Previous BIM-GIS Integration Approaches: Analytic Review and Discussion

Elio Hbeich, Ana Roxin and Nicolas Bus

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Elio Hbeich[1, 2], Ana Roxin[2], Nicolas Bus[1]

[1] Information System and Applications Division, CSTB, Sophia Antipolis 06560, France,
{elio.hbeich, nicolas.bus}@cstb.fr

[2] Université of Bourgogne Franche-Comté – LIB EA7534
Ana-Maria.Roxin@u-bourgogne.fr

Résumé : Malgré que, BIM et SIG sont deux technologies différentes (ex : normes, format de données), et utilisées pour différentes situations / objectifs, elles sont complémentaires. De plus, nous avons remarqué au cours des dernières années une augmentation de l'incorporation entre le modèle d'information du bâtiment (BIM) et le système d'information géographique (SIG) dans les projets de construction pour des cas d'usages multiples. Ou, d'un côté, le BIM représente les informations géométrique et sémantique détaillée tout au long du cycle de vie du bâtiment, tandis que le SIG couvre la visualisation, la prise de décision et la modélisation géo-spatiale. Dans cet article, nous allons représenter un revue analytique (approches, avantages et limites) des études précédentes abordant l'intégration des systèmes BIM et SIG.

Mots-clés : BIM, GIS, analyse analytique.

Abstract: Even though, BIM and GIS are two different technologies (e.g. standards, data format), and used for distinctive situations/objectives they are complementary. As a result, we have noticed an increase association between Building Information Model (BIM) and Geographic Information System (GIS) in construction projects for multiple use cases. Where on one hand, BIM represents detailed geometric and semantic information through building life cycle, while GIS covers geo-visualization, decision making and geospatial modelling. In this article, we are going to present an analytic review (approaches, advantages and limits) and discussion of previous studies that tackle BIM and GIS incorporation.

Key-words: BIM, GIS, Analytic review.

1 Introduction

While BIM is used to reconstruct a 3D virtual building model that contains a range of information concerning: geometry, costs, materials, load-bearing structural members, health and safety aspects, thermal and energy performance characteristics, maintenance and facility management life cycle, etc. GIS is defined as information related to existing topographic and man-made phenomena and used in numerous fields associated with urban built environment and construction industry, ranging from Smart cities to urban planning. Even though BIM and GIS are different on several scales (methods, processes, standards, etc.), there is a general tendency of combining them in order to benefit from their cumulated advantages. In this article, we are going to present an analytic review (approaches, advantages and limits) of previous studies that tackle BIM and GIS incorporation and discus which incompatibilities/ barriers have/ haven't been resolved by each study. The article is divided as follows: section 2 introduces BIM and IFC, section 3 introduces GIS standards and applications, section 4 describes BIM and GIS incompatibilities and barriers, while section 5 presents the approaches, limits, and advantages of previous work done to couple BIM and GIS, section 6 discusses which barriers/ incompatibilities each study have/ haven't overcome and finally we conclude in section 7.

2 Building Information model (BIM)

Even though, BIM definition has changed over the years, in our point of view 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, Paul, & Stefan, 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. It is based on the ISO 29481 standard and is defined as an interchange agreement(*ISO 29481-1: Building information models—Information delivery manual—Part 1: Methodology and format*, 2016).
2. Model View Definition1 (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:Building information models—Information delivery manual—Part 3: Model View Definition.*, 2010)
3. Industry Foundation Classes (IFC) (Liebich, Chipman, & Weise, n.d.) represent the conceptual model for buildings and comprises all classes and relations for representing a building. In addition IFC model is specified in EXPRESS and complies with ISO 10303 (*ISO 10303: Industrial automation systems and integration—Product data representation and exchange—Part 21: Implementation methods: Clear text encoding of the exchange structure*, 2016).

2.1 IFC Model for Building Data

As mentioned before, IFC is an EXPRESS schema developed by buildingSmart International to describe a building. It enables the exchange of building information between different CAD (Computer-aided design) systems, supports a wide range of geometric representations, contains rich semantic information and can be used in various phases of the construction. The EXPRESS language is used to define a schema for modelling products as contained or used in the building. Also, the EXPRESS schema contains formal concepts along with the links among them. By means of entities, attributes, types, and concepts necessary for describing products specified on a conceptual level. STEP files allow importing and exporting product data as instances of the conceptual elements previously defined. The table below contains a listing of the main IFC elements along with a description of what they support or how they should be used.

