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Digital management of large building stocks: BIM and GIS integration-based systems

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Abstract. Organizations involved in the management of large building stocks require high quality data in order to properly manage their assets. Due to more restricted environmental requirements, funding and intervention times, these organizations need to solve inefficiencies and uplift tasks adopting improved digital systems for the management of their assets and related data. Currently, each stakeholder involved adopts its software for specific tasks, with limited data interoperability and standards for data exchange. A comprehensive system which can handle large scale and heterogeneous data is required, but it must be designed to precisely fit the needs of the organization and to overcome current technical limitations. Since BIM and GIS are two IT-based methodologies which can provide data about built assets and related environment, the BIM/GIS integration is investigated through the analysis of over 100 journal and conference papers published in the 2015-2020 period. This analysis reveals categories and sub-categories explored in the current state of art, features that have been satisfied by future BIM-GIS integrated systems and a roadmap for its implementation. The results of the study can support scientists and practitioners in addressing their research interests and implementation activities for leading a digitization of data and information in large building stocks management.

Keywords: BIM, GIS, Large Building Stocks, Integration

1 Introduction

The concept of large building stocks is not a fixed term, since it can include whole city centers or a fragmented collection of punctual buildings. Organizations involved in this field and in the more general AECO/FM sector (Architecture, Engineering, Construction, Operation and Facility Management) require consistent and non-redundant datasets about their assets, with GIS providing georeferenced information and BIM for detailed components. In this perspective, BIM can be seen as a digital synthesizer of several unlinked and non-semantic data, such as paper documentation or CAD files. The BIM model, therefore, constitutes a centralized, 3D, and semantic database of the building, but it lacks geo-referencing at the geographic scale and query potential. The integration with GIS, by means of ontologies or scripts for IFC to CityGML conversion, allows performing at lower scales tasks, which are usually done with territorial data and

larger contexts. However, usually the system design and its implementation require intensive manual work, and they depend on the quality of existing data for the BIM modeling of the assets and their integration within GIS databases.

The heterogeneity of data is addressed in literature by means of ontologies and graph databases, which are generally preferred to complex interventions on BIM and GIS data model, since data loss is hardly evitable, since it typically involves the fitting of the more detailed IFC into CityGML, which requires specific extensions. Instead, the conversion of BIM and GIS files into RDF/OWL with semantic web technologies allow a smoother approach and the availability to link with other sources such as IoT sensors. Depending on the organizations involved, the BIM/GIS integration system can cover one or more kind of the managed assets data: for example, social housing organizations would like to cover both the energy performance, user comfort and loans regularity, and a BIM/GIS database can support the management of the asset providing visualization, centralization of data and analysis tool. The management of the assets therefore can require multi-level data, in which for example the technical, energetic, economic and social levels intertwine.

Even if there are already feasible methods for multi-scale systems, the technical limitations of BIM/GIS integration are still addressed to achieve a smooth, bidirectional, and automated conversion. Commercial software already provide some of these features, but an omni-comprehensive and open-source approach is still an open topic, especially for uncovered semantic fields by the two technologies (e.g., HBIM) or to interact with new data sources (e.g. technical databases, IoT sensors). Besides this, the required systems should take into account that high-detailed BIM models require cost and time, and they can be quite heavy files at the data level. Depending on the size of the assets portfolio, BIM models should be more or less detailed, depending on which data are required by the agencies in order to properly manage their assets. If a component-level is not required by the agency, then BIM models can be at a lower detail regarding material and other details, focusing instead on other data and bigger granularity, such as space usage or maintenance cost at story or whole building level, rather than single room details.

Based on the described context, the BIM/GIS integration becomes relevant for enabling the centralization, geo-location, and digitalization of assets information. This paper aims to analyze the literature about the integration of BIM/GIS for more efficient management of large building stock, which can be adopted by several stakeholders such as asset and facility managers, maintenance personnel, and technicians. Based on the review of more than 100 papers, the results allow to provide a structured classification of the current studies in categories and sub-categories, to provide an overview of the main features to be satisfied by a system based on a BIM/GIS integration and on the proposal of a roadmap of steps for leading such integration.

