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Integration of Building and Urban Information Modeling – Opportunities and Integration Approaches

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Summary

Information mined from building information models as well as associated geographical data and GIS analyses can increase the success of construction process and asset management including roads and public facilities. This paper gives an overview of the status of Building Information Modeling (BIM) / Urban Information Modeling (UIM) integration research. The paper starts with a literature review that classifies current integration approaches into four categories. Also, the paper attempts to analyze significant contributions and advances for the use of BIM / UIM integration and classifies them into groups with respect to their applications. Gaps in the research are identified. Challenges and future development considerations for BIM (IFC) and UIM (CityGML) integration is provided for proper BIM integration in geo-context.

1 Introduction

This paper gives an overview of information integration approaches for bringing together information about the built environment from two information communities, namely the Building Information Modeling (BIM) / Architecture Engineering and Construction (AEC) Facility Management (FM) domain on the one hand and the Urban Information Modeling (UIM) / Geospatial domain on the other hand[1].

The aim of the information integration is to support business processes which require information from both domains, such as business processes in Facility Management as well as planning and construction of large infrastructure facilities. Rich & Davis (2010) provide examples of such business processes which have in common that information for the building interior is retrieved from CAD systems (the predominant software systems in the BIM community) whereas information for the exterior is provided by Geographic Information Systems (GIS) – the software systems predominantly used by the UIM community:

- Power and water utilities do not stop at the outside of the building. They have to be integrated and traced from the exterior to the interior of buildings.

[1] Although it would be more appropriate to discuss BIM / UIM integration (in case we mean the integration of the two methods) or CAD / GIS integration (in case we mean the integration of software tools), in the remainder of the paper, as in most of the literature, the terms “BIM / GIS integration” is used.

- Pedestrian movement does not stop at the entrances of buildings; people move in and out of buildings. In a big shopping center or an airport, finding the needed destination in a timely manner is a crucial issue.
- Maintenance management workflows in a building require both inside and outside work, which is done across the entire supply chain.

The examples above are related to the design, construction and management of individual buildings, which traditionally is the main usage of the BIM method. It is only within the past few years that BIM research and implementation extended to infrastructure construction and management (SHOU et al. 2015) and political directives like the initiative "Phased introduction of Building Information Modelling (BIM) until 2020"[2] of Germany's Federal Ministry of Transport and Digital Infrastructure will contribute to the further adoption of BIM in infrastructure management and construction. Obviously the business processes related to infrastructure construction and management have a strong demand for information on the geographic context of the infrastructure facility to be designed, constructed or maintained and therefore also require the integration of information coming from systems in the BIM and the UIM domain.

Standardization of data models has been suggested and practiced as a major stride towards achieving the goal of interoperability (AKINCI et al. 2008; PEACHAVANISH et al. 2006; WEIMING et al. 2010). IFC (BSI 2016) and CityGML (GRÖGER et al. 2012) are officially recognized as two standards, and have been independently developed; the former by buildingSMART International (bSI), which is the standardization body for the Architecture Engineering and Construction (AEC)/Facility Management (FM) community, and the latter by the Open Geospatial Consortium (OGC), which is the standardization body for the geospatial community. Most recently both standardisation organisations jointly worked on representations of objects related to road and railway construction which are going to result in standards with a common information model but specific encodings for each of the two information communities[3].

Despite these efforts for achieving interoperability, integrating information from these domains is not trivial and goes far beyond a format conversion between the encodings defined for IFC on the one hand and CityGML on the other hand.

2 BIM(IFC) and UIM Modeling Paradigms

The standards and formats for the representation, storage and exchange of 3D city models are the results of application requirements or purpose of use. Industry Foundation Classes (IFC) (BUILDINGSMART INTERNATIONAL 2016) and City Geographic Markup Language (CityGML) (GRÖGER et al. 2012) are two standards which have been independently developed. Although IFC and CityGML both deal with object geometry, surface materials/appearances, semantics and their inter-relationships, the information models are different, as they are adapted to the specific requirements of the domains they originate from. Major differences between the models are for example: The IFC schema is described using the modeling language EXPRESS which follows the entity relationship modeling paradigm whereas the

