Integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) – a literature review and future needs.

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Abstract
For years, researchers have been trying to integrate Geographical Information Systems (GIS) with Building Information Modeling (BIM) systems for various purposes. An important application of BIM in construction is asset management, and the integration of BIM and GIS can provide a highly detailed and holistic picture of a project - as information mined from building information models as well as associated geographical data can increase the success of asset management. The purpose of this paper is to present a systematic literature review on the approaches towards the integration of BIM with GIS systems. This paper attempts to analyze the significant contributions and advances in the field of BIM and GIS integration, while highlighting the implication for asset management. Gaps in research will be identified, which can be addressed for potential future research.

Keywords: BIM, GIS, BIM-GIS integration, BIM-GIS application, Asset management

1 Introduction
The Architecture, Engineering, Construction, Operations and Facility Management (AECO/FM) industry is highly dynamic and with the advent of technology, it is now becoming possible to have an unprecedented amount of control over nearly every stage of a project. With the industry being highly fragmented in nature, there have been several attempts to overcome the challenges of effective exchange of information between people and processes (Isikdag and Zlatanova 2009b).

Building information modeling (BIM) is widely accepted as one of the major technological advances that has increasingly impacted the construction industry over the years, as it allows stakeholders to capture and exchange information throughout the lifecycle of a building construction project. This platform has been used in bridging the gap of interoperability among industries players thus boosting its popularity amongst clients and stakeholders. BIM is now considered as facilitator of integration, interoperability, collaboration and process automation in construction industry (Isikdag and Zlatanova 2009b).

Geospatial information can be defined as the information that relates existing topography and man-made phenomena using a particular geographic reference system. Geographical Information systems (GIS) provide a means of accessing detailed spatial information on specific locations using coordinates. Recent research has been trying to incorporate GIS data with BIM data for various purposes. Although each has its own specialty - BIM focuses on information related to buildings whereas GIS focuses on information related with spatial configuration - when used together, BIM and GIS can provide a highly detailed and holistic picture of a project. As such, their integration is well suited for the needs of urban management tasks and various processes in the construction life cycle.

One of the important applications of BIM is in asset management, as it enables its users to hold detailed information of every aspect of a project. Asset management has been described by Zhang, Arayici, Wu, Abbott and Aouad (2009) as, "… the systematic process of maintaining, upgrading and operating physical assets." (p.1). These physical assets could range from a portfolio of buildings, to site equipment and infrastructure such as roadways and bridges. Information mined from both building information models as well as associated geographical data can increase the success of asset management.

There has been a lot of previous research done in the field of BIM, as well as in the field of GIS - independently of one another. Each of these technologies come with their own strengths and weaknesses. The main reason there is a need for their integration is due to the complementary nature of the information provided by each technology. The merging of a 3d building information model with its associated 3d geographical information creates an even more powerful tool that can be used in the AECO/FM industry.

2 Review Approach

The purpose of this paper is to present a systematic review on the current status of research approaches concerning the integration of BIM and GIS. To that end, the criteria used for selection of the literature during the search was limited to that of papers which referred strictly to the topics of BIM and GIS integration. Ultimately, the total number of papers reviewed were 44, and spanned nearly a decade of research, from 2006 until 2015. Figure 1 below shows the years of publications and the number of papers published, that were associated with this topic.

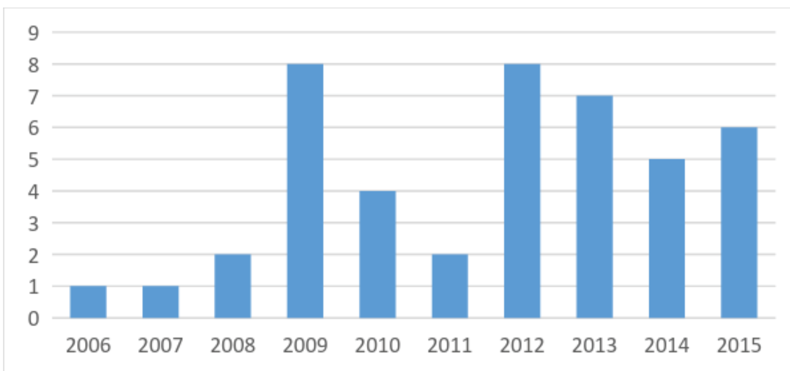

Figure 1 Frequency of Publications vs Year of Publication

From all of the reviewed papers, 15 individual journals and 10 individual conferences were identified as the sources, shown in table 1 below:

