GeoBIM for Urban Sustainability Measuring: A State-of-the-Art in Building Permit Issuance

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Abstract. The integration of Geographic Information System (GIS) and Building Information Modelling (BIM) has shown promising applications in different sectors related to urban transformation and at various scales, ranging from the district to the building level. This approach, also known as GeoBIM, presents opportunities and challenges for assessing urban indicators, with both technical and social implications. This paper aims to define the state-of-the-art and to explore the possibilities opened by GeoBIM for urban transformation measurement, with a focus on planning and building permits issuance. Accordingly, a literature and project review is conducted, to better understand the challenges and potential of GeoBIM. The results show that there are still technical problems to be addressed (e.g., data acquisition approaches and interoperability). Moreover, further research can be directed at the social implications of GeoBIM in practice, including updating political and cultural frameworks, enhancing competencies, and rethinking conventional practices from digitalization to re-coding processes.

Keywords: Geographic Information System (GIS) · Building Information Modelling (BIM) · GeoBIM · Urban sustainability · Building permits

1 Introduction: GeoBIM and Urban Sustainability

Digital technologies are becoming increasingly relevant to solving urbanization problems and ensuring sustainable development [1]. In particular, smart cities have become an increasingly widespread concept in public and scientific debate as an urban development model aimed at achieving these goals [2–4], capable of meeting resilient and sustainable city transformation goals [3]. Information is therefore essential to treat cities as systems and, consequently, as devices that can be addressed and improved through technologies [5].

To make sustainable smart cities possible in operational terms, City Information Modeling (CIM) is recognized as a tool that can improve city management, consisting of an urban model – both spatial and temporal [3] – that allows modeling, monitoring, analysis and simulation actions [2, 4, 6]. Indeed, a CIM model makes it possible to automatically manage information and conduct advanced simulations on complex problems

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O. Gervasi et al. (Eds.): ICCSA 2023 Workshops, LNCS 14104, pp. 308–321, 2023.
https://doi.org/10.1007/978-3-031-37105-9_21

from both economic, social and spatial parameters, with the possibility of integrating different scales [1]. CIM is understood as a tool that combines and integrates data from different sources, including geographic information systems (GIS) and building information modeling (BIM), into a comprehensive and up-to-date urban database, which should have open data, be accessible and interactive for all stakeholders [5]. Accordingly, CIM has relevant technical potential for understanding urban data, visualizing public policies, measuring and monitoring urban indicators, and even project evaluation and planning [3, 7, 8]. It can thus improve decision-making processes related to urban transformation and city management by providing information to administrations, urban planners, designers, and citizens [5, 7, 9] through a constantly updated spatial database. Moreover, by fostering stakeholders' understanding of public management actions, it can stimulate social participation and reconciliation and negotiation between the needs of different parties [10, 11]. The dissemination of open and quality data is important to strengthen the link between citizens and local government in understanding and discussing the planning actions that shape cities [5], from the district to the building level [12, 13].

Sustainable smart cities can be achieved, and urban sustainability can be assessed through the smart, multidisciplinary and holistic approach of CIM, aimed at [5, 7, 8, 14]:

(i) helping to achieve the global goals related to reducing human activity in the environment;
(ii) accounting for the systemic impacts of resource and waste flows over the entire life cycle of projects;
(iii) visualizing integrated data and models with different levels of detail on the whole set of urban development operations;
(iv) promoting the negotiation and discussion among the instances of different stakeholders.

The integration of BIM and GIS, henceforth referred to as GeoBIM [3, 5, 15, 16], is a topic that has attracted much attention in recent years as an integrated and systemic approach to urban sustainability and measurement [8, 17, 18]. Indeed, GeoBIM has the potential to overcome current information barriers [1], with a mutual fulfillment of BIM and GIS in terms of scale and system accuracy, allowing the entire built environment, from building to urban space, to be represented and controlled in a single solution [3]. Currently, BIM contains detailed building information, but excludes anything that does not relate to the architectural model; in contrast, GIS can conduct large-scale spatial analysis, but does not report building information [1, 8]. The development of GeoBIM stems precisely from the need to integrate these functions and achieve all urban design goals with one system.