[2] https://www.bmvi.de/SharedDocs/EN/PressRelease/2015/152-dobrindt-bim.html
[3] http://www.opengeospatial.org/pressroom/pressreleases/2520

CityGML schema is described using the Unified Modeling Language (UML) and therefore follows the object oriented modeling paradigm. The semantic model of IFC in its current version "IFC4 Addendum 2" focuses on buildings and the physical elements of the building construction like slabs and beams whereas CityGML models all major observable natural and manmade entities in a city or landscape including buildings. For representing entities with their geometric and semantic properties in different granularity, CityGML includes five well defined levels of detail (LOD[4]). In IFC, a building element may have multiple geometric representations, which according to GEIGER et al. (2015) cannot directly be compared to the CityGML LOD concept. The main problem in the integration of BIMs with geospatial information occurs at the point of transferring the geometric information (WU & HSIEH 2007). Building models use representations such as CSG and Sweep Geometry mostly in local coordinate reference systems, while geospatial models mainly use Boundary Representation (BRep) and in global coordinate reference systems (NAGEL et al. 2009). The fundamental difference arises from their distinct modelling paradigms which are due to the way 3D models are acquired in the GIS domain respectively in the field of BIM and Computer Aided Architectural Design (CAAD). In GIS, 3D objects are derived from surface observations of topographic features based on sensor-specific extraction procedures. Features are hence described by their observable surfaces applying an accumulative modelling principle (NAGEL et al. 2009). In contrast, BIM models reflect how a 3D object is constructed. They follow a generative modelling approach and focus on the built environment rather than on topography. Therefore, BIM models are typically composed of volumetric and parametric primitives representing the structural components of buildings (KOLBE & PLÜMER 2004).

However, the relation between the two semantic models (IFC and CityGML) for BIM (design model) and geospatial models (real world model) has been researched to develop common unified spatial applications with minimum conversion overhead (AKINCI et al. 2008, ISIKDAG & ZLATANOVA 2009, NAGEL 2009).

3 Approaches to Integration

There are four primary BIM/GIS integration approaches: Conversion of IFC to CityGML, Conversion of GIS/CityGML to IFC, Unified Modeling and Linking BIM and UIM.

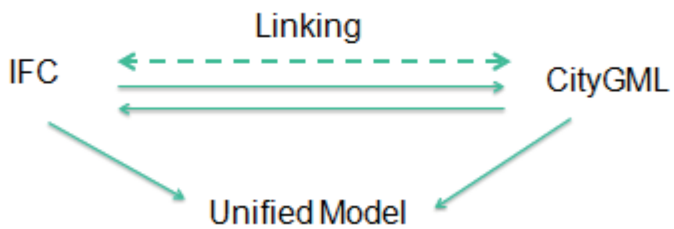

Fig. 1: Approaches to integration.

[4] Please note that the acronym LOD is also used by the BIM domain (not in the IFC standard though). LOD stands for "level of development" and is used for specifying the "the content and reliability of Building Information Models (BIMs) at various stages in the design and construction process" (BIM-FORUM 2016).

3.1 Conversion of IFC to CityGML

This approach integrates BIM data in GIS based on the conversion of IFC to UIMCityGML having the resulting model hosted on the GIS platform. The aim is to enriching the CityGML dataset with more information or use it further for geo analysis. EL-MEKAWY et al. (2012b) investigate the potential of unidirectional conversion between IFC and CityGML. Different IFC concepts and their corresponding concepts in CityGML are studied and evaluated. The investigation also includes concepts that are represented implicitly in the building schemas such as building objects relations, hierarchies of building objects, appearance and other building characteristics. The result of the study shows that only a few concepts are classified as 'direct matching', a few as well as 'no matching' while most of the building concepts are classified as 'partial matching'. It is concluded that unidirectional approaches cannot translate all the needed concepts from both IFC and CityGML standards. Also, EL-MEKAWY et al. (2012b) concluded that information loss is associated with this integration approach. Loss of semantics, limitations in geometric conversion and sole focus on the major building elements and neglecting the other aspects (e. g. utilities or connections) are some of the concerns associated with these methods.