In the next section, the systematic literature review method will be detailed. In Section 3, the papers classification in categories and sub-categories and the main features to be satisfied in a BIM/GIS integration will be described. Section 4 proposes a roadmap of steps for BIM/GIS integration based on the analyzed literature. Finally, Section 5 concludes the paper.

2 Systematic Literature Method

This paper follows the Systematic Literature Review (SLR) approach as the research methodology. The SLR is a type of review that is defined as the identification, evaluation, and interpretation of a field of research that can be reproduced by other researchers [1]. The research is focused on a qualitative analysis, although it also provides schematic classification and highlights found in the literature. The paper selection process must be clearly explained and circumscribed to be replicable.

The SLR treated in this paper, took place on the online database Scopus for retrieving academic papers, both from journals and conferences, and it included works published between January 2015 and February 2021. Given the wide scope of the analysis, the search process was based only on the use of the keywords BIM and GIS and their combination. References to the type of building were avoided in order to collect a wider set of studies and insights for leading future research. Therefore, the following query was performed on the database: ("BIM" or "Building information model*") and ("GIS" or "Geographic information system*") and "integration". BIM and GIS were also expressed in their extended form in order to avoid missing papers.

The query retrieved a total of 196 papers in the chosen period. After that, a selection was performed in order to remove non-English, not available or out of topic papers. This required a manual check of title and abstract, and finally, 163 out of 196 articles were kept. **Erro! Fonte de referência não encontrada.** shows the number of papers published by year, highlighting a positive trend and thus an increasing interest of the subject in literature.

Table 1. Numbers of papers published by year

Year	2015	2016	2017	2018	2019	2020
Number of papers	13	13	28	24	28	50

3 Fields of application

The review unveiled that the BIM/GIS integration was employed in several AECO/FM applications and with several methods. In fact, the term "BIM/GIS integration" referred to different strategies and objectives and thus it can be considered an umbrella term [2]. Moreover, among the 163 papers investigated, over one-third (63 out of 163) were addressing how to implement a BIM/GIS integration, discussing it at a high-skill technical level or in other cases discussing it at a general level, without applying it to a specific context.

Based on these premises, the first classification of the papers found delimited the scale of intervention, which were subdivided as:

- **City and Urban:** BIM/GIS integration is discussed in relation to subjects which interest urban areas or whole cities;

- **Infrastructure**: infrastructures which are both inside or outside cities, (e.g., underground utilities and roads) are treated in this category;
- **Building**: applications on a single building, or a small set of them are described;
- **Technical**: They are not focused on a specific AECO/FM context, and rather discussed the BIM/GIS integration on a technical level or general purposes.

This high-level classification was needed to evaluate a preliminary distribution of the BIM/GIS integration. As it can be seen, the first three referred to physical entities, like buildings, infrastructures and cities or urban areas, intended as a collection of constructions. These three categories will be referred as "thematic contexts". Instead, the "technical" category refers to papers in which the BIM/GIS integration is investigated at the information and technical level. This last category treats technological issues that are out-of-scope of this study, therefore, it is not considered in the remaining part of the analysis.

Table 2. Classification of papers by category

Category	References	Total Number	% on the total
City and Urban	[3]–[35]	33	20%
Infrastructure	[36]–[66]	31	19%
Building	[67]–[102]	36	22%
Technical	For consultation the reference list is available here: https://cpdm.unisalento.it/icplm/annex.html	63	39%

Below this classification, a vast collection of sub-categories can be defined, as reported in **Erro! Fonte de referência não encontrada.** The granularity of the classification was evaluated in order to identify trend topics and insights related to each category and to assign a paper to only one category.

