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Previous BIM-GIS Integration Approaches: Analytic Review and Discussion

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Résumé : Malgré que le modèle d'information du bâtiment (BIM) et le système d'information géographique (SIG) sont deux silos technologiques disjoints (par exemple, les normes, le format des données), et utilisés pour des situations / objectifs distincts, ils sont complémentaires. D'une part le BIM est utilisé pour modéliser un bâtiment, sa géométrie, les coûts induits, les matériaux employés, ses éléments structuraux porteurs, ses caractéristiques de performance thermique et énergétique, et de la gestion des installations. D'autre part le SIG est conçu pour capturer, stocker, manipuler, analyser, gérer et présenter tous les types de données géographiques. Afin de combiner leurs avantages, nous devons résoudre les problèmes d'interopérabilité et les incompatibilités entre les deux domaines. Dans cet article, nous allons présenter des études adressant l'interopérabilité BIM et SIG, discuter des différentes approches et limitations.

Mots-clés : BIM, GIS, analyse analytique.

Abstract: Even though, Building Information Model (BIM) and Geographic Information System (GIS) are two different technologies (e.g. standards, data format), and used for distinctive situations/objectives they are complementary. While BIM is used to reconstruct building model including geometry, costs, materials, load-bearing structural members, health and safety aspects, and facility management life cycle. GIS is designed to capture, store, manipulate, analyze, manage, and present all types of geographical data. Also, it can be used as a tool in problem solving and decision-making processes, as well as data visualization. In order to combine their advantages, we need to address the interoperability issues and incompatibilities between both domains. In this article, we are going to present previous studies that tried to solve BIM and GIS interoperability, discuss their adopted approaches and which barriers they have/haven't overcome.

Key-words: BIM, GIS, Analytic review.

1 Introduction

Even though, Building Information Model (BIM) and Geographic Information System (GIS) are two different technologies (e.g. standards, data format), and used for distinctive situations/objectives they are complementary. As result, we have noticed an increase association between BIM and GIS in construction projects for multiple use cases. While BIM is used to reconstruct a building model including geometry, costs, materials, load-bearing structural members, health and safety aspects, and facility management life cycle (Volk et al., 2014). GIS is designed to capture, store, manipulate, analyse, manage, and present all types of geographical data. Also, it can be used as a tool in both problem solving and decision-making processes, as well as data visualization. (Kaden & Clemen, 2017). In order to combine their advantages, we need to address the interoperability issues and incompatibilities between both domains. In this article, we are going to present previous studies that tried to solved BIM and GIS interoperability, discuss their approach and barriers they have/haven't been overcome.

The article is divided as follows: section 2, introduces BIM model and its standards families, section 3 introduces GIS model and its standard family, section 4 introduces interoperability types and approaches, section 5 describes BIM and GIS incompatibilities and barriers, while section 6 presents the approaches, limits, and advantages of previous work done to achieve BIM and GIS interoperability, section 7 discusses the previous approaches on the light of the interoperability approaches and levels (ISO 11354), section 8 discusses which barriers/incompatibilities each study have/ haven't overcome and finally we conclude in section 9

2 BIM (model and standards)

Even though, BIM definition has changed over the years, the most suitable definition is the following: BIM is a process for combining information and technology to create a digital representation of a project that integrates data from many sources and evolves in parallel with the real project across its entire timeline, including design, construction, and in-use operational information (David et al., 2015). In addition, BIM acronyms are defined as following:

1. B stands for the act of building something and not just the noun, which could indicate infrastructure, building, landscape, and private projects.
2. I stands for the information surrounding the project.
3. And finally, M stands for model which includes programs, techniques, design and processes used to represent the built environment.