3.2 Conversion of CityGML to IFC

The result of the CityGML to IFC conversion approach is aiming to produce a model that can be hosted on the BIM platform, although much of the IFC content is specific to the building; significant efforts have been made to promote the scope of IFC to other civil engineering domains, such as GIS-based systems. IFC for geographic information systems (IFG) has been developed to enable the exchange of geographic information in GIS with the IFC schema. The two main business themes were (EL-MEKAWY 2010).

- to store both building and geographic information in the same data storage system in order to retrieve, use and handle them together and do so faster, and
- to support the development of planning and building processes by having access to both the CAD system of building details and GIS in order to study relationships with a building area or other buildings.

The IFC specification was used in this project to exchange information between the two systems. The intention was to use an existing and established environment. The project did not create complete geographical information inside the IFC. Instead, it used an existing modeling framework, GML, for providing the bridge and facilitating the mapping of information between AEC/FM and GIS. As a first step in the project, all IFC entities that support or might support GIS applications were identified in the IFC schema. The project mapped 34 entities from IFC to a new GML application schema they created, mapping positional data and adding infrastructure information (roads/services/adjacent buildings). The project team finally succeeded in creating a mapping specification from the XML version of IFG geometry to GML and vice versa. This specification can be used for transforming information from the IFC modeling system to GML.

NAGEL et. al (2009) developed a two-step strategy for BIM model reconstruction from uninterpreted 3D graphics models which incorporates CityGML as an intermediate layer between 3D graphics models and IFC/BIM models. Rules were used for the process of reconstructing a component-based volume model of IFC from the CityGML surface model.

3.3 Unified Model

In order to overcome the limitations of the existing unidirectional approaches described above, a new approach was developed to achieve interoperability. The unified building model (UBM) is a unique concept which was introduced by EL-MEKAY et al. (2012a) as a solution which encapsulates both the CityGML and IFC models in a separate unified model, thus avoiding translations between the models and loss of information. The UBM concept was based on reference ontology and meta-concepts. All classes and related concepts were initially collected from both models, overlapping concepts were merged. The UBM was tested for specific use case related to building evacuation. EL-MEKAWY (2012a) and HIJAZI et al. (2012) use the same approach to integrate indoor and outdoor utilities. The main advantage of the UBM approach is the fact that it allows the bi-directional conversion of data between IFC for BIM and CityGML for GIS; this is different from the unidirectional methods as it implies that the information loss can be minimized during the conversions. However, this approach is still limited to building objects. Also, it is required having a new data repository that will replicate the BIM and GIS data. Moreover BIM data is including access restrictions with different levels between the different stakeholders. Also, the described methodology does not explain how the different geometry representation such as CSG and BRep are considered. Another important issue is that application programs would be required to support the unified model. This is unlikely, unless UBM would become an adopted standard.

3.4 Linking BIM and UIM

Papers classified for this group offer a novel concept or approach for the integration of BIM and GIS. This mode of integration was realized on different levels: 1) application level where tools are reconfigured or rebuilt, 2) process level, and 3) data level related to semantic web technologies and ontologies.

BIM or GIS applications reconfiguration or rebuilding is one of the attempts to create a full BIM/GIS integration solution (KARIMI et al. 2008), where existing GIS or BIM tools are reconfigured. This method is generally costly and inflexible.

An integration on process level was introduced by the OGC Web Services, Phase 4 testbed in 2007 (OGC 2007). They use Service Oriented Architecture (SOA) to allow the participation of BIM and GIS systems in those tasks that require the capabilities of both while they simultaneously remain live and distinct, therefore BIM data is made available for use and integration with the GIS through an open API. This is essentially a “here it is, come and get it” approach. This method provides more flexibility than the first group. However, in this method, the challenges of integration are still to be resolved at the underlying data level to provide interoperability between these systems. This approach requires custom application development in order to take advantage of the data in both the GIS and BIM applications. The primary advantage of this approach is its flexibility.

Data level integration methods were developed by several authors. This led to the creation of extensions to software tools, either from the BIM or from the Urban Information Modeling domain, that give the desired added functionality to one or the other platform such as the GeoBIM extension (DE LAAT & VAN BERLO 2011), or the Urban Information Modeling extension for facility management (MIGNARD & NICOLLE 2014); as well as the BG-ETL software architecture proposed by KANG & HONG (2015). Daum et al. (2016) present a spatio-semantic query language to analyse BIM and CityGML in an integrated context. The query language is executed on a proposed data model that wraps an object supplied by an external data model.