Table 3. BIM and GIS fields of application classification

Category	Sub-category	N. Papers	References
City and Urban	Analysis	6	[4], [5], [9], [13], [28], [35]
	Application	3	[8], [20], [29]
	Cadastre	2	[3], [15]
	e-permit	2	[16], [21]
	HBIM	2	[18], [32]
	Modelling	3	[22], [30], [31]
	Planning	3	[10], [11], [25]

	Safety	2	[14], [17]
	Sustainability	7	[7], [19], [24]–[26], [33], [34]
	Visualization	3	[6], [12], [23]
Infrastructure	Roads	6	[37], [43], [49], [55], [57], [62]
	General	4	[39], [41], [48], [58]
	Utility	4	[47], [50], [56], [59]
	Railway	8	[38], [42], [44], [54], [61], [63], [65]
	Electrical systems	2	[40], [66]
	Subway	2	[45], [51]
	Tunnel	1	[46]
	Bridge	2	[52], [60]
	Hydraulic	2	[36], [53]
Building	Analysis	7	[67], [68], [73], [80], [86], [93], [95]
	HBIM	11	[71], [76], [77], [81], [83], [89], [91], [96], [97], [101]
	Management	10	[69], [72], [75], [78], [85], [87], [88], [92], [94], [100]
	Safety	4	[79], [84], [90], [98]
	Sustainability	4	[70], [74], [99], [102]

At the technical level, the BIM/GIS integration is divided into two main issues, namely the geometric and semantic conversion of data. During the years, researchers achieved one or both of them, but as can be found from recent papers, the matter still suffers several problems, such as intensive manual work or scarce generalization capability [103]. The BIM/GIS integration workflow, on a practical level, is mainly intended as an IFC to CityGML uni- or bi-directional conversion [104], [105], or in the alternative as the employment of Semantic Web Technologies and Linked Data approach (e.g. ontologies, [106], [107]). This brief insight about the technical aspects of the matter is necessary because it is a transversal theme that interests every classified article in this review.

3.1 City and Urban

Since GIS relates to territorial and environmental data, it is a natural deduction that the integration with BIM can be applied to large collections of buildings, such as urban areas or whole cities. The sub-category distribution shows a trend, with the "Sustainability" topic as the most frequent one (22%, 7 papers out of 33). Following this, a series of general activities are recognized, such as Analysis (16%), Visualization (10%), Planning (10%), Modelling (9%). The Sustainability sub-category also refers to work related to energy management [19], planning [7], [34], and assessment [27]. Moreover, a

dedicated literature review of the sustainable built environment and BIM/GIS integration was found [24]. The other sub-categories cover a heterogeneous plethora of topics. For instance, the BIM/GIS integration was involved in noise analysis [5], comfort and quality of public spaces [35], and smart city appraisal [4]. City and urban contexts involve not only buildings, but also every element that offers services and well-being to citizens. Data and their management play a crucial role in delivering these services to stakeholders and end-users, and since this means that several data sources need to be handled together, a BIM/GIS integrated environment can constitute the core of solutions for several purposes. For example, thanks to a Linked Data approach, McGlenn et al. [10] integrated the spatial data storage Prime2 of Ireland's national mapping agency, namely Ordnance Survey Ireland (OSi)m with IFC and Dbpedia data. This interlinking led to a richer data hub integrated with BIM data. Since BIM models were not originally intended to handle geospatial data, they are expressed in a local reference system that needs to be transposed in GIS environments with the required coordinate reference system (e.g., coordinates in WGS84). Some commercial software allows to easily import and locate BIM models, [30], and almost open-source solutions can be found [6]. BIM can support the development of virtual 3D City models, which are nowadays mainly based on the CityGML data model and format, and they could be employed for several applications such as 3D cadastre, utility management, emergency response etc. [20]. The BIM/GIS integration can also provide support to automate permitting, shifting from paper-based permits to automated and BIM/GIS permitting systems [21].

