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▶ To cite this version:

Ana Roxin, Elio Hbeich. Semantic interoperability between BIM and GIS – review of existing standards and depiction of a novel approach. 36th CIB W78 – Information Technology for Construction, Sep 2019, Newcastle, United Kingdom. hal-02279633

HAL Id: hal-02279633
https://hal.science/hal-02279633

Submitted on 13 Sep 2019

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Semantic interoperability between BIM and GIS – review of existing standards and depiction of a novel approach

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Abstract

When it comes to Big Data ecosystems, main technical challenges pertain to defining links between data, information and knowledge, thus reaching interoperability. Interoperability issues are addressed in the context of data curation related tasks. Interoperability is a major pre-requisite for achieving data automation, validation, thus fighting counter-productiveness (notably through data incentivisation). The demand for interoperable, reusable and open data is more and more present, thus pushing forward the research for innovation data curation approaches. This article gives a high level description of our approach for bridging the interoperability gap among GIS (Geographic Information Systems) and BIM (Building Information Modelling) systems. After a summary of standards existing in the considered application domains, we further specify the interoperability issues applying and present existing approaches for reaching interoperability among models. Based on the study of these approaches, we then discuss our approach and the related multi-scale modelling. We illustrate how it allows reaching federation among GIS and BIM systems, while supporting consistent reasoning on the features of the federated systems. We conclude with a listing of future work to be done in order to reach this vision.

Keywords: BIM, GIS, Semantic Interoperability, Cyber-Physical Systems, Granularity

1. Introduction

Our today's society faces what we call the fourth industrial revolution (4IR) along with its impacts on our everyday lives. 4IR differs from the three previous revolutions because it not only addresses production automation but also knowledge automation. Sometimes referred at as "Industry 4.0" (the term was coined in Germany's manufacturing industries, a dozen of years ago), the epoch we are living is heavily impacted by the development of Cyber-Physical Systems (CPSs) in almost every activity sector. As the Web changed our lives 25 years ago, so the CPSs will also change the interactions we have with the physical world surrounding us. Usually defined as "*physical and engineered systems whose* operations are monitored, coordinated, controlled and integrated by a computing and communication core" (Rajkumar, 2010), CPSs can be applied in a multitude of application domains (e.g. agriculture, energy, buildings, manufacturing). Their design and implementation come with several issues that are usually best addressed through multi-disciplinary researches.
In this article, we consider the domain of urban processes' implementation, in the context of tomorrow's smart cities. Today's urban scopes usually come with a number of specific challenges that are too complex to address for a single stakeholder or territorial community. We are witnessing the occurrence of more and more individual behaviours and collective practices, along with innovative rules and norms (be it at a national or international level), all seeking to conceive multi-level and multi-scale solutions addressing the overwhelming challenges associated with the vision of smart cities. More specifically, when considering knowledge automation, smart cities become sandboxes for problem-solving, or incubators for intelligent approaches providing local answers to challenges such

as climate change, energy efficiency or inhabitants' comfort. Cities and urban environments in general represent complex systems: they can hardly be reduced to their geographical scopes, and need to be interpreted from a multi-dimensional perspective encompassing their spatial, economic, social and cultural aspects. Complexity is pushed at an even higher level when taking into consideration the different standards and regulations that apply on each of the aspects listed above. Notably, regarding spatial aspects there are two main standard families that apply: a) Standards pertaining to Building Information Modelling (BIM), promoted by buildingSmart International (bSI) and the ISO TC 59 b) Standards pertaining to Geographic Information Systems (GIS), promoted by the Open Geospatial Consortium (OGC) and ISO TC 211.

While GISs allow integrating different types of geographic information along with their attributes (e.g. raster images, digital maps), BIM aims at delivering methods for easing the management of building information thorough the built lifecycle (e.g. from design to demolition). While both standard families come with structured information models and processes for describing aspects from the considered domains, no links have been defined between the two worlds. Thus when it comes to implementing knowledge automation approaches in the context of smart cities, data must be seamlessly integrated into a system ensuring its consistent interpretation by the machine. In other words, interoperability must be reached among the models used for integrating the data. Or as such, a building's digital twin (as conceived with BIM standards) has no relation to a system's twin defining constraints and contexts the building has to integrate e.g. the urban scape. This prevents conceiving interoperable approaches for predictive maintenance, dynamic simulation or energy-efficiency improvement.

For addressing this issue, we present our approach for interoperability, based on meta-model federation. The article is divided as follows: section 2 introduces BIM and GIS information models as defined in the respective standard families, section 3 reviews existing standard approaches for interoperability, while section 4 describes BIM and GIS barriers. Our approach is discussed in section 5 and finally we conclude in section 6.