Following this, strides were made in an attempt to accomplish BIM/GIS integration using semantic web technologies in a variety of ways: KARAN & IRIZARRY (2015) and HOR et al. (2016) used semantic web technology to integrate BIM and geospatial analyses to manage the planning process during the design and preconstruction stages. To achieve this, building's elements and GIS data were translated into a semantic web data format. Then they use a set of standardized ontologies to integrate and query the heterogeneous spatial and temporal data. Through scenario examples, the potential usefulness of the proposed methodologies was assessed. The work presented by KARAN & IRIZARRY (2015) aims to manage the planning process during the design and preconstruction stages. Semantic web technology was used to integrate and query the heterogeneous spatial and temporal data. Through two scenario examples, the potential usefulness of the proposed methodology was validated.

4 Applications

In the last ten years, there have been various successful academic and industrial efforts to simplify BIM models and integrate them into the geospatial context. The integrations were created with various applications in mind. This section is identifying these applications and categorizes them into the following applications areas: Controlling and monitoring energy, evacuation activities in an emergency situation, utility network analysis, indoor/outdoor navigation, site selection, construction site layout optimization and clash detection. The applications also spanned facility management, shadow analysis, visibility analysis, as well as visualization of facilities within their urban context. A selection of these applications is discussed in detail in the following subsections, including application area, GIS analysis used and level of integration.

4.1 Controlling and Monitoring Energy

Improving energy performance of existing buildings plays a crucial role in achieving energy efficiency targets and carbon emission reduction goals. There are very few studies conceived to investigate the potential utilization of BIM in the geospatial context to improve energy efficiency of a massive volume of buildings. WU et al. (2014) propose a tool for energy assessment based on cloud computing (GIS-BIM Based Virtual Facility Energy Assessment VFEA). The aim is to provide location-based building information, dynamic simulation capacity based on BIM for real time building energy performance detection, visualization, analysis and optimization across campuses. The developed framework provides stakeholders a dynamic and holistic virtual assessment for energy performance of buildings that are geographically dispersed. The paper describes the feasibility analysis, the system framework of VFEA, and discussed the use case of CSU, Fresno campus for VFEA implementation.

HJELSETH & THIIS (2008) develop a tool for automatic energy assessment of buildings or building parts. The study uses BIM to undertake the evaluation and to provide a feedback to project owners to what degree the project goal is achieved.

Saran et al. (2015) provide a study for the urban energy simulation based on 3D City Models. The paper presents a methodology for the creation of a CityGML models using CAD and GIS software tools and the integration with BIM models. The paper explores the semantic characteristics of the CityGML model for solar thermal and photovoltaic energy production potential assessment based on semantic building components. The amount of solar irradiation on boundary features and also illumination obtained through openings of buildings is quantized using SunCast and RadianceIES application of IESVE Software, respectively. The simulated energy data are integrated with semantic building objects and stored in using the open source DBMS PostGIS.

4.2 Facility Management

Several papers were exploring how BIM can be a beneficial platform for supplementing Facility Management practices. Kang & Hong (2015) propose a software architecture for the effective integration of BIM and GIS for Facility Management applications. The paper describes the acquisition of data from various sources followed by the transformation of these data into an appropriate format. The software architecture was tested using a case study where different information about specific building elements were retrieved and displayed for municipal facilities. Mignard & Nicolle (2014) present a system architecture for the integration of different data sources which allows for reducing the gap of heterogeneity between BIM and GIS. The aim is to take into account the management of urban elements contained in the building environment. The particularity of the platform is that data can be accessed either by a semantic view or through a 3D interface. The SIGA3D (a semantic BIM extension to represent urban environment) project describes a set of processes that aims, for all the stakeholders of urban projects, to manage pieces of information through all the lifecycle of construction projects. This SIGA3D defines spatial, temporal and multi-representation concepts to build an extensible ontology. The knowledge database can be populated with information coming from standards like IFC and CityGML. This information system has been adopted and implemented into the existing platform and is today fully operational and used by thousands of users.

