thus we'd like to explore federation, and federation addressing schema heterogeneity. So we consider two future axis for work - horizontal federation, and vertical federation.

4. BIM/GIS interoperability

As concluded in the previous section we are going to use federate approach to build the operability between BIM and GIS because no partner imposes their models, language or methods, plus the ability to map between diverse models/systems and finally the meta-model is not a pre-defined one but established 'dynamically' through negotiation. To be able to do so we need to convert IFC, CityGML and GIS to Resource Description Framework (RDF).

4.1. IFC-to-RDF

[21] [22] [23] introduce the process providing a semantic model from the IFC schema by using an IFC-to-RDF-Converter to get a semantic repository. They apply filtration (geometrical and semantic pre-processor) to get an RDF equivalent compact triplet. Over these triples, they build a high-level vocabulary by using SPARQL rules (e.g., highest store concept) and SWRL. [24] mention an approach to simplify ifcOWL building data by releasing of geometrical and (re)presentation data, and correct mapping of IFCRelationship. [25] proposed another version of the ifcOWL ontology that contains two main changes: first the EXPRESS collections (e.g.

LIST) are mapped as OWL properties, second the ifcOWL ontology is simplified, as IFC defined types are not directly converted into OWL classes. This approach presents the following advantages: it facilitates the data access and improves the query execution time since we have fewer triples to match and the ontology has a fewer class than the buildingSMART IFCOWL. In [26] , authors present the IfcWoD (Web of Data) ontology that correctly adapts the IFC relationships and property sets into OWL, without applying direct mapping of all EXPRESS constructs. ifcOWL is used as a meta-model for IfcWoD, without redefining all concepts and relationships. This approach presents multiple advantages such as enhance reasoning and easier query writing and relation understanding which contributes to better performances. Authors from [27] used a Java program based on Apache Jena libraries for automatically translating IFC to RDF, and generating a mapping between the so-generated IFC ontology and the CityGML 2.0 ontology.

4.2. CityGML-to-RDF

[27] have developed a Geotools API for translating CityGML to RDF (http://docs.geotools.org/latest/javadocs/), and generate a mapping between IFC ontology and CityGML ontology. Authors from [19] propose that the UML diagram of the transportation model of CityGML can be translated into the OWL language with the ontology editor Protégé. The UML classes and relations of CityGML can be directly translated into OWL classes and properties. The attributes can be either translated into datatype properties or object properties. The cardinality restrictions can be represented by formulas in descriptive logic. In [28] authors define the ontology of CityGML as the following: UML classes will be translated into concepts, associations/roles will be translated into semantic relations; association, cardinalities will be expressed as restrictions relatively to relations, aggregation/composition will be expressed "as part" of links, generalisation will be expressed as "is a" links, UML attributes will be translated either into concepts attributes or into relations between concepts

4.3. GIS-to RDF

In [29], authors introduce TripleGeo, an open-source ETL utility that can extract geospatial features from various sources and transform them into triples for subsequent loading into RDF stores. The author aims to bridge the gap between typical geographic representations from a variety of proprietary files and the geo-reference system with the demand of geospatially-enabled RDF store. TripleGeo provide multiple advantages such as: Directly access the geographic formats (oracle, PostGIS, shape files), Recognize many geometric data types (points, line-strings, multi-line-strings, polygons, multi-polygons), extract thematic attributes (identifiers, names, types, etc.), Allow on-the-fly projection between coordinate reference systems, export triples into various notations (RDF/XML, TTL, etc.). In [30] the authors present GeomRDF, as a tool that helps users to convert spatial data from traditional GIS formats to RDF model easily. It generates geometries represented as GeoSPARQL WKT literal but also as structured geometries that can be exploited by using only the RDF query language.

4.4. FOWLA approach

Federated architecture for ontologies (FOWLA) is defined as an architecture based on autonomous ontologies (including TBox and ABox) with sharing described as a rule-based format controlled by inference mechanisms (e.g. SWRL). The architecture contains two main components: The Federal Descriptor (FD) and the Federal Controller (FC). FD component is responsible for describing ontology alignments, and the FC model is executed at query time and allows exchanging data among ontologies according to the FD alignments. The main contribution of FOWLA architecture to interoperate numerous ontologies. This proposal provides several advantages: it allows for inferring new ontology alignments, it avoids data redundancy, it allows for modularizing the maintainability, through preserving the autonomy among ontology-based systems, it allows for querying with vocabulary terms issued from different ontologies and it improves the query execution time [31].