3.2 Infrastructure

Built infrastructure is the second main category that can benefit from the BIM/GIS integration, since it merges detailed modelling of the assets from the BIM side and the geospatial analysis that can be performed in a GIS environment. Infrastructures are built both in and between cities. For instance, the "Railway" sub-category considers high-speed railway [42] and urban rail [63], [64]. "Railway" was the most frequent sub-category found (27%), followed by "Roads" (20%), "Utility" (13%), "General" (13%), "Bridge" (7%), and other minorities. Infrastructures included in cities can be embedded in the smart city management, such as utilities [40], [47], [50], [56], [59] and subways [45], [51]. BIM/GIS infrastructure models can be used for full lifecycle digital control [63], and can be integrated with technologies such as computer vision and machine learning [41]. Moreover, the idea of a BIM/GIS digital twin was proposed for highway maintenance and monitoring [49], [57]. It is worth noting that on the BIM side, infrastructures are still not fully developed and implemented in the data model. However, works are in progress to deliver these kinds of constructions in the IFC format, thanks to buildingSMART initiatives such as IFC bridge, IFC road and IFC airport [108].

3.3 Building

The "Building" category includes papers in which the focus of the BIM/GIS integration is on applications at the building scale. The most frequent sub-category is "HBIM", namely "Historic BIM". HBIM refers to existing buildings whose geometry is obtained

by survey, for instance by point-cloud technology, from which the BIM model is consequently generated [109]. HBIM can benefit from the BIM/GIS integration because it can provide semantically rich models, and it can help to document and analyse cultural heritage sites [97]. An 8 years research, named Chimera, led to a BIM/GIS system which allows managing transversal information on different levels, from object to building to the environment [81], [101]. As in other studies, a common workflow for the BIM/GIS integration in HBIM adopted FME software [77], [91], [102]. The work of Cecchini et al. declines the HBIM both on a city and single building, with a focus on the energy management of the heritage [102]. Similarly to the City/Urban, the integration of BIM/GIS can be supported by other data sources such as IoT sensors [73], [99]. In the "Building" category are also included studies focused on facility and asset management, [75], [78], [92], [94], [87], [88] in which GIS aid BIM models to be queried, georeferenced and located. GIS also allows relating BIM models with their surroundings, in order to analyse and assess external factors which can impact on the buildings, such as a flood [67], [68], fire emergencies [90], [98] or to link indoor and outdoor routes for planning [86].

3.4 BIM/GIS features for integration

Public agencies and organizations which have to manage large building stocks require detailed and authoritative data about their assets [91]. Depending on the scale of intervention, the BIM/GIS integration can aid at both large territorial environment and detailed in-building components scale. Between the three main scales, namely territorial, building and component, there are a series of intermediate level which can be identified. For instance, the BIM/GIS integration effort performed by Li et al. [74] is based on a case study on the University of New South Wales (UNSW) campus. Another intermediate level between the building scale and the city scale can be the neighborhood level [70]. In these two cases, the distribution of the buildings is concentrated in a single area, but this is not always the case. For instance, agencies dealing with social housing management commonly have large building stocks which can be spread through one or more cities [80]. Regarding this point, Vacca et al. [110] converted IFC models of social housing buildings and their components into geodatabase .gdb format to store them in Arcgis, using FME software a single georeferenced environment. While these last examples are relatable to the main subject of this paper, the literature review was extended to the general BIM/GIS integration topic in order to find insights for the management of large building stocks, even from less related contexts such as infrastructures. In fact, in this perspective, large building stocks can be placed in a fluctuating context which is the function of the managed assets and their area of intervention. Being a hybrid context, several features taken by the classified categories can suit a system for managing this kind of assets and related data. **Erro! Fonte de referência não encontrada.** collects a list of key features observed in the literature, organized by categories.

Table 4. Key features suitable for BIM/GIS integrated system for large building stock

Category	Features
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City and Urban	City planning, georeferenced visualization, buildings metadata management, socio-economic and political analysis, environmental context definition, aggregated performance and data monitoring and analysis, city operation and management, policy development
Infrastructure	Intra-building utility, in-cities utilities and in cities infrastructures
Building	Component inventory definition, facility management, single building simulation, performance management and monitoring, life-cycle management
Transversal features	
Supply chain management, data monitoring, digital twin features, environmental analysis, cost and time management	

The supply chain management feature, for instance, was commonly found in relation to the construction phase [69], [93], [9] and it can be extended to the whole lifecycle of one or more buildings through its operation and maintenance.