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

TABLE 1 – IFC elements and their description

IFC elements	Descriptions
IFC Entity	Building project information is represented as a set of IFC Entities, such as elements, materials and their relationships. Each IFC Entity includes a fixed number of IFC Attributes, however new properties from a set of IFC Properties can be added to an IFC entity
IFC Attributes and Properties	IFC attributes are fixed identifiers of IFC entities. IFC properties are additional parameters assigned to an IFC entity. Several IFC Properties are already defined in the IFC standard, by means of so-called property sets. For example, Pset_PipeConnection contains the property ConnectionType that is an IfcPropertyListValue and can only be applied to the IfcDistributionElement entity
IFC Classification Reference	A classification reference is used for grouping IFC elements into one category. Such grouping can be identified with an Item Reference, while holding a classification Name attribute along with other optional parameters for project elements.
IFC Assignments	IfcRelAssigns allows linking the different project elements (i.e. the building, the stories, the building elements). Each assignment type can have its own IFC Attribute and IFC Properties. For example, an IfcZone is used to group several IfcSpace elements
IFC Type Product	It is an IFC Entity that defines a particular type for other IFC entities by specifying common IFC Attributes and Properties. For example, IfcDoorStyle is an IFC Type Product referred to by many doors IfcDoor entities

3 Geographic Information Model (GIS)

GIS is a system 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 visualization of data in a spatial environment. Where geospatial data can be examined to determine (1) location features and their relationships to other features, (2) where the most/ least of some feature occurs, (3) 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 is ISO TC 211 and Open Geospatial Consortium (OGC)

3.2 ISO TC 211

Dedicated to develop and deploy 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 of geographic information standards- Concepts and organisation of the reference model defined in ISO standard 19101*, 2005). The conceptual modelling in the ISO 19100 series is based on the principles described in the ISO CSMF (Conceptual Schema Modelling Facilities). This conceptual schema includes four levels: Metamodel, conceptual (abstract) schemas, conceptual (applications) schemas and implementation schemas.

3.3 OGC

Founded in 1994 to make geographic information an integral part of the world's information infrastructure. OGC collaboratively develop 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.). As a result, based in OGC standard many application systems have been developed such as CityGML, IndoorGML, and InfraGML.

1. **CityGML:** has numerous features that are useful and pertaining to represent urban information. Among them, we may cite modularization, multi-scale modelling, coherent semantic and geometrical modelling, closure surfaces, Terrain Intersection Curves (TICs) (Gröger, Kolbe, Nagel, & Häfele, 2012).
2. **IndoorGML:** is an open data model and XML schema for indoor spatial information. It aims to represent and allow the exchange of geo-information that is required to build and operate indoor navigation systems ("IndoorGML OGC," n.d.)
3. **InfraGML:** concentrates on the land upon which infrastructure facilities are built. It focuses on land parcel ownership, administrative boundaries, and easements information that is critical to infrastructure designers, which will help them understand what land is available for use and if any additional land will need to be acquired before construction ("OGC 15-111r1—LandInfra Conceptual Model," n.d.)

Adding to what have been said before the following table will illustrate the characteristics of each domain:

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

4 BIM and GIS Incompatibilities

While BIM is defined as a process of planning, design, implementation and maintenance of a building that uses the information model of a building containing all the information regarding its entire life-cycle, GIS environments are highly customizable, well-equipped for multi-dimensional analysis, and ideal for projects involving multi-site environments. 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 3 – BIM and GIS Incompatibilities

	BIM	**GIS**
Modelling Environment	Focuses on the building model without taking into consideration it environment. In addition, BIM model is not grounded for example you don't know which part is above/underground, and it is presented as a single block.	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.)
Reference System	Use local coordinate systems and a reference to a global coordinate system	Objects are defined with global coordinate systems such as Coordinate reference system, Geographic Coordinate Systems, Projected Coordinate Systems, World Geodic System, etc.
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	GIS is focused on urban and city areas
3D modelling	Work in full 3D environment. Where it has a rich set of spatial features and attributes.	Limited to simple 2D shapes
Semantic	Use IFCOWL (Beetz, van Leeuwen, & de Vries, 2009)	Use ISO TC 211 Ontologies(“Resources,” n.d.)
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 properties. Also it links and represents geometrical elements in different life cycle phases.

5 Interoperability approaches

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". 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 [ISO/IEC 20944-1:2013] Information technology—Metadata Registries Interoperability and Bindings (MDR-IB)—Part 1: Framework, common vocabulary, and common provisions for conformance*, n.d., p. 2013)
- **Syntactic Interoperability**: concerns information formats and the ability of two or more systems to exchange structured information (*ISO 16678: Guidelines for interoperable object identification and related authentication systems to deter counterfeiting and illicit trade*, 2014, p. 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: Guidelines for interoperable object identification and related authentication systems to deter counterfeiting and illicit trade*, 2014, p. 2014)