Table 1 Journals, Conferences and Author list

JOURNALS	AUTHORS
3D Geo-Information Sciences	Isikdag, U., and Zlatanova, S. (2009b)
Advanced Engineering Informatics	Isikdag, U., Underwood, J. and Aouad, G. (2008); Nepal, M., Staub-French, S., Pottinger, R. and Webster, A. (2012); Shen, W., Hao, Q., Mak, H., Neelamkavil, J., Xie, H., Dickinson, J., and Xue, H. (2010)
Advances in 3D Geo-Information Sciences	de Laat, R., and van Berlo, L. (2011); Hijazi, I., Ehlers, M., Zlatanova, S., Becker, T., and van Berlo, L. (2011); El-Mekawy, M., Östman, A., and Shahzad, K. (2011)

Automation In Construction	Wu, W., Yang, X., and Fan, Q. (2014); Irizarry, J., Karan, E. and Jalaei, F. (2013); Love, P., Matthews, J., Simpson, I., Hill, A. and Olatunji, O. (2014); Love, P., Simpson, I., Hill, A. and Standing, C. (2013); Karan, E. and Irizarry, J. (2015)
Building and Environment	Tashakkori, H., Rajabifard, A. and Kalantari, M. (2015)
Computers, Environment and Urban Systems	Chen, L., Wu, C., Shen, T. & Chou, C. (2014); Isikdag, U., Zlatanova, S. and Underwood, J. (2013).
Computers in Industry	Mignard, C. and Nicolle, C. (2014)
Computing in Civil Engineering	Liu, R. and Issa, R. (2012)
Digital Earth	Hijazi, I., Ehlers, M. and Zlatanovab, S. (2012); Amirebrahimia, S., Rajabifarda, A., Mendisb, P. and Ngo, T. (2015a)
Geographical Information Science	El-Mekawy, M., Östman, A. and Hijazi, I. (2012)
Photogrammetry and Remote Sensing	Gröger, G. and Plümer, L. (2012)
Information Technology in Construction	Irizarry, J. and Karan, E. (2012)
The Scientific World Journal	Kivits, R. and Furneaux, C. (2013)
Universal Ontology of Geographic Space: Semantic Enrichment for Spatial Data.	El-Mekawy, M. and Östman, A. (2012)
Urban and Regional Data Management	Isikdag, U. and Zlatanova, S. (2009a)
CONFERENCES	**AUTHORS**
3D Geo-Info Conference	El Meouche, R., Rezoug, M. and Hijazi, I. (2013)
Computing in Civil and Building Engineering	Wu, W., Yang, X., & Fan, Q. (2014)
Civil Structural and Environmental Engineering Computing	Zhang, X., Arayici, Y., Wu, S., Abbott, C., & Aouad, G. (2009)
Cooperative Design, Visualization, and Engineering	Wang, J., Hou, L., Chong, H. Y., Liu, X., Wang, X., and Guo, J. (2014)
Product and Process Modelling	Hjelseth, E., and Thiis, T. (2008).
Research Challenges In Information Science (RCIS)	Hwang, J. R., Hong, C. H., and Choi, H. S. (2013)
Construction And Real Estate Management	Shen, G., & Yuan, Z. (2010)
Mobile Data Management:	Hagedorn, B., Trapp, M., Glander, T., & Dollner, J. (2009)

Systems, Services and Middleware	
Locate '15 Conference	Amirebrahimi, S., Rajabifard, A., Mendis, P., & Ngo, T. (2015b)
Design and Decision Support Systems in Architecture and Urban Planning	Rafiee, A., Dias, E., Fruijtier, S. and Scholten, H. (2014).