2. The need for interoperability

2.1 BIM information model

Building Information Modelling (BIM) is a 3D model-based process that gives architecture, engineering, and construction professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure. BIM model can be used for analysis to explore design options and to create visualizations that help stakeholders understand what the building will look like from start to finish. The model is then used to generate the design documentation for construction. Finally, BIM describes a method of work by which all relevant information for the life cycle of the building is integrated, administered and exchanged among the project participants. ISO 29481 (ISO 29481-1 2016) defines BIM as a shared digital representation of an object built to facilitate design, construction and operating process and form a reliable basis for decision-making. The first stage of BIM standardization was carried out in 1999 by IAI (now buildingSmart International) (Eastman et al., 2011). BIM relies on the following international standards:

- Information Delivery Manual (IDM) specifies how information is exchanged in a process. It is based on the ISO 29481 (ISO 29481-1:2016) standard and is defined as an interchange agreement. IDM is a natural language description of the exchange.
- Model View Definition [1] (MVD) describes the data model needed to meet the exchange requirements described in the IDM. The underlying methodology is described by Part 3 of ISO 29481 (ISO 29481-3:2010).
- Industry Foundation Classes (IFC) (Liebich et al., 2013) represent the conceptual model for buildings and comprises all classes and relations for representing a building (ISO 16739 2013). The IFC model is specified in EXPRESS and complies with ISO 10303 (ISO 10303-21:2002)

[1] http://www.buildingsmart-tech.org/specifications/mvd-overview

also called STEP part 21 (STandard for the Exchange of Product model data). STEP focuses on the representation and exchange of product data and aims to integrate the processes of design, development, manufacture, and maintenance (see figure 1).

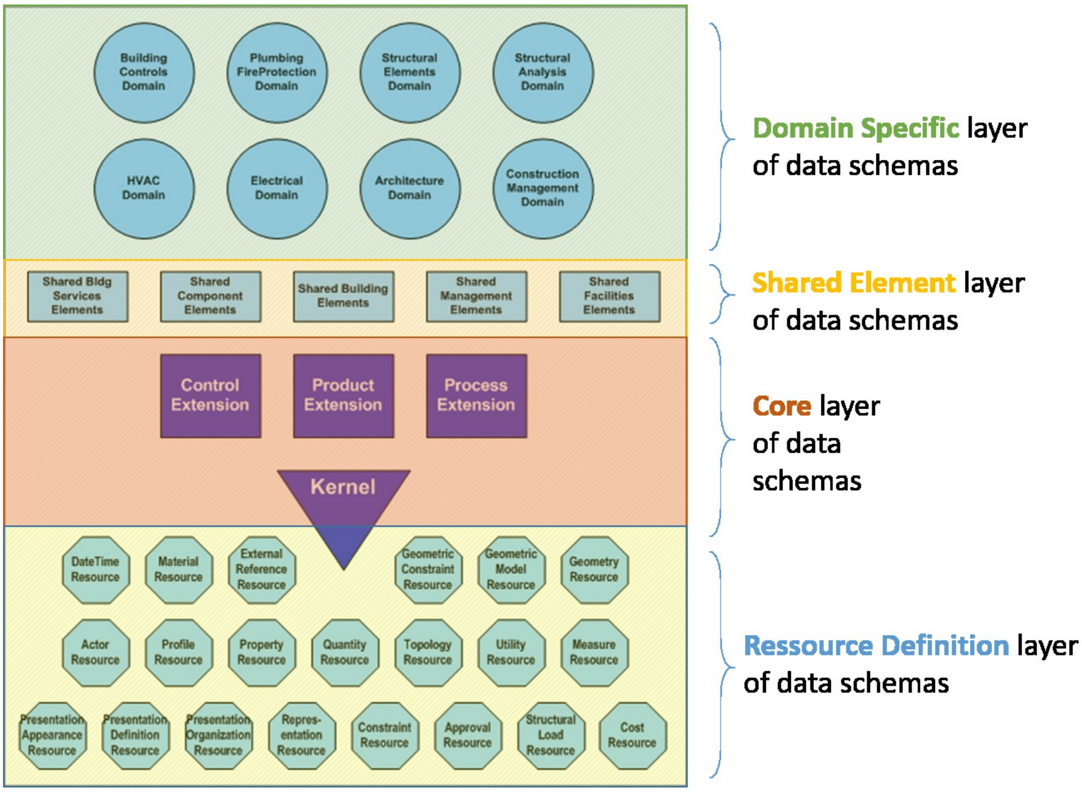

Figure 1: IFC layers of data schemas (ISO 16739-1) and modelled in the EXPRESS Schema (ISO 10303-11).

2.2 The GIS standard family

GIS allows capturing, storing, handling and analysing geographical data (Sahoo, 2017). The main international organization developing standards for geospatial information is ISO TC 211. ISO's Technical Committee 211 (ISO/TC 211) is dedicated to developing and deploying standards relating to geographic information. ISO/TC 211 specifies methods, tools, and services for data management, acquisition, processing, accessing, presenting, and transferring such data digitally (ISO 191xx series 2006).

The approach to conceptual modelling in the ISO 19100 series is based on the principles described in the ISO CSMF (Conceptual Schema Modeling Facilities) (ISO 191xx series 2006). This conceptual schema includes four levels: metamodels, conceptual (abstract) schemas, conceptual (applications) schemas and implementation schemas (see figure 2). The first contains the General Feature Model defined in ISO 19109, which specifies the concepts, terminology, operations, and assumptions needed to build the basic constructs in the Conceptual Schema layer level. The contents of the meta-meta model level is usually expressed in natural language and is not itself subject to standardization. Conceptual Schema layer contains the definitions of the concepts, terminology, operations and assumptions needed to construct application schemas. Application schemas define the types of features and processes that are instantiated to produce datasets of geographic information. Application schemas are expressed using syntax and semantics from one or more conceptual schemas. The "bottom" layer contains the actual data that is defined by the application schema at the application model level.

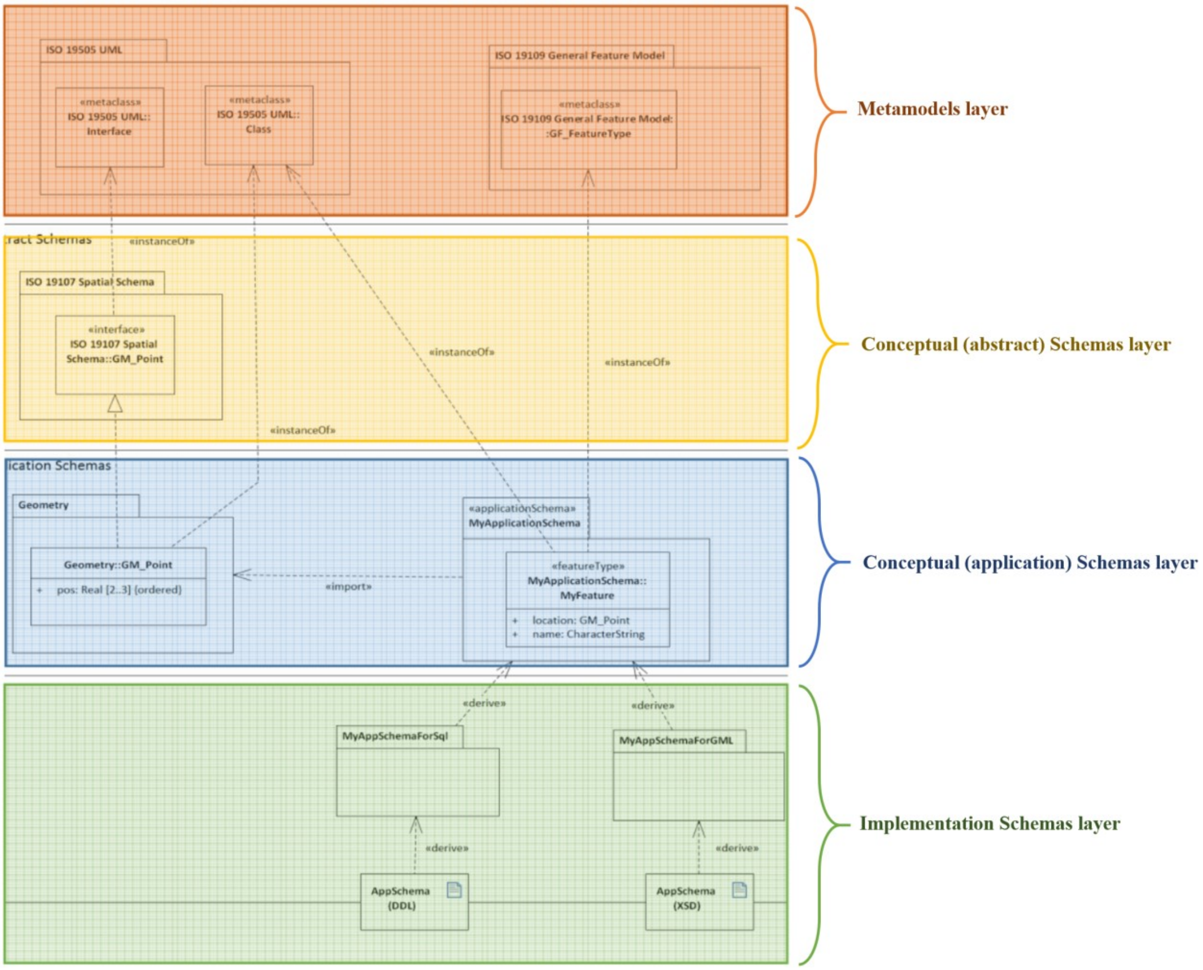

Figure 2: ISO TC 211 Conceptual model (ISO 191xx series 2006)

3. The need for interoperability

3.1 The concept of interoperability and its flavours

Defining "interoperability" isn't an easy task. Several definitions exist for this concept: the ISO alone holds more than a dozen standards, each coming with its own definition of "interoperability". The oldest definition of "interoperability" is from the ISO/IEC 1993 "Information Technology – Vocabulary – Part 1: Fundamental terms", and was updated in the vocabulary's 2015 version (ISO 2382:2015). Interoperability is defined as the "capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units". This definition implies that when interoperable two systems can either exchange information or be accessed with a single method. The heterogeneity of definitions and interpretations harden the implementation of interoperable approaches in real-world applications and enterprises. In order to avoid potential ambiguities with "replace ability", "compatibility" is often used as a synonym of "interoperability" (ISO/IEC/IEEE 24765:2017, 3.2089). Given the above discussion about issues among GIS and BIM standard families, an approach for sustainable interoperability among those artefacts becomes more needed in related smart city knowledge automation applications. Indeed, as mentioned by the authors in (Dassiti et al. 2013), "in today's globally networked environment, one cannot achieve environmental, social/ethical or economic sustainability of any artefact […] without achieving ubiquitous ability of the artefact and its creators and users to exchange and understand shared information and if necessary perform processes on behalf of each other in other words, interoperate."

In order to further specify and tackle the interoperability issues among BIM and GIS, we follow the General System Theory (GST) abstraction (Von Bertalanffy et al.1969) and adapt it to the previous definition of CSPs. We thus consider BIM and GIS abstracted as systems comprising several parts, each part exhibiting some behaviour (that can be different from the overall system's behaviour). These behaviours and their related components, mechanisms and processes are monitored, managed and coordinated by some computer. Hence interoperability is achieved using standards that enable behaviours of parts of the system and the overall behaviour of the system to cooperate seamlessly in order to reach a common goal or function.
With these definitions and statements in mind, the next sections present existing levels of interoperability and discuss existing standard approaches for implementing interoperability.

3.2 Levels of interoperability

Existing standards identify three main levels of interoperability, namely: data, syntactic, and semantic interoperability. These layers are connected and build upon each other, lower levels providing elements required by upper levels functionalities (Kubicek, Cimander, & Scholl, 2011). The following figure illustrates those levels along with their definitions as pertaining to ISO standards.

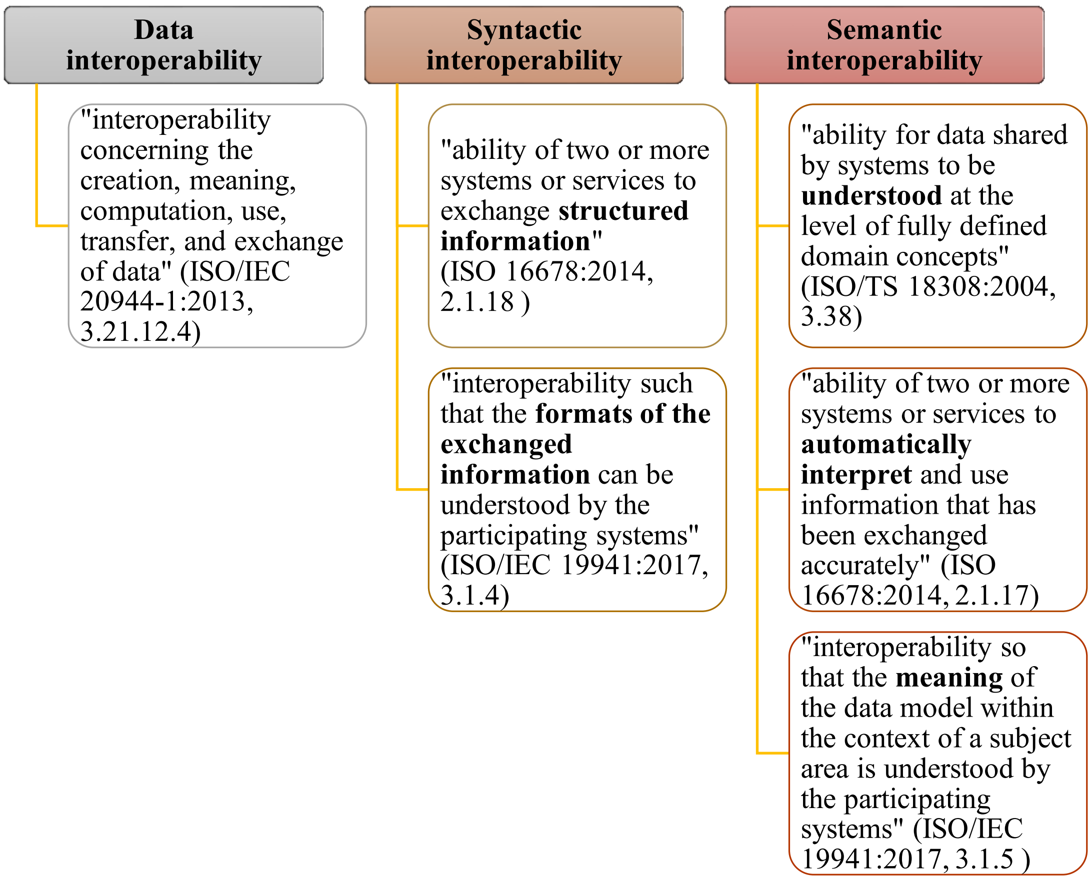

Figure 3: Levels of interoperability

Sometimes referred at as physical interoperability, the issues pertaining to the data level of interoperability have been long resolved with the adoption of hardware standards such as Ethernet (IEEE 802.3,2018); along with standard protocols for lower layers of the ISO network architecture e.g. TCP/IP (RFC 791, RFC 793) and HTTP (RFC 2616).
Syntactic interoperability addresses the syntax of messages exchanged among CSPs considered artefacts. The related issues have been resolves through the adoption of XML and related syntax standards e.g. HTML, WSDL (Web Service Language) and SOAP (Service Oriented Access

Protocol).

Semantic interoperability addresses the meaning of the messages exchanged and related issues have not yet been resolved by existing standards and approaches. Semantic Web standards and languages allow specifying such meaning, by means of formal and explicit specifications of conceptualisations e.g. ontologies. Considering the different Semantic Web languages existing, semantic interoperability comes with different flavours:

- *Minimum* semantic interoperability is enabled by the use of RDF ("RDF – Semantic Web Standards") and allows specifying the minimum knowledge than can be exchanged through a sentence e.g. what is expressed through the sentence itself. One simple example of such minimal semantic interoperability is a sentence (or message) specifying that the object "Paris" is linked to the object "France" through the property "is capital of". Such low level of semantic interoperability requires further manual and/or automated handling of the exchanged data.
- *Extended* semantic interoperability allows defining a minimal ensemble of beliefs onto which two computer agents agree. Such ensemble of beliefs allows computer agents to make new deductions from the implicit facts contained in the message they exchange. Such level of semantic interoperability is enabled by the use of RDF Schema ("RDF Schema 1.1"). With RDFS, the elements forming a statement are identified by URIs (Unified Resource Identifiers), thus computer agents can dereference those URIs and access some shared RDFS-defined ontology specifying, for example, that a capital is a city, has a population, a name, etc. Extended semantic interoperability allows defining a common interpretation of the elements contained in the messages exchanged. There is no agreement upon what those elements may not be.
- *Full* semantic interoperability is enabled by the usage of the OWL ontology language family. An OWL shared ontology can specify what computer agents may agree upon, while preventing them from making erroneous deductions. OWL allows specifying a knowledge conceptualization bounded to a given domain: the lower bound represents what computer agents are allowed to believe, while the upper bound identifies what they may not believe. Coming back at our previous example, full semantic interoperability would allow having an OWL ontology preventing computer agents from deducing that "Dijon" is also the capital of "France".

Following these definitions, semantic interoperability denotes the ability of applications and business partners to interpret exchanged data in a consistent way, implying explicit and formal structures. Such structures define the meaning of data elements and the relationship between them. As mentioned above, ontologies being "formal and explicit specifications of shared conceptualisations of a knowledge domain" (Studer et al, 1998) they represent the building blocks of semantic interoperability. Still, relying on ontologies doesn't lower semantic heterogeneity of the so conceived knowledge models. As an example, we can cite the numerous versions of OWL ontologies conceived for the IFC standard (Schevers & Drogemuller 2005), (Beetz et al. 2009), (Zhang & Issa 2011), (Gao et al.2015). Indeed, while following the advice of Eastman et al (Eastman et al, 2008) suggesting that building data must be represented with Semantic Web technologies in order to reach semantic interoperability, all these ontologies have been defined independently from one another. No semantic links were defined to identify alignments between concepts and relations in those ontologies. Thus, no consistent interpretation can be delivered based on those ontologies solely. The need for defining links among existing knowledge models pertaining to BIM and GIS becomes urgent. And for doing so, the same approaches used for coupling models can be applied to ontologies. In this context, the ISO standard about the integration of industrial automation systems (ISO 14258, 1999) defines three possibilities: models can be *integrated*, *unified* or *federated*. These approaches have been then withdrawn from ISO 14258 and integrated into ISO 15704 addressing the requirements for enterprise-reference architectures and methodologies (ISO 15704, 2000). These three types of approaches were more recently considered as standard interoperability approaches in the context of ISO 11354, defining the Enterprise Interoperability Framework or EIF (ISO 11354, 2011). The sections below further discuss these three approaches, notably based on their specification in the EIF.

3.3 Standard Approaches for Semantic Interoperability

In the context of an *integrated approach*, all exchanged elements have to be represented with respect to a common form. Such common form must have an associated level of expressiveness allowing to capture the specific details of the elements exchanged, especially those impacting interoperability (ISO 11354, 2011). All elements and artefacts in the considered system or organization have to be described according to the common form, even if the latter isn't built upon an existing International standard. This approach is suitable when designing and implementing new systems rather than when reengineering existing systems for interoperability (Métral et al., 2010)
ISO standards implementing model integration are the "Industrial automation systems and integration — Product data representation and exchange" (ISO 10303) and the ISO standard about "Enterprise integration — Constructs for enterprise modelling" (ISO 19440). Outside the ISO, model integration is also applied in the context of ebXML[2], a joint OASIS/UNCEFACT international initiative for enabling the consistent use of XML to "exchange electronic business data" and thus "facilitate open trade between organizations regardless of size".
Unified approaches require a common meta-model. In its simplest version, such meta-model can be a reference vocabulary, while in a more advanced version it can represent a complete ontology. Defined as a meta-model, it allows establishing semantic equivalences among considered concepts or entities. All other considered models with their related syntaxes and semantics have to be mapped to the common meta-model. Using the common meta-model, a translation between the constituent models is possible even though they might encounter loss of some semantics or information. Unified approaches thus rely on model fusion (ISO 11354, 2011).
Unified approaches are best suited for collaborative or networked environments, or in situations implying for a large enterprise to collaborate with several SMEs (ISO 11354, 2011). Examples of unified approaches are very common in the context of the ISO standard families from defined in the TC184 "Industrial data" (SC4) and "Interoperability, integration and architectures for enterprise systems and automation applications" (SC5) sub-committees. Most researches in the domain of interoperability also adopted unified approaches. 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 (Métral et al., 2010).
Federated approaches imply that no partner imposes their models, languages, or methods of work. Such approaches do not imply a common form or a common meta-model (ISO 11354, 2011). They mainly apply to contexts where the entities considered for interoperability rely on too different or too complex vocabularies or methodologies. In a federated approach, each entity needs to adapt its processes and methods. Computer agents are only provided with *a priori* information, about each entity along with their related capabilities. For reaching interoperability in such a context, mappings must be specified among input and output information of the considered entities or artefacts. Remaining inconsistencies must be manually addressed.
Implementing successful federation among organizations or systems comes with more challenges than the two previous approaches. As an example of such implementation, we may cite the federation approach in ISO 16100 "Manufacturing Software Interoperability Services" (ISO 16100). The "Open systems application integration framework" and more specifically the profiles defined in its third part (ISO 15745-3:2003) e.g. process profiles, information exchange profiles and resource profiles, bring additional support for federation-based approaches.

Table 1: Comparison among the three standard approaches for semantic interoperability (ISO 11354, 2011)

	Integration	Unification	Federation
Level of standardization	System level	Meta-level	Model level
Advantages	The form is not necessarily an international standard. All models are built and interpreted according to the	Establishes semantic equivalence allowing mappings between different models	Links are explicitly and formally defined at the level of the ontologies themselves, and the sum

[2] http://www.ebxml.org/

	common form considered	Ensures global consistency and coherence of the system Mapping one's model/system to the neutral meta-model without the need to make changes on its own model/system	of all links is an integrated ontology (sometimes called a Linkset) Partners must dynamically adapt to achieve an agreement No partner imposes their models, languages, and methods of work
Drawbacks	The form of integration must be agreed upon by all parties that will elaborate models and build systems respecting the integration form. Not suitable for inter-enterprise interoperability Standardization on the system level and not on meta level.	Only suitable for developing interoperability for collaborative or networked enterprises Can't achieve dynamic agreement upon mappings	Most challenging to implement Usually used for short-term collaboration projects The lack of a central model increases the effort needed for interoperability at the system level.

4. Bringing semantic interoperability between BIM and GIS

While BIM comes with detailed 3D visualization and various functionalities to organize huge volumes of data related to buildings, GIS environments are highly customizable, well-equipped for multi-dimensional analysis, and ideal for projects involving multi-site environments. While BIM systems are best suited for managing data related to the buildings themselves, GIS applications pertain to the urban scope outside buildings. Even though one is usually struck by the differences among the methods and processes underlying both approaches, there is a general tendency of combining them in order to benefit from their cumulated advantages. Reaching a common vision in which BIM and GIS are complimentary to each other, would bring highly productive outcomes in the field of digital AECO (Architecture, Engineering, Construction and Operations). The integration of BIM and GIS can offer substantial benefits to manage planning processes during design and construction phases. While BIM systems focus on developing objects with maximum levels of detail for respective geometries, GIS are more focused on analysing the objects from the physical environment, based on different abstractions. Combining BIM and GIS processes and methods would allow a continuous and consistent interpretation of the data at different scales and from different point of views. However, reaching such vision comes with several challenges, the main ones being listed below:

1. Coordinate systems and spatial referencing: GIS use two dimensional real world coordinates (RWC 9), while BIM systems use three dimensional relative coordinates between objects, with a reference to RWC at root object. GIS is based on a global spatial reference systems and use boundary representation. BIM applications use local spatial reference systems.
2. Temporal aspects: In BIM applications, a building object is characterized by its geometrical representations and its geometrical and non-geometrical properties. Such object can have several geometrical representations, as they each correspond to a different point of view. Still, the BIM standards do not define any links between these geometrical representations and geometrical properties of the considered building object. Initially such permissiveness was wanted for BIM applications (in order to cope with how levels of detail are handled in GIS systems). But today, standards should restrict or specify explicitly the possible choices. The level of permissiveness allowed by today's standards hinders the efficient implementation of BIM ecosystems, as it all depends of the choices made at the level of software implementations

3. Semantics: BIM and GIS use different vocabularies to describe their entities and properties. No equivalencies have been defined among these elements. While bSI and there is no define link between the IFC and GIS vocabulary has developed the bSDD (buildingSmart Data Dictionnary) listing all existing terms and properties in the IFC standard, there are no explicit links defined between the bSDD vocabulary and other similar initiatives such as the French standard XP P07-150 (AFNOR PPBIM), promoted in the context of CEN/TC 442 WG4. Such semantic links are essential for implementing consistent information exchanges based on the IFC format.

With respect to these challenges, next section will outline our approach for semantic interoperability between BIM and GIS ecosystems.

5. Our approach for achieving BIM/GIS semantic interoperability

Considering the above approaches, along with our application context e.g. knowledge automation in smart cities, approaches based on federation appear as the most suitable. Indeed, integrated approaches imply using one single common model according to which all other models are conceived and interpreted. As mentioned above (Table 1), these approaches are best suited when engineering novel CPSs, and fail in addressing all subtleties of existing CPSs. More specifically, in the context of our approach, two axis are considered for federation - horizontal, and vertical. For the first case, we consider relying on an existing approach namely the federated architecture for OWL ontologies or FOWLA (Farias et al, 2015). For the latter, Hobbs' granular partition theory (Hobbs, 1985) gives several interesting perspectives and future work directions. Both approaches are discussed in the sections below.

Following the database federation approach (Sheth et al, 1990), FOWLA is an approach relying on SWRL rules for federating autonomous ontologies (including TBox and ABox). The architecture contains two main components: The Federal Descriptor and the Federal Controller (Farias et al, 2015). The first is responsible of identifying missing concept instantiations and identifying new alignments (based on previously defined ones). The latter is mainly responsible of executing SPARQL queries. More specifically, it comes with a Rule Selector module that is responsible of selecting only the subset of SWRL rules that allow returning results pertaining to the considered SPARQL query.

Granularity is the extent to which a system is composed of distinguishable pieces or grains. It can either refer to the extent to which a larger entity is subdivided, or the extent to which groups of smaller indistinguishable entities have joined together to become larger distinguishable entities. For example, a kilometre broken into centimetres has finer granularity than a kilometre broken into meters. Information granules, as the name itself stipulates, are collections of entities, usually originating at the numeric level, that are arranged together due to their similarity, functional adjacency, indistinguishability, coherency or alike (Pedrycz and Bargiela, 2002). The granular partition theory (Hobbs 1985) builds upon the classical extensional mereology, and considers that the world surrounding us can be represented through a global theory pertaining to First Order Logic theories. Granular approaches aim at extracting from this global theory, local theories that are less complex, easier to interpret and calculate. Thus, having $\mathcal{P}$ the ensemble of predicates available in a global theory $\mathcal{T}$, $\mathcal{D}$ being the interpretation domain, for a local theory, one has to identify the ensemble of relevant predicates on $\mathcal{P}$, namely $\mathcal{R}$. This can be done by applying the indiscernibility relation defined by Hobbs (Hobbs 1985):

$$(\forall x,y)\ \ [(x \sim y)\equiv(\forall p\in R)(p(x)\equiv p(y))]$$

In order to best understand how this can be applied to our context, let us take an example. Consider planning a trip. In this case, the route one has to travel can be abstracted as a one dimensional curve. When considering an infrastructure use case involving for example works on the asphalt on the road, one can no longer approximate the road as a curve, but has to take into account its volume – it thus becomes a 3D volume. With the indiscernibility relation previously defined, one can identify predicates pertaining to the use cases considered. In the first one, two points in the asphalt, identified through their respective coordinates will be undiscernible. An example of a predicate pertaining in the context of this first use case would be the distance between one point on the road and the destination point.

Granular computing is an approach orthogonal to existing modelling approaches. It allows separating one knowledge domain into smaller pieces of knowledge, by means of consistent and structured methods, thus building a granular perspective. This allows consistent reasoning on these smaller pieces of knowledge but also on the whole knowledge domain. Still, while several formal models of granularity have been defined in literature (Mani 1998), (Keet 2008), the different granular perspectives have to be explicitly and formally defined, with regard to the considered application domain. Moreover, in applications involving context awareness, one has to further study and specify the relation between knowledge granularity and context granularity.

Given the above considerations, a first step in our approach addresses consistent semantic modelling of BIM and GIS information. Together with experts from the domain of BIM and GIS, the next steps of our work will investigate what alignments can be defined among BIM/GIS concepts and models (as defined in the respective ISO TC 211 and IFC ontologies). As such, the rules defined in the ISO 191xx standard family for application schemas (ISO 19109) and feature catalogues (ISO 19110) allow to represent IFC by means of UML. But as UML is not formal, additional alignments have to be investigated. More specifically, our future work will consider the following levels of alignments:

- Alignments among metamodels: the General Feature Model (GFM) of ISO 19109 has to be compared with the IFC elements contained in the core layer of data schemas of the IFC schema. IFC classes such as IfcKernel, IfcControlExtension, IfcProcessExtension, IfcProductExtension have to be mapped to their equivalents in ISO 19109 GFM.
- Alignments among abstract conceptual GIS schemas and data schemas contained in the Ressource Definition layer of IFC: Several geometry and topology elements from the GIS temporal schema (ISO 19107) are equivalent to sub-classes of IfcDateTimeResource or IfcTopologyResource. Also several elements from ISO 19107 Temporal schema have equivalents in the IFC terminology notably subclasses of IfcGeometryResource and IfcPresentationAppearanceResource. IFC classes such as IfcGeometricConstraintResource or IfcGeometricModelResource have to be mapped to their equivalent concepts in ISO 19111 Geographic information — Spatial referencing by coordinates.
- Alignments among application schemas in GIS and domain specific and shared elements IFC data schemas: IFC classes such as IfcKernel, IfcControlExtension, IfcProcessExtension, or IfcProductExtension have to be mapped to their equivalent concepts in ISO 19109 GFM. Concepts from the IFC Shared Elements layer of data schemas have to be mapped to their respective equivalents in ISO 19130.

With the above considerations in mind, future work to be done in the context of this approach also involves the following items:

- Missing ontologies: for example which ontology mediation will be used to establish compatibility on terminological level
- Missing links: some can be identified fairly easily, others require exchanges with business experts and are more complex to define.
- Granular approaches impact: the concept of granularity, seems intuitive and easy to implement, however the manner of ontologies, the associated levels and perspectives must be explicitly and formally specified by integrating the characteristics of the domain of knowledge concerned (Livi et al, 2016). In addition, when it comes to integrate granularity into application that handle business knowledge it is necessary to investigate, define and specify the granularity if knowledge and it is context.

6. Conclusion

In this article we aim at defining the interoperability issue among GIS and BIM systems, and specifying an approach addressing this issue. Our approach relies on Semantic Web technologies and granular approaches for performing two-axis federation. In our approach, we do not seek to merge BIM and GIS, neither to promote one over the other, hence we intend to reuse the FOWLA approach and its advantages in terms on lightly-coupled ontology federation. Granular approaches further help in conceiving and managing different abstractions of the same context or scape, which is highly pertaining to the urban environments considered by our application domain. The purpose of achieving interoperability between BIM and GIS is to specify and implement means to describe buildings along with their environment, at different scales.

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