The differences between the two systems, however, necessarily imply numerous technical challenges [15, 16], in terms of different modeling methods, representation, scale chosen for data restitution, purposes for which data are produced, and local or supra-local reference of coordinate systems. At the same time, a general professional inadequacy and lack of expertise in both fields also imply societal challenges with respect to city decision-making processes [3, 16], in terms of informed stakeholder involvement, the need for knowledge in the specific fields, and the urgency for changes in legislation and regulations regarding planning at the institutional level [19]. The implementation

of GeoBIM is then a socio-technical issue, which needs problematization to move from manual analysis to automation of some procedures.

This paper aims precisely to define the state-of-the-art and explore the possibilities opened by GeoBIM for urban indicators, focusing on building permit issuance. Accordingly, a literature and project review is conducted, to better understand the challenges and potential of GeoBIM, both in terms of technical problems to be addressed, and social implications in practice and operationalization of such technology.

The application of GeoBIM to the realm of issuing building permits, with a more efficient authorization process, is an emerging area of research. Recently, the creation of cadastral databases through GeoBIM integrations has enabled developments in the direction of managing information more interactively and automating some measurements and verifications [1, 16, 20]. In particular, verification of project compliance with building permits, widely approached and managed in Europe through manual verification work against regulations by technical experts from municipalities, is being tested in the possibility of standardizing and automating the process by automatically issuing building permits [16]. Such an approach, through GeoBIM, could ensure not only the requirements, but also to measure several urban indicators, at different scales, to guarantee a sustainable and controlled development of the built environment.

Accordingly, the paper is organized as follows: Sect. 2 proposes the research design and defines the steps and aims of the literature and project review; Sect. 3 presents the background on GeoBIM technology, with a focus on building permits issuance; Sect. 4 presents the results of the literature and projects review, highlighting its technical and social challenges; Sect. 5 introduces conclusions and future work.

2 Research Design

This section illustrates the research design in conducting the literature review.

In the earliest stage of the review process, the Web of Science database has been chosen to support the literature search, with a query related to “GIS”, “BIM”, “urban”, and “sustainability indicators”. The selection of the papers has been filtered by considering the following criteria: (i) English language papers; (ii) the study must be related to the integration of GIS and BIM; (iii) the papers must explore a specific project application to be deepened in the review.

Then, given the goal of this paper to review the state-of-the-art of the challenges and potential of BIM and GIS integration both in technical and societal terms, a screening process has been conducted. First, the abstracts of all the references have been read in order to select and identify the most related research to the aims of this study. Second, the full paper texts of the appropriate references have been included in the research database. Finally, the 24 selected papers have been read, in order to collect information about the state-of-the-art and theoretical background of GeoBIM applications, to be included in a textual analysis.

The results of the analysis are reported in Sect. 4, aimed at defining the state-of-the-art and exploring the possibilities opened by GeoBIM for urban indicators, focusing on building permit issuance.

3 GIS and BIM Integration: An Operational Perspective

As briefly explored in the introduction, GeoBIM can facilitate urban development as integrating BIM and GIS can provide spatial analyses that combine an efficient architecture/building-scale flexible management with a broader city-level visualization and information [1, 8, 21]. The two systems are able to compensate for reciprocal shortcomings.

BIM, as a 3D digital model at the building scale, provides geometric and semantic information for the project and enables detailed visualization of components and continuous updating of information, in a single platform for data processing [3, 22]. This, made available to multiple professionals, allows control of large volumes of data on the components of the project itself, with collaborative and circular digital management coordinated through the description of geospatial information. This technology thus allows for improved performance of the built environment, but also improved information quality with impacts on decision-making processes.

However, the hardware costs and resources required to process the BIM data of an entire city are unimaginable [22], making it impossible to exclusively use this technology for urban development, planning, and construction of smart sustainable cities. On the other hand, GIS makes it possible to obtain and manage spatial and geographic information at the city level, with a hierarchical data processing logic that reduces the amount of hardware computation [8, 23] to display and analyze it. In addition, the type of data that GIS effectively handles is derived from multiple sources, including not only morphological elements, but distributive ones, related to distances, location, and especially potential analyses of relationships between different dimensions. Therefore, GIS enables analysis from not only representations of space, but also of events occurring in it.