Other sources that were also referenced but did not fall under the category of Journal or Conference were scholarly papers from Digital Earth Summits (El-Mekawy and Östman 2010); Annals of GIS (Saran, Wate, Srivastav and Krishna-Murthy 2015; Lapierre and Cote 2007); Symposium of the Urban-Data-Management-Society (Döllner and Hagedorn 2007); Construction research congress (Marzouk and Aty 2012); and Workshop on 3D Geo-Information (Hijazi, Ehlers, Zlatanova and Isikdag 2009).

Once gathered, the reviewed papers were coded into groups based on the category of integration approach used. These categories were named as follows: BIM to GIS, GIS to BIM, BIM and GIS integration, Unified Building Model, Web viewing applications. Table 2 below shows the various identified approaches, and offers a brief description of each.

Table 2 Category descriptions

CATEGORIZED APPROACH	DESCRIPTION
BIM – GIS	Papers in this category deal with the conversion of BIM to GIS/ IFC to City GML/ have the resulting model hosted on a GIS platform
GIS – BIM	Papers in this category deal with the conversion of GIS to BIM / City GML TO IFC / have the resulting model hosted on a BIM platform
BIM AND GIS INTEGRATION	These papers offer a novel concept or approach to the integration of BIM and GIS through new tools/extensions/frameworks/ontologies
UNIFIED BUILDING MODEL	This encompasses papers that deal with the development of a separate unified model that contains both BIM and GIS data
WEB VIEWER	This encompasses papers that venture to the route of converting BIM and GIS data for web visualization

The first three approach categories encompass the creation of new tools such as software extensions, frameworks and architectures. These shall be discussed further in the next section.

3 Discussion

GIS and BIM originate from separate domains and were developed to suit the specific needs of professionals within those fields. While BIM systems are focused on generating objects with maximum detailing with respect to geometry, GIS systems are used to analyze objects which already exist around us. However, there is a growing need for more interoperability in order to facilitate the exchange of information between these two domains. As such, various studies have been carried out in order to explore and uncover the most efficient method of integrating BIM technology in GIS environments - and vice versa.

3.1 Integration of BIM and GIS

BIM and GIS integration is not a novel idea. For successful implementation, the integration of GIS and BIM technology must be accomplished by fully combining the strengths from both systems in the contexts of each other as proposed by (Zhang et al. 2009). However, there are several incompatibilities that exist between BIM and GIS systems in various aspects. While BIM focuses on the indoor environment, GIS is primarily concerned with the outdoor environment; BIM provides a higher level of detail and primarily deals with buildings, however GIS is lacking the high level of detail and develops only on information provided on actual existing objects which are geo-referenced. While BIM tends to be focused on buildings and their attributes, GIS has a wider span and deals with entire cities and urban areas, and is predominantly 2D as opposed to the 3D nature of BIM. Moreover, the dominant standard for GIS is the CityGML while the IFC is more commonly related with BIM. These two formats hold different kinds of information at different details – which ultimately leads to most of the interoperability issues when it comes to data conversion between them.

Despite these incompatibilities, various approaches have been attempted in order to overcome the individual weaknesses of BIM and GIS, and secure a more stable and acceptable integration technique that can be widely adopted.

As indicated earlier, the review process yielded papers that were dedicated to this topic which were dated as far back as 2007 (Döllner et al 2007) which started the concept of using web platforms to provide a web client as an intermediary between the BIM IFC and GIS CityGML platforms (Döllner et al 2007; Lapierre and Cote 2008). This web client viewer would allow the combined visual display of both models. More recently, Karan and Irizarry (2015) proposed a method for integration via semantic web format for querying integrated models.

Hagedorn, Trapp, Glander and Döllner (2009) introduced their work on a conceptual dual graph for representing topological relationships among indoor entities such as rooms and corridors; while Nagel, Stadler, and Kolbe (2009) proposed a method of transitioning from a KML graphics model to BIM through CityGML.