4.3 3D Spatial Analysis

Rafiee et al. (2014) present an example of the use of 3D GIS functionalities for the analysis of a Building Information Model (BIM). Several methods were applied to automatically transform the geometric and semantic information of a BIM model to a geo-referenced model. Two analyses, namely view and shadow analysis have been performed using the geometric and semantic information within the geo-referenced BIM model and other existing geospatial elements. These analyses demonstrate the value of integrating BIM and spatial data for spatial planning i. e. specifically view quality and shadow analysis.

In another study Daum et al. (2016) present a spatio-semantic query language to analyse BIM and CityGML in an integrated context. The query language was tested by a case study for the construction of a subway line. In this study the planned subway track was intersected with existing buildings.

4.4 Utility Networks and Building Service System

HIJAZI et al. (2011a) investigate the possibility to represent interior building utilities using the CityGML Utility Network Application Domain Extension (ADE) (BECKER et al. 2011). The paper describes preliminary ideas and directions for how to acquire information from IFC and map it to the CityGML Utility Network ADE. The investigation points out that, in most cases, there is a direct one-to-one mapping between the IFC schema and the Utility Network ADE schema. Many examples are shown of partial IFC files and their possible translation in order to be represented in UtilityNetworkADE classes. Thematic information was extracted from IFC objects and matched to their corresponding CityGML UtilityNetworkADE classes. Also, connectivity information was investigated in both standards and the classes that comprise the graph in UtilityNetworkADE were further investigating its related concept in IFC and the possibilities to generate the UtilityNetwork graph classes. In another study HIJAZI et. al (2011b) provide a topological model called NIBU. The aim of this study was to relate network object to the building hierarchy structure, in order to provide a direction to easy access point to access the different network objects for maintenance operation.

LIU & ISSA (2012) provide a proof of concept study for the creation of utility networks using Autodesk Revit MEP and the conversion to ArcGIS for visualization purposes.

4.5 Construction Management

BIM/GIS integration was utilized in different stages of facility lifecycle. ISIKDAG et al. (2008) investigates the applicability of BIMs in the geospatial environment by focusing specifically on these two domains: site selection and fire response management. Two use case scenarios were developed in order to understand the processes in these domains in a more detailed manner and to establish the scope of a possible software development for transferring information from BIMs into the geospatial environment. The overall research demonstrated that it is possible to transfer a high level of geometric and semantic information acquired from BIMs into the geospatial environment. The results also demonstrated that BIMs provide a sufficient level and amount of (geometric and semantic) information (about the building) for the seamless automation of data management tasks in the site selection and fire response management processes.

WANG et al. (2014) use GIS and BIM to design a localized traffic and producing viable solutions of where the parking lots, roads, entrances, exits, and the associated facilities should be built. The research aims to optimize and evaluate the site layout for effective traffic planning based on an integrative approach of BIM and GIS.

IRIZARRY et al. (2012) introduce a research for layout optimization for a construction site to locate the tower cranes. GIS were used to facilitate the analysis of spatial data used in the process of location optimization for tower cranes. Once the geometry of the construction site is generated by the BIM tool, the model determines the proper combination of tower cranes in order to optimize location and then generates 3D models to visualize the optimum location of tower cranes. As a result, potential conflicts are detected in different 3D views in order to identify the optimal location. The research was undertaken using a real world example. In another study IRIZARRY et al. (2013) utilize BIM/GIS in the process of construction supply chain management (CSCM). In order to support this objective, the researcher integrate BIM and GIS into a unique system, which enables keeping track of the supply chain status and providing warning signals to ensure the delivery of materials. First, the proposed methodology is implemented by using BIM due to its capability to accurately provide a detailed takeoff in an early phase of the procurement process. Furthermore, in order to support the wide range of spatial analysis used in logistics (warehousing and transportation) of CSCM, a GIS is used in the present model. Thus, the paper represents the integrated GIS-BIM model manifesting the flow of materials, availability of resources, and "map" of the respective supply chains visually. A case example is presented to demonstrate the applicability of the developed system.