Furthermore, BIM standardization was carried in 1999 by International Alliance of Interoperability (now known as BuildingSmart International) (Wang, 2012) and relies on the following international standards:

- 1 Information Delivery Manual (IDM) specifies how information is exchanged in a process and it is based on the ISO 29481 standard (ISO 29481-1, 2016).
- 2 Model View Definition¹ (MVD) defines the data model needed to meet the exchange requirements described in the IDM which is reported by Part 3 of ISO 29481 (ISO 29481-3, 2010)
- 3 Industry Foundation Classes (IFC) (Liebich et al., n.d.) represent the conceptual model for buildings and comprises all classes and relations for representing a building (ISO 16739, 2013)

BuildingSMART aims to improve the exchange information between software applications in the construction industry through the development of IFC as a neutral and open specification for BIM. IFC is an object-based, open file format that is not controlled by a single vendor, developed to facilitate interoperability between architecture, engineering and construction. This enables the exchange of building information between different CAD (Computer-aided design) systems, supports multiple geometric representations, contains rich semantic information and can be used in various phases of the construction. In addition, IFC model is specified in EXPRESS schema that holds formal concepts along with the connection among them. Finally, the EXPRESS file is compliant with STEP (Standard for the Exchange of Product model data) files that allow importing and exporting product data as instances of conceptual elements previously defined and integrate the processes of design, development, manufacture and maintenance.

3 GIS (model and standards)

¹ <http://www.buildingsmart-tech.org/specifications/mvd-overview>

GIS is a system designed to capture, store, manipulate, analyse, manage, and present all types of geographical data. It can also be used as a tool in both problems solving and decision-making processes. Where geospatial data can be examined to determine (1) location features and their relationships to other features, (2) density of features in a specified space, (3) and how a specific area has changed over time (and in what way), etc. In addition, Geographical features have two formats: Raster (e.g. ADRG, binary file, etc.) or Vector (e.g. GeoJSON, shapefile, etc.). Finally, the main international organization developing standards for geospatial information are ISO TC 211 and Open Geospatial Consortium (OGC)

1. **ISO TC 211** defines a structured set of standards for information regarding objects or phenomena that are directly or indirectly related to a location relative to the Earth. It specifies methods, tools, and services for data management, acquisition, processing, accessing, presenting, and transferring such data digitally (ISO 191xx, 2005).
2. **OGC** dedicated to developing open interface standards and associated encoding standards, and also best practices that enable developers to create information systems that can easily exchange geospatial information and instructions with other information systems (Portele, n.d.). In addition, based on OGC standard many application systems have been developed such as CityGML, IndoorGML, and InfraGML.

4 BIM and GIS Incompatibilities

While BIM is defined as a process of planning, design, implementation and maintenance of a building, GIS environments are highly customizable, well-equipped for multi-dimensional analysis, and ideal for projects involving multi-site environments (Karan et al., 2016). In order to take advantage of both platform characteristics we need to achieve BIM and GIS interoperability. To achieve the interoperability between the two domains we need to overcome the following incompatibilities and barriers:

TABLE 1 – BIM and GIS Incompatibilities

	BIM	GIS
Modelling Environment	Focuses on the building model without taking into consideration its environment. In addition, BIM model is not grounded which means that you don't know which part is above/underground. Furthermore, it is presented as a single LOD. (for more BIM characteristics see table 2)	Focuses on out-of-doors environment, where each element is connected to his surroundings. In addition, it contains multiple levels of development (LODs) and multiple layers (e.g. land use, elevation, etc.) (for more GIS characteristics see table 2)
Reference System	Use local coordinate systems that has an arbitrary unit, covers limited scale, has no zone limitation, composed by small number, and has no projection and height distortion	Use global coordinate systems such as Coordinate reference system that has linear unit as meter, covers the world, is fixed by zones limitation, has a large number of digits (7-8 before and 2-3 after the decimal point), and contains height and projection distortion
Details of Drafting	Utilized to develop larger scales with higher level of details	GIS builds upon existing information and objects. It covers a large area with less detail and in smaller scales
Application Area	BIM is rooted in the building and its attributes, it is used in analysis, documentation, detailed design, renovation, construction process, operation, etc.	GIS is used to represent urban and city areas, facilities management, planning and engineering, environmental resources management, etc.
Tools	Revit, Autodesk, etc.	ArcGIS, QGIS, etc.
Semantics	Use IFCOWL (e.g. Beetz et al., 2009) to represent the building and construction data, entities, concepts and	Use ISO TC 211 Ontologies (e.g. Resources, n.d) to represent the UML models of ISO/TC 211 with Web Ontology language. Which

	properties of IFC schema with Web Ontology Language. It is updated with each new IFC version.	enable to expose the ISO/TC 211 to other communities and connect different concepts.
Temporal aspects	Even though BIM contains attributes, and entities that represent building life cycle, there is no link between the different building life cycle phases.	Do define links between geometrical representations and geometrical properties, and links and represents the element in different life cycle phases