Following this, strides were made in an attempt to accomplish the BIM/GIS integration in a variety of ways. Innovative methods which resulted in the use of standards available to incorporate aspects of each domain into a new tool were developed by several authors. This led to the creation of extensions that could give the desired added functionality to one or the other platform such as the Geo BIM extension (de Laat and van Berlo 2011), or the Urban Information Modeling extension for facility management (Mignard and Nicolle 2014); as well as new architectures to support the integration such as the BG-ETL software architecture proposed by Kang and Hong (2015).

Amirebrahimi, Rajabifard, Mendis and Ngo (2015) proposed the use of a data model to integrate BIM into GIS; while Hjelseth and Thiis (2009) created an IFC based tool for the same purpose. Rafiee, Dias, Fruijtierc and Scholtend (2014) tackled the conversion of IFC to Geographic vector format to include spatial data.

The Unified building model (UBM) approach was proposed by El-Mekawy and Östman (2010); El-Mekawy, Ostman, and Shahzad (2011); El-Mekawy and Östman (2012); El-Mekawy, Östman and Hijazi (2012). This was a unique approach that enabled users to fully combine the BIM and GIS features and capabilities into one central model. The main advantage of the UBM approach is the fact that it allows for bi-directional conversion of data between IFC for BIM and CityGML for GIS. This differs from other unidirectional methods as it implies that the data loss can be minimized during the conversion for the exchange. Research has focused on the unidirectional conversion from IFC to CityGML, however, Isikdag and Zlatanova (2009a) concluded that manipulating data from one system to the other requires a two-part transformation of both the geometric and semantic datasets. Because the two systems are conceptually misaligned, one dataset cannot be transformed without the transformation of the other.

Shen and Yuan (2010) proposed the use of IFC standards to convert both GIS and BIM data, while El Meouche, Rezoug and Hijazi (2013); Hwang, Hong and Choi (2013) implemented a prototype that showed how interoperability could be achieved using existing software.

Purely conceptual frameworks were also proposed, such as the virtual facility energy assessment framework developed by Wu, Yang and Fan (2014), and the GNM-based BIM information-supported framework proposed by Chen, Wu, Shen and Chou (2014). Isikdag and Zlatanova (2009b) also outlined their developed framework for the automatic translation from BIM to GIS.

The number of reviewed papers per each category of integration approach is depicted in the chart shown in figure 2 below.

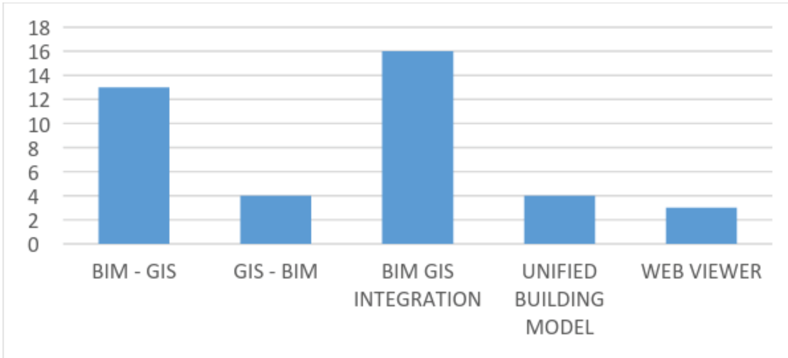

Figure 2 BIM/GIS Integration Approaches and the number of respective papers

3.2 Application

These approaches to integration were created with various applications in mind. From the papers reviewed, the following categories of application areas were identified: in the area of analysis the application of an integrated BIM GIS model was applied to the analysis of the energy consumption of facilities; analysis of the adaptation of a building to its environment; and to the assessment of the view quality and shadow effect of buildings.

The applications also spanned facility management, as well as the visualization of utility lines. Spatial queries were conducted by several researchers, in addition to the use of the unified model to locate assets and navigate through spaces. The integrated model could also be used for traffic planning, planning with regards to site selection, and for the analysis of emergency situation responses. The table below provides a summary of the various application areas found in the reviewed literature.