Recently, with a proliferation of visible benefits, BIM is being extended to much broader applications than just buildings. Transportation is the largest beneficiary of this managed modeling approach, given the state and quality of transportation infrastructure. BORRMANN et al. (2015) use the BIM approach to plan and model subway tunnel constructions. The aim is to support different scales of planning and design problems. Also to extend the BIM schema with further classes to support tunnel design and planning at different scales with its different level of detailed requirements. STEUER et al. (2014) describe a collaboration platform that allows the integration of BIM and GIS to support the planning and design of sub terrestrial inner-city-railway-tracks.

NEPAL et al. (2012) describe the process and methods that were formalized to partially automate the extraction and querying of construction-specific information from a BIM model. The described methods were used to analyze BIM models and query for spatial information that is relevant for construction practitioners, and that is typically represented implicitly in a BIM model. The presented approach integrates ifcXML data and other spatial data to develop a richer model for construction users. Custom 2D topological XQuery predicates to answer a variety of spatial queries were applied. The validation results demonstrate that this approach provides a richer representation of construction-specific information compared to existing BIM tools.

4.6 Emergency Management

Types of emergencies reviewed below include human-caused emergencies (e. g., fires), and natural disasters (e. g., flood). Emergency management depends on data from a variety of sources. During an actual emergency, it is critical to have the data organized and displayed logically to respond and take appropriate actions. ISIKDAG et al. (2008) describe the information requirement for fire emergency response. In this research a use case scenario was developed to determine the process and the information need. Tools for data conversion were developed in order to transform the required data from BIM into GIS. The application allows to guide firefighters through buildings during an emergency situation.

CHEN et al. (2014) develop a 3D geometric network model based on BIM to support fire fighting. By spatial analysis the best position for the deployment of the ladder trucks was determined using the proposed frameworks before the arrival of firefighters.

AMIREBRAHIMI et al. (2015a, b) use BIM/GIS to undertake a flood damage assessment (FDA). The aim is to consider the uniqueness of the buildings in the analysis. The paper presents an integrated framework for utilization of detailed 3D building models for the assessment and 3D visualization of flood damage to buildings according to their distinct behavior in the case of flood. A proof-of concept demonstration of the framework in a case study underlines the feasibility of implementation of the framework.

4.7 Indoor Navigation

ISIKDAY et al. (2013) present a data model for indoor navigation considering different applications such as emergency response, delivery, utility maintenance and facility management. BIMs were used to populate the data model and the complexity of BIM-IFC structure was simplified to support indoor navigation. In another study TASHAKKORI et al. (2015) describe a 3D model to support emergency responders with semantic information about the complex indoor environment. This work aims at overcoming the insufficiencies of existing indoor modeling approaches by proposing a new Indoor Emergency Spatial Model (IESM) based on IFC. The model provides the first responders to disaster with 3D indoor architectural and semantic information coupled with outdoor geographical information. The aim is to enhance situational awareness about both interiors and exterior of buildings. The model is implemented and tested using the ESRI GIS platform. The research presents the effectiveness of the model in both decision making and navigation by demonstrating the model's indoor spatial analysis capabilities and how it improves destination travel times.

BECKER et al. (2009) developed the Multi Layered Space Event Model (MLSEM). The aim is to provide a conceptual framework for indoor navigation. MLSEM provides a mechanism to connect localization techniques that require complementary models reflecting the characteristics of sensors and transmitters. It therefore defines a partitioning of building space for indoor navigation and localisation. The MLSEM is the core of the OGC standard IndoorGML.

KHAN et al. (2014) describe a multi-step transformation process to automatically generate IndoorGML datasets from existing indoor building model data given in either IFC or CityGML LoD4. Moreover, they address semantic transformations, geometric transformations, topologic analyses, and spatial reasoning in order to derive navigation structures for different types of locomotion like walking, driving and flying inside of buildings. The developed method was tested with a complex public building.

5 Identification of Gaps

The aim of this section is to identify gaps in the integration approaches as well as in the applications described above.