It is worth noting that the relation between BIM and GIS is of mutual benefit. In fact, while BIM can be expanded by GIS, on the other hand, GIS can be supported by BIM models which provide digitalized data in order to populate the geospatial database. Due to the wide number of applications for GIS, data sources can be heterogeneous, and without standards, they can suffer technical and cooperation limitations. BIM can therefore provide standardized and detailed data at building and even smaller scale, such as facility management. Regarding this, the literature review of Wong et al. [94] investigated BIM, GIS, and IoT sensors for facility management, highlighting the need for interoperability data and BIM/GIS integrated database for assets. Agencies and organizations involved in the maintenance and management of large building stocks are in an in-between situation in which they need data that range from the component to the territorial level. Moreover, multidisciplinary data are involved, since technical, social and economic management of the assets can be required. Thus, the BIM/GIS integration can be seen as a common core in which other sources can be integrated based on the specific case. The linkage between this core and other data sources can be achieved by geospatial databases [8], [74], [77], [102], [111]. To this point, the work of Cecchini et al. [102] addresses the BIM/GIS integration with a multi-scalar approach using a relational database on PostgreSQL with PostGIS extension, allowing to perform tasks at both urban and building scale. On the former scale, the GIS component is prevalent, with geolocation of EPC (Energy Performance Certificates) in the city center of Pavia. The latter scale is focused on the building stock of the University of Pavia, with the visualization of the thermal and electrical demand of building stock and a detailed energy assessment on a single building. To build this system, several data sources were needed, which on the GIS level are commonly provided by territorial information systems and surveys, while building-specific data need to be provided by owners (e.g., plans, sections and elevations).

4 A roadmap for BIM/GIS integrated systems

Based on the analyzed literature, a roadmap is defined (**Erro! Fonte de referência não encontrada.**), showing the conceptualization of the main modules that could be implemented in a BIM/GIS integrated system. The roadmap tries to overcome the gaps in the

current literature on BIM/GIS integration, proposing a path to better address the management of the large building stocks, taking into account that the solution can be composed in a modular way, according to the specific needs of the stakeholders. In detail, it tries to cover and organize currently missing, in development and existing modules addressing the the hybrid dimension of “large building stocks”, which lies between the city and building scale; the generalizability of the solution depends on the complexity of the asset portfolio, the context of application, and the stakeholders involved in the processes. Due to these factors, an important underlying premise for the effective implementation of this roadmap is to develop vendor-neutral solution. The adoption of commercial software was found in literature, although BIM promotes open interoperability by means of IFC files. In complex contexts like large building stocks, with assets that can be spread on a large territory with different stakeholders, the lack of open standards could hinder or compromise the overall implementation of the solution.

The modules are disposed in a 2D space, whose dimensions are the heaviness of the system and the importance of semantic in data for the given module. Oriented lines mean that the previous module can provide data for the following module.