The integration of a process of digital management of information related to a work (BIM) and the representation with geographic information systems of a territory and what happens on it (GIS) allows the exchange of data between the systems in a single database, without loss of information and indeed with a mutual feeding of them.

The literature analyzes the potentials and criticalities of GeoBIM from different points of view. As highlighted in the introduction, the differences between the two systems necessarily imply numerous technical problems, and at the same time a general professional inadequacy and lack of expertise in both fields also imply societal issues. Given the operational objectives of the literature and project review proposed, to better understand the challenges and potential of GeoBIM and socio-technical implications in the operationalization of such technology, this work specifically addresses a recent line of research that emphasizes the need to bridge the gap between theory and practice [16]. As Ohori et al. clearly state “most of the research conducted so far has covered only the high-level and semantic aspects of GIS-BIM integration” [24]. On the contrary, an “application-oriented perspective” is introduced as a key to investigating the actual problems and opportunities in the use of GeoBIM and the broader implications it might have on research and professional work contexts [25]. The assumption underlying this perspective is that operational issues concerning the potential of BIM-GIS integration can only be addressed with respect to specific scenarios and use cases [26, 27].

Many possible GeoBIM application areas are discussed in the literature. Some of the most common fields of operation in the built environment include, for example, 3D mapping [28], city analysis, infrastructure and building design and monitoring [8, 16, 29], urban development [5], energy performance assessment [30].

GeoBIM is therefore used as a support to urban planning and performance assessment at very different scales, ranging from single buildings to much wider systems as in the case of infrastructure asset management or underground networks [8, 31, 32]. In addition, the literature review suggests the possible use of this tool at different stages of the process, from decision-making to construction, to management throughout the entire life cycle of an asset [31, 33].

Given this overview, this research adopts an application-oriented approach to question how GeoBIM can support the measuring of sustainability in urban transformation processes. To this end, the result analysis presented in the next chapter focuses on a specific use case, namely building permit issuing, with specific attention to automation in code-check compliance. Several reasons motivate our interest in this specific field of application. First, although sustainability goals are now increasingly adopted by public institutions operating at various levels, it is rarely questioned how they can be included in ordinary planning and design processes. This means moving from the level of exceptional pilot projects to their actual possibility to be scaled up to produce results on the large scale. Second, building permits extend the scope of sustainability measurement to private processes and buildings, for which data and assessment tools are often lacking. Finally, the application of GeoBIM to building permit issuing would allow laying the foundations in the design phase for the measurement of performance in the subsequent project life cycle.

4 Digital Building Permit for Urban Sustainability Assessment: Opportunities and Challenges

In recent years there has been increasing interest in automated code-checking systems for issuing building permits. Actually, academic papers show that themes pertaining to the digital building permit (DBP) problem have been surfacing since the early 2000s, although a systematic approach only emerged recently. In the last ten years, the number of research and experiments has grown exponentially. Generally, the building permit process is part of the broader framework of digitalization in the construction sector [26]. Nonetheless, the research for automation remains strongly linked to the condition of locality, and it still suffers technical, methodological and social difficulties. In the following sections, first of all we focus on what kind of diffusion such systems are having, also highlighting some geographical trends in this regard. Then, we explore the most common implementation difficulties highlighted in the literature, identified in three macro-aspects. Finally, we briefly emphasize the implications – and related difficulties – opened up by GeoBIM for urban indicators, starting from the in-depth focus on building permits issuance.

4.1 State of the Art of DBP Projects: A Geographical Overview

Recent papers focused on the global state of DBP have tried to frame the geographical distribution of projects related in some ways to this sphere, providing an articulated state of the art [27, 34, 35]. On a general level, a broad geographic distribution emerges, with a good concentration of projects and initiatives located in Europe (and especially Central and Northern Europe). Among the non-European cases, which enclose Australia, Brazil, Canada, Chile and the