TABLE 2 – Characteristics of BIM and GIS

	BIM	GIS		
	IFC	CityGML	IndoorGML	InfraGML
Schema	Express	UML	UML	UML
Data	STEP	GML3.2 and 3.3	GML3.2 and 3.3	GML3.2 and 3.3
File Format	.ifc, .ifcowl, .ifcxml	.gml, XML-based	.gml, .XML	LandXML, .xml, .gml
Identifier	GUID	ObjectID	ObjectID	ObjectID
Standard	ISO 16739, ISO TC 184/SC4	OGC, ISO/TC 211	OGC, ISO/TC 211	OGC, ISO/TC 211

5 Interoperability approaches

While BIM systems focus on developing objects with the maximum level of detail in geometry, GIS is applied to analyse the objects, which already exist in the physical environment, in the most abstract way (Liu et al., 2017). That is why achieving interoperability between both domains will offer substantial benefits, as each domain bring information and services the other lack. In this section, we are going to introduce different levels and approaches of interoperability. It 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". Furthermore, existing standards identify three main levels of interoperability:

- **Data interoperability** concerns the creation, meaning, computation, usage, transfer and exchange of data (ISO/IEC 20944-1:2013)
- **Syntactic Interoperability** concerns information formats and the ability of two or more systems to exchange structured information (ISO 16678, 2014)
- **Semantic interoperability** concerns the ability of two or more systems or services to automatically interpret and use information that has been exchanged accurately (ISO 16678, 2014)

These layers are connected and build upon each other, where the lower levels provide elements required by upper levels functionalities. (Joudrey and Taylor 2017, 189) expresses that without all levels of interoperability metadata cannot be shared effortlessly, efficiently and profitably. Therefore, without data interoperability information would not be sent correctly from one device to another. Furthermore, without syntactic interoperability data is not handled properly which means it will not respect the formats, encoding, properties, values and data types. And finally, without Semantic interoperability, the meaning of the language, terminology and metadata values used cannot be exchanged or properly assumed (Koch, 2006). Hence, in regards to BIM and GIS interoperability levels, only the semantic level has not been yet solved. Therefore, ISO 11354 (ISO 11354-1, 2011) proposes to achieve semantic interoperability between multiple systems through three semantic approaches: unification, integration, federation approaches (see table 3)

TABLE 3 – Semantic interoperability scenarios

Paradigm	Description	Approach
Integrated	<ul style="list-style-type: none"> • Standard format for all models • The format must be detail as models 	<ul style="list-style-type: none"> • Standardization • Mapping to the standard
Unified	<ul style="list-style-type: none"> • Common format only exists at the meta-level • Meta-model is not executable entity 	<ul style="list-style-type: none"> • Must have a pre-defined meta-model for semantic equivalent • Mapping via meta-model
Federated	<ul style="list-style-type: none"> • No common format • Dynamic accommodation 	<ul style="list-style-type: none"> • Must share an ontology • Concepts mapping done at ontology level

The next section will present the previous work that attempts to achieve interoperability between BIM and GIS domains.

6 Previous approaches

In this section, we are going to present the different studies (approaches, limits, and advantages) done in the previous years to combine BIM and GIS advantages in different scenarios and applications such as: enrich urban model with BIM information (semantic or/and geometric) and vice-versa (e.g. uni/bidirectional transformation, Unified Ontology), Energy consumption and evaluation on building, district and city level, Facility scenarios (e.g. water facilities, tunnel, facility assessment and management, infrastructure), Navigation system and emergency response, Environmental analysis (e.g. flooding), Cultural heritage, and finally urban management.