These layers are connected and build upon each other, where the lower levels provide elements required by upper levels functionalities. However, not all interoperability levels have been achieved for example, the issues related to the data level of interoperability have been long resolved with the adoption of hardware standards such as Ethernet (Hollenbeck, n.d.), furthermore the issues related to syntactic level have been resolved through the adoption of XML and related syntax standards e.g. HTML (“HTML 5.2,” n.d.). But the related issues related to semantic interoperability have not yet been resolved by existing standards and approaches. Therefore, ISO 14258 (*ISO 14258: Industrial Automation Systems- concepts and rules for enterprise models*, 1998) proposes to achieve semantic interoperability between multiple systems through three semantic approaches: Unification, integration, federation approaches (see table 4)

Table 4 – Semantic interoperability scenarios

Paradigm	Description	Approach
Integrated	• Standard format for all models • The format must be detail as models	• Standardization • Mapping to the standard
Unified	• Common format only exists at the meta-level • Meta-model is not executable entity	• Must have a pre-defined meta-model for semantic equivalent • Mapping via meta-model
Federated	• No common format • Dynamic accommodation	• Must share an ontology • Concepts mapping done at ontology level

The next section will present the previous work that try to achieve a degree of collaboration between BIM and GIS domains.

6 Previous approaches

In this section, we are going to present the different approaches 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.	• Allow facility managers to support the life cycle of urban environments • Improve quality of knowledge models • Facilitates the volume of data • Friendly 3D interface	• 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, Pispidikis, & Dimopoulou, 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.	• Time efficient • Improve existing converting tools	• Don't investigate a fully complex model • Convert only into LOD 3
(Deng, Cheng, & Anumba, 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).	• Bidirectional conversion • Capture all semantic information (semantic mapping) • Generates all LOD levels	• 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	• Used for simulations and investigations of sustainable city design • Transform IFC Swept Solid into Boundary Representation • Different LODs representations of a building	• Transform only swept solid geometry information • Unidirectional conversion • Support only IFC and CityGML standards
(Sebastian, Böhms, Bonsma, & van den Helm, 2013)	Aim to enable an open information capture, exchange, sharing, comparison and storage of the relevant building and GIS models for designing energy-efficient buildings in healthcare districts.	• Generate semantic BIM + GIS typology models; • Interconnect the design, construction and facility management models • Design a decision-support tool • Grab semantic and geometrical data	• Tackle only building energy issues and models • Use only IFC and CityGML standards • 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.	• BIM model can be checked by GIS tools • ETL provides a data warehouse for the heterogeneous systems, and can be used for information mining	• Unidirectional integration from BIM into GIS tool • BIM object geometry can be viewed only in LOD 100 and 200 • Selection of BIM property

		• BIM geometry information can be visualized into a simplified surface model	information which indicates semantic data loss
(Vilgertshofer, Amann, Willenborg, Borrmann, & Kolbe, 2017)	Achieve to connect a tunnel model represented in both CityGML and the IFC data model by applying semantic web technology to emphasis the important role of semantic technologies in allowing the coexisting and coherence between the entities of both standards	• 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	• Connect only IFC and CityGML standards • Approach applied only on tunnel models • The mapping is not automatic (need for human intervention)
(McGlinn, Debruyne, McNerney, & O'Sullivan, 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.	• 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	• 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, Mahdjoubi, Zverovich, Fadli, & Barki, 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), Industry Foundation Classes (IFC), GIS analysis methods and data structure, as data input.	• 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	• Based only on IFC geometrical information • Don't use GIS standards • No connection with the outdoor environment
(Amirebrahimi, Rajabifard, Mendis, & Ngo, 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.	• Shows quantitative and qualitative damage effect • Used for cost estimation, decision making and urban planning • Spatiotemporal parameters are taking into consideration	• 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, Cheng, & Miao, 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 achieve refined and efficient management of urban components	• 3D and real time visualization platform • Achieve urban component management and smart fire protection • Manage a variety of urban components with different granularities • Achieve multilevel precise management • Achieve the fusion of geographic information and building information	• Input data are transformed into Cesium file format • Used only for urban management scenario • Is not based on standards
(de Laat & van Berlo, 2011)	Describe the development of a CityGML extension called GeoBIM to get semantic IFC data into a GIS context.	• Consider IFC semantics and properties • Transform 60 to 70 classes from IFC to CityGML	• Support only IFC and CityGML standards • Generated geometry issues when transforming IFC to

		• Bidirectional transformation	CityGML

7 Discussion

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.
(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, 3d modelling, 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 3D modelling and application area barriers, partial achieve semantic interoperability but failed to tackles 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.

8 Conclusion

In this article, we have introduced different approaches that tried to benefits from BIM and GIS cumulative advantages. However, we have noticed that not all barriers and Incompatibilities have been surpassed and only a certain degree of interoperability has been generated depending on the case study and the actual need. Furthermore, we can add that when the approach achieves uni/bidirectional integration it only concerned 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 cases. 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

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