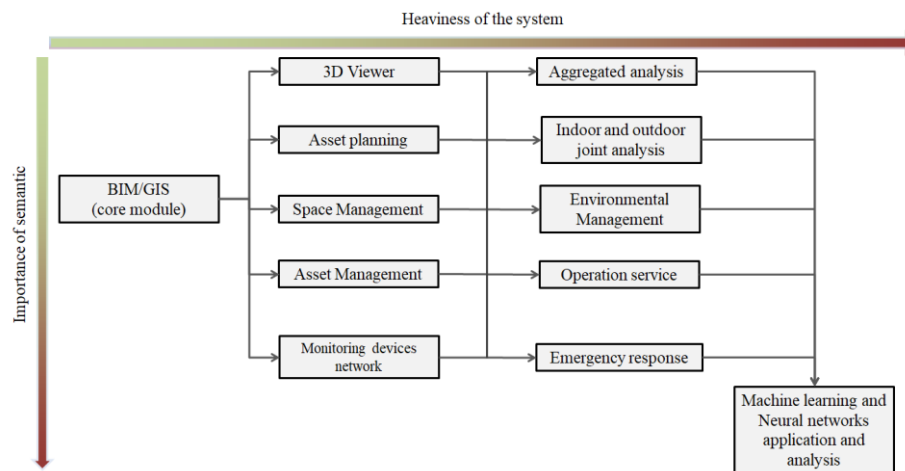


Fig. 1. 2D axis conceptualization of modules for systems for large building stocks

Starting from the BIM/GIS module, the core of the system can be of several types (e.g., PostgreSQL DBMS, graph database), and the complexity of the purposes which need to be achieved and the importance of semantic must be taken into account. If users need a BIM/GIS ground mainly focused on visualization and overall asset planning, then 3D viewers, which merge GIS maps and BIM models, are available on commercial software. On this application, the semantic importance of data is relatively low and the overall level of detail of BIM models can be focused on external features of the assets. When indoor features data are required, BIM models become more detailed, with the definition of spaces and components. Here, thanks to GIS power of analysis, indoor and

outdoor context can be jointed and applications like network analysis and indoor/outdoor routing can be achieved. Managers for large building stocks, in order to shift to a BIM/GIS integrated system, need to preserve data on existing asset management and CAFM (computer-aided facility management) software. On this kind of system, a data model is required to map and link BIM objects with existing data. The complexity of the system rises when data are not simply collected, but also analyzed and processed. In these cases, the semantic preservation of data becomes more important, because data are commonly exchanged between stakeholders and software. For example, the environmental management of the assets implies life-cycles assessment (LCA) studies, and at the current state of the art the BIM and LCA integration is another open topic.

To allow the convergence of heterogeneous and redundant data, semantic web technologies can provide support to develop a system in which a link between information is provided, rather than converting and attempt to fit a data model into another. Semantic web technologies also provide a lean way to a more complex system, in which dataset are also processed by machine learning and neural networks, which could automate tasks in every stage of the buildings. However, semantic web technologies imply information technology expertise and costly and time-consuming processes, and these types of system may be of interest for experimental studies or long-period projects with governments and public agencies. The BIM/GIS integrated system can be developed for several purposes, and most of them can be satisfied by recent technological achievement, but the lack of standardized procedures and limited generalizability could require intense manual tasks and expensive tailored solutions.

5 Conclusions

Considering the relevance and the contribution provided by an integrated environment for managing BIM models with GIS information for large building stocks, the literature review suggests a categorization of the current studies in four main categories “City and Urban”, “Building”, “Infrastructure” and “Technical”. The first three categories are explored in the paper to suggest current fields of applications and guide practitioners and scientists in a structured overview of the existing studies, and to discover insights for extracting useful features for the discussed BIM/GIS systems. Starting from this contribution, papers under a specific sub-category can be selected based on the needs of further specific research.

Furthermore, the paper provides a summary of the main features that a system integrating BIM and GIS has to satisfy. This finding is based on the analysis of the literature and aggregates the features successfully implemented in other studies. Practitioners can consider this summary for defining the functionalities of a new BIM/GIS integrated system.

Finally, the last contribution of the paper is a roadmap of steps to follow to guide an appropriate integration for concrete digital management of information assets of large building stocks. Practitioners and scientists can benefit from this contribution. It can be

used as a guideline for future implementations or single steps that can be integrated into an own roadmap.

Therefore, future studies should continue to investigate in order to provide a standardized, open and intuitive solution for effective, flexible and scalable BIM/GIS integrated systems, providing a tool that can support the management of assets throughout their whole lifecycle. This topic is strategic for the digitization of the AECO/FM sector and it is the subject of research for BIM and GIS-based leading communities such as buildingSMART and ESRI.

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