TABLE 4 – PREVIOUS WORK RELATED

Reference	Approach	Advantages	Limits
(Mignard & Nicolle, 2014)	Create an Urban Information Model (UIM) as a crossroads between building model and geographic information systems, which allows to integrate all the information of the city, including urban proxy elements, networks, buildings, etc. into an ontology.	<ul style="list-style-type: none"> • Allow facility managers to support the life cycle of urban environments • Improve quality of knowledge models • Facilitates the volume of data • Friendly 3D interface 	<ul style="list-style-type: none"> • Usage of database to store the instance of the ontology • Ontologies are not fully used • Unable to make logical reasoning or inconsistency checking of the model
(Floros et al., 2017)	Present a framework, where an IFC model is generated and converted to a LOD 3 CityGML Model, which is validated and evaluated on its geometrical correctness and semantical coherence.	<ul style="list-style-type: none"> • Time efficient • Improve existing converting tools 	<ul style="list-style-type: none"> • Don't investigate a fully complex model • Convert only into LOD 3
(Deng et al., 2016)	Present a reference ontology called Semantic City Model and adopt an instance-based method to achieve automatic data mapping between IFC and CityGML in different levels of details (LOD).	<ul style="list-style-type: none"> • Bidirectional conversion of geometrical information • Capture all semantic information (semantic mapping) • Generates all LOD levels 	<ul style="list-style-type: none"> • Miss some building components • Tackles only building model • Transforming only IFC BRep and swept solid geometries
(Deng et al., 2016)	Present a mapping procedure between IFC and CityGML by transforming them into ontologies and harmonization IFC with the four LoDs of CityGML	<ul style="list-style-type: none"> • Used for simulations and investigations of sustainable city design • Transform IFC Swept Solid into Boundary Representation • Different LODs representations of a building 	<ul style="list-style-type: none"> • Transform only swept solid geometry information • Unidirectional conversion • Support only IFC and CityGML standards
(Sebastian et al., 2013)	Aim to enable an open information capture, exchange, sharing, comparison and storage of the relevant building and	<ul style="list-style-type: none"> • Generate semantic BIM + GIS typology models; • Interconnect the design, 	<ul style="list-style-type: none"> • Tackle only building energy issues and models • Use only IFC and