5.1 Integration Approaches

The integration approaches described above cannot be regarded as seamless information integration. This is due to the dissimilarities between the two standards IFC and CityGML in terms of spatial scale, level of granularity, geometry representation methods, storage and access methods as well as semantic mismatches between them (ISIKDAG & ZLATANOVA 2009; KARIMI & AKINCI 2010; EL-MEKAWY & OSTMAN 2010). Even though all the integration approaches found in the literature are providing solutions to the above mentioned issues, they are found to be applied with examples where they are limited to very specific cases and situations. Moreover, the examples only demonstrate that the proposed approach worked within the defined circumstances and not necessarily in typical real world and practical scenarios. Future research and development activities should develop into the extent of actual use of integrated BIM/GIS applications in industry in order to uncover the real world challenges asset managers and users are facing. The most important challenge is the fact that moving all BIM data to GIS would result in issues that could be looked into for future research including:

- Privacy issues: BIM and GIS integration is associated with negative consequences related to privacy issues. Various stakeholders have different access rights and restrictions on the BIM database. Moving BIM data that should be not accessible by many stakeholders to public city database is not acceptable by many organizations e. g. military or government authorities; therefore a proper integration has to consider the privacy issue and where the BIM data will be cached.
- Information overload: Although BIMs will continue to act as information resources for LOD N of a Digital City Model (with N LODs), the transfer of information from BIM into a GIS will produce a huge amount of data for the GIS database. Therefore, there is a need to provide a tool to compress the huge amount of building information, also to control the data transformation with rules in order to reduce the redundant semantic information, redundant detailed geometric information about building elements, methods on how to integrate the data for the different applications without replicating the data needs further research.
- Integrate building sensors with BIM/GIS: Integrating systems from the BIM and UIM domain with building sensor systems will increase the efficiency of monitoring and real time response for the different facility management operations. Moreover, integrating BIM/GIS with building sensors will provide dynamic and real time data for simulation and analysis such as optimal path, augmented reality, energy and water consumptions.

5.2 Applications

There are several papers related to different applications mentioned in section 4. However, BIM and GIS integration do not consider other aspects that can be extracted from both domains such as processes and dynamics. The following list shows integration use cases that can be research topics for the BIM and GIS integration:

- Energy: Building thermal performance and energy efficiency is greatly influenced by urban planning legislation and surroundings environments (GEETHA & VELRAJ 2012). Architects took account of the relationship between newly designed buildings and the surrounding environment. Currently, thermal simulation tools do not easily integrate the urban context (surroundings) of the new design; this is related to the interoperability issues between BIM and UIM. Integration of BIM models and GIS data in one database will allow the monitoring of the energy use by buildings; also associate it with different actions that can be undertaken on the building level or city level. Modeling the process of thermal design and the interaction between the indoor and outdoor on the energy efficiency of buildings and outside the building will allow to determine the interaction of indoor and outdoor and its effects of energy consumptions.
- Facility management and traffic: Building objects are associated with dynamic activities specifically during construction phases. The integration of BIM models and GIS data will facilitate to plan using this information for traffic and estimate cascading effects of different construction and facility management activities on the city traffic plan.

- Utility network infrastructure: Building service systems and city infrastructure are connected to provide services to building occupants. The systems inside buildings are associated with different objects within buildings. Also, city infrastructure is interconnected with other city objects. There is a need to provide a framework that allows managing the interaction between the different system components. In case there is an operation taking place in a specific place there is a need to consider the cascading effects of this operation on other city objects.
- Indoor/outdoor navigation and walking patterns: An integrated model that can support path findings in indoor/outdoor environment would be of great importance. It needs understanding of both types of navigation environments, i. e., indoor and outdoor.

6 Conclusions

The paper reviews current uses of BIM and GIS integration. Different papers that provide solutions for BIM and GIS integration were revised; the aim was to determine the integration mechanism that was used to realize integration. The paper determines gaps in the current integration approaches and provides directions for future considerations. Also the paper highlights some applications that rely on the combined usage of BIM models and GIS data. In addition, it seems important to consider that there is a need to develop BIM and GIS into the extent of actual use of integrated BIM/GIS applications in industry in order to uncover the challenges asset managers and users are truly facing. Research can also involve identifying which sectors of the AEC/FM industry are adopting these technologies more readily, in order to investigate how various companies are adapting and evolving, as a result of these advances and applications of BIM/GIS technology.

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