Table 3 BIM/GIS Integration application areas

Application	Authors
Climate Adaptation /Energy Analysis	Wu, W., Yang, X., & Fan, Q. (2014); Saran, S., Wate, P., Srivastav, S. and Krishna Murthy, Y. (2015); Hjelseth, E., & Thiis, T. K. (2008)
View Quality And Shadow Effect Analysis	Rafiee, A., Dias, E., Fruijtier, S. and Scholten, H. (2014)
Utility Visualization	Hijazi, I., Ehlers, M., Zlatanova, S., & Isikdag, U. (2009); Hijazi, I., Ehlers, M., Zlatanova, S., Becker, T., & van Berlo, L. (2011); Liu, R., & Issa, R. (2012)
Facility Management	Kang, T. and Hong, C. (2015); Mignard, C. and Nicolle, C. (2014); Marzouk, M., & Aty, A. A. (2012); Kivits, R. and Furneaux, C. (2013)
Spatial Querying/Location And Space Navigation	Isikdag, U., Zlatanova, S. and Underwood, J. (2013); Barton, J., & Plume, J. (2006); Karan, E. and Irizarry, J. (2015); Nepal, M., Staub-French, S., Pottinger, R. and Webster, A. (2012); Tashakkori, H., Rajabifard, A. and Kalantari, M. (2015)
Planning	Wang, J., Hou, L., Chong, H. Y., Liu, X., Wang, X., & Guo, J. (2014); Irizarry, J., Karan, E. and Jalaei, F. (2013); Irizarry, J., & Karan, E. P. (2012); Isikdag, U., Underwood, J. and Aouad, G. (2008)
Emergency Situations /Natural Disaster Damage Analysis	Amirebrahimi, S., Rajabifard, A., Mendis, P., & Ngo, T. (2015b); Chen, L., Wu, C., Shen, T. & Chou, C. (2014); Isikdag, U., Underwood, J. and Aouad, G. (2008)

3.3 Identifying Gaps - Findings in Literature

The integration of BIM and GIS can have a significant positive impact on asset management. From the lowest level of detail to the highest – i.e., from the management of assets within a single facility to the management of a portfolio of assets across several buildings. BIM/GIS can aid with the location of various assets; with the energy assessment and the space inventory analysis of assets; and can facilitate the management of assets in a portfolio through a centralized and dynamic database.

One cannot deny that the amount of time it would take to fully input all the necessary data would be rather substantial - especially with older buildings which have less than accurate floor plans. Research will have to be done to uncover more efficient ways of populating a BIM asset database in the least amount of time. However, with the rapid adoption of technologies such as BIM it will only be a matter of time until all large asset owners require their assets to be initially created and accurately documented in BIM, making their input into the database of their asset portfolio much simpler.

One of the major issues that is yet to be fully resolved is storage for all the data. Once the BIM/GIS integration is complete there will be copious amounts of data to deal with. Thus, for future asset managers utilizing BIM/GIS platforms, it will be worth looking into and deciding on:

- How much access and restrictions various stakeholders will have to the BIM/GIS asset database, and where this data will be cached.
- How to resolve clashes and inconsistent records entered in real time.

Other issues that could also be looked into for future research include:

- Methods on how to track mobile assets in real time and incorporate them in the BIM/GIS asset management system for easy location and assessment.
- How to integrate BIM/GIS asset database with energy management and building automation systems for efficient monitoring of building consumption - as a step towards implementation of sustainable measures.
- How to integrate intelligent building systems and sensors with BIM/GIS systems for more efficient real time responses to ongoing environmental factors e.g. during emergency drill simulations - surrounding/nearby traffic conditions and its integration with newer technology which would require the addition of real time dynamic data for optimal path allocation for use in augmented headsets/devices.

4 Conclusion

This paper has presented a look at the current research in the field of BIM and GIS integration. A brief introduction to BIM for asset management was also presented, and the possible benefits of the integration of all three were discussed. The various approaches that have been taken to integrate BIM and GIS model have also been discussed in the paper. Even though these approaches are constantly gaining higher levels of accuracy, those found to be applied with examples were limited to very specific cases and situations. Moreover, those examples presented only demonstrated that the proposed approach worked within the defined circumstances and not in typical real world and practical scenarios. Future research will delve 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 AECO/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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