	GIS models for designing energy-efficient buildings in healthcare districts.	<p>construction and facility management models</p> <ul style="list-style-type: none"> • Design a decision-support tool which accommodates • Grab semantic and geometrical data 	<p>CityGML standards</p> <ul style="list-style-type: none"> • Focus on BIM and GIS building model
(Wook Kang & Hee Hong, 2013)	Propose a BIM-GIS-based architecture model in which data were extracted from different heterogeneous systems such as BIM, GIS, and Facility Management database using ETL. The architecture is used for facility management, energy management, and design evaluation.	<ul style="list-style-type: none"> • BIM model can be checked by GIS tools • ETL provides a data warehouse for the heterogeneous systems, and can be used for information mining • BIM geometry information can be visualized into a simplified surface model 	<ul style="list-style-type: none"> • Unidirectional integration from BIM into GIS tool • BIM object geometry can be viewed only in LOD 100 and 200 • Selection of BIM property information which indicates semantic data loss
(Vilgertshofer et al., 2017)	Achieve to connect a tunnel model represented in both CityGML and the IFC data model by applying semantic web technology to emphasize the important role of semantic technologies in allowing the coexisting and coherence between the entities of both standards	<ul style="list-style-type: none"> • Identify clashes between existing buildings/infrastructure and the planned tunnel • Execute queries that access both data pools • Connect IFC to each CityGML LOD • Achieve Semantic and geometric coherence between both models 	<ul style="list-style-type: none"> • Connect only IFC and CityGML standards • Approach applied only on tunnel models • The mapping is not automatic (need for human intervention)
(McGlenn et al., 2017)	Propose a methodology in which the Ordnance Survey Ireland (OSi) data is transformed into RDF and then interlinked to other open building data to support a wide range of use cases, related to building navigation, control, sustainability, etc.	<ul style="list-style-type: none"> • Contain more than 40 million spatial objects that have multiple representations • Link OSi geographic information to different building ontologies IFCOWL, BOT, etc. • Query information using SPARQL and GeoSPARQL 	<ul style="list-style-type: none"> • OSi information are not authoritative, and not always correct. • The building is represented as a point and it is located in its centroid • Does not support 3D geometry • Unable to manage the changing nature of building data in the OSi database
(Boguslawski et al., 2015)	Integrate BIM and advanced GIS analysis to improve 3D analytical model for emergency response. The objective is achieved by using Green Building XML (gbXML) and Industry Foundation Classes (IFC), and GIS analysis methods and data structure, as data input.	<ul style="list-style-type: none"> • Generate an automatic navigation model for complex interior based on BIM model • Reconstruct the navigable network and primal-dual representation. • Create indoor topology with their connection • Generate route calculation 	<ul style="list-style-type: none"> • Based only on IFC geometrical information • Don't use GIS standards • No connection with the outdoor environment
(Amirebrahimi et al., 2016)	Present an integrated framework that allows for a case-by-case analysis of flood damage to a building and its components. In addition, it provides a comprehensive understanding of flood risks at different levels of the community.	<ul style="list-style-type: none"> • Shows quantitative and qualitative damage effect • Used for cost estimation, decision making and urban planning • Spatiotemporal parameters are taking into consideration 	<ul style="list-style-type: none"> • Semi-automatic process • Unified model treats only flooding use case • Applicable only on new building or those in their pre-construction phase • Don't consider all flooding factors such as weather.
(Zhang et al., 2019)	Propose a new urban management method through the combination of the GeoSOT grid code and BIM technology, where a real-time 3D visualization earth platform was built by using the Cesium platform to	<ul style="list-style-type: none"> • 3D and real time visualization platform • Achieve urban component management and smart fire protection • Manage a variety of urban 	<ul style="list-style-type: none"> • Input data are transformed into Cesium file format • Used only for urban management scenario • Is not based on standards

	achieve refined and efficient management of urban components	components with different granularities <ul style="list-style-type: none"> • Achieve multilevel precise management • Achieve the fusion of geographic information and building information 	
(de Laat & van Berlo, 2011)	Describe the development of a CityGML extension called GeoBIM to get semantic IFC data into a GIS context.	<ul style="list-style-type: none"> • Consider IFC semantics and properties • Transform 60 to 70 classes from IFC to CityGML • Bidirectional transformation 	<ul style="list-style-type: none"> • Support only IFC and CityGML standards • Generated geometry issues when transforming IFC to CityGML

7 Relation between previous studies and Interoperability approaches

After presenting in the above section each study approach, limits, and advantages, we are going to introduce the relationship between each study and the interoperability approaches and levels (see table 5). Based on the below table we have noticed the following: (Mignard & Nicolle, 2014), (Floros et al., 2017), (Deng et al., 2016), (Vilgertshofer et al., 2017), (McGlenn et al., 2017) tried to achieve BIM and GIS interoperability based on semantic interoperability level while (Sebastian et al., 2013), (Wook Kang & Hee Hong, 2013), (Boguslawski et al., 2015), (Amirebrahimi et al., 2016), (Zhang et al., 2019), (de Laat & van Berlo, 2011) tackle the interoperability between the two domains relying on syntactic interoperability level.