4.5. Contextual Levels Approach

[32] presents a modelling process which built the ontology and define the context and the mechanism of Contextual Levels of details that aim at improving the management level of data. The ontology is based on C-DMF (Contextual Model Framework and Data Model Framework) the SIGA3A extends C-DMF to defined new relational items and resources for the geographic world. The model data Framework aims to define a data model. It can model semantic information as well as geometric and spatial-temporal entities. CMD consists in defining a context for the DMF graphs to simplify the management of the evolution of integrated information. This approach is a crossroads between building modeling and geographic information system, where a model is created for all information in the city, including urban proxy element, network, building, etc. into an ontology.

4.6. Conclusion

In this section we have present the previous work done to transform IFC, CityGML and GIS into RDF. In addition, we have introduced FOWLA, and contextual level that have mapped and combine different ontologies. As we aim at BIM/GIS interoperability, modelling approaches of these different domain could be linked or connected, notably by means of semantic vocabularies such as ontologies. The section 4.1, 4.2, 4.3, 4.4, and 4.5 could be used to helps us in our work but doesn't solve the interoperability between BIM and GIS.

5. Regulation for compliance checking

As we have transformed information model to RDF and federated them into one meta model. Local Urban Plain (PLU) defines the urban planning rules, the different zones and the architectural prescriptions. A conversion of textual regulation to SPARQL is needed to query, and check the information contained in the generated meta model. As, PLU is divided to multiple level (Area, zone, district, construction rule) and the Meta-model contain multiple LOD. We aim to create a textTordf conversion method and an alignment between each PLU level and LOD.

6. Future Work

When considering a more global semantic interoperability between BIM and GIS domains, one has to take into consideration what specific use case is addressed. Reaching semantic interoperability between GIS and BIM would imply considering coupling several approaches: first an alignment or mapping should be defined for the different syntactical standards (data formats) as used in the two domains, and the second one could investigate coupling the models behind EXPRESS and GFM through model federation. By achieving BIM and GIS interoperability and aligning meta-model LOD to regulation level we can navigate between different levels (BIM, CIM, LIM) while conserving semantic and geometric information and applying SPARDL query representing regulation (building, city regulation, etc.) on multiple scale to enable the compliance checking of different objects.

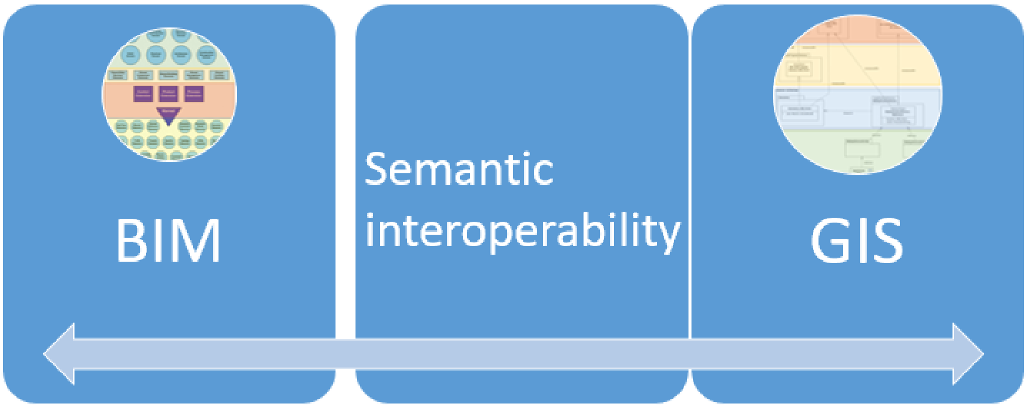

Figure 7: Mapping between BIM and GIS through semantic interoperability

7. Conclusion

In our future work, we aim at creating a multi-scale digital mode (building, district, city, and region) combining GIS and BIM features and relying on Semantic Web technologies for semantic interoperability between the different components. In our approach, we do not seek to merge BIM and GIS, neither to promote one over the other. As discussed in previous sections, when considering model-driven approaches for interoperability, one can do model union, model fusion, or model federation. As a first approach we will investigate a federation approach, and consider tow axis for such federation: a) Horizontal federation will be implemented by defining semantic links among terms/concepts in different ontologies/vocabularies from the domains considered (Ontologies for BIM ontologies for GIS), b) Vertical federation will be addressed by conceiving a meta-model for BIM/GIS. Such meta-model will provide the means necessary to switch between different levels of abstraction.

8. Figures

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