The syntactic approach relies on the extension of existing tools or software to transform data from one format to another so the information encoded is relevant to the system and can be processed without any error. However, it does not ensure that each system processes the data in a consistent manner because it lacks the intended meaning. For that reason, the presented studies that adopt the syntactic approach will fall short and achieve a partial and limited degree of interoperability. On the other hand, semantic interoperability requires more than compatible data format. It enables two or more systems and services to automatically interpret and use information that has been exchanged accurately. Based on the table below we have noticed that most adopted semantic approaches are unification and integration. For example, (Floros et al., 2017), (Deng et al., 2016), (Vilgertshofer et al., 2017), (McGlenn et al., 2017) apply the integrated approach where a common form shall be used to represent the exchange entities. Those approaches aim to integrate BIM into GIS or vice-versa in order to fill the shortage of information in order to proceed with further analysis. On the other hand, (Mignard & Nicolle, 2014), (Mignard & Nicolle, 2014) use a common reference, to map the existing models, syntax, and semantic, which enables a translation between the consistent entities. However, the unification approach generates a common reference suitable only for a specific use case, causes information losses, and cannot achieve dynamic agreements. Finally, it is worthy to mention that we have not found any study that adopt the federation approach. Even though, semantic approaches reached a higher degree of interoperability some incompatibilities and barriers have not been solved yet. We are going to further explain in the next section.

TABLE 5 – PREVIOUS WORK AND INTEROPERABILITY

Previous Studies	Semantic interoperability			Syntactic interoperability
	Unification approach	Federation approach	Integration approach	
(Mignard & Nicolle, 2014)	X			
(Floros et al., 2017)			X	
(Mignard & Nicolle, 2014)	X			

(Deng et al., 2016)			X	
(Sebastian et al., 2013)				X
(Wook Kang & Hee Hong, 2013)				X
(Vilgertshofer et al., 2017)			X	
(McGlinn et al., 2017)			X	
(Boguslawski et al., 2015)				X
(Amirebrahimi et al., 2016)				X
(Zhang et al., 2019)				X
(de Laat & van Berlo, 2011)				X

8 Previous studies vs incompatibilities

All the presented studies tried to accomplish their objectives and applications by seeking a solution for the integration and coexisting of data heterogeneity between BIM and GIS. Based on part 4 (BIM and GIS Incompatibilities and Barriers) we are going to compare the result of each approach and see which barriers/ Incompatibilities have been overcome and the level of interoperability achieved.

(Mignard & Nicolle, 2014) aims to achieve semantic interoperability through unification approach where IFC and CityGML are merged in a reference ontology (UIM). In addition, the process was able to overcome the differences in reference system, and temporal aspect but came short on modelling environment, details of drafting and semantics.

(Floros et al., 2017) focuses on transforming IFC to LOD 3 CityGML, the unidirectional approach partially overcame semantic and reference system barriers but failed to tackle the other barriers and incompatibilities.

(Deng et al., 2016) achieves bidirectional conversion from IFC to CityGML using a reference ontology. The process was able to overcome reference system and application area barriers, partial achieve semantic interoperability but failed to tackle the other barriers and incompatibilities.

(Wook Kang & Hee Hong, 2013) aims to transform BIM information format into GIS format through ETL tool. The approach addresses the syntactic interoperability and was able to overcome details of drafting and 3D modelling but it failed to overcome the other barriers. The same thing can be said to (Zhang et al., 2019), (Amirebrahimi et al., 2016) and (Boguslawski et al., 2015).

(de Laat & van Berlo, 2011) applies the integrated approach to add IFC information into CityGML model. The unidirectional integration was able to overcome the differences in reference system, details of drafting, 3D modelling and application area, came short on achieving semantic interoperability and failed to tackle the other barriers.

9 Conclusion

In this article, we have introduced different approaches that tried to benefit from BIM and GIS cumulative advantages. However, we have noticed that not all barriers and incompatibilities have been surpassed and only a small degree of interoperability has been generated. Furthermore, we can add that when the approach achieves uni/bidirectional integration it only concerns semantic or geometric information, even though some studies consider both information not all classes and attributes are considered or mapped between both domains. Most created models and approaches can only be applied to specific use case. And finally, most studies rely on transforming data format from one domain to the other if it is not the case it is limited to using IFC, CityGML or IndoorGML standards. Finally, despite the fact that the federation approach was not embraced in any previous study, is the most challenging to implement, and lack a central model. It has the following advantages neither

BIM or GIS can impose their model, languages or methods, can achieve dynamic adaptation and agreement between partners, both models stay independent. In our future work, we are going to investigate it is potential to achieve a full semantic interoperability between both models and overcome all the incompatibilities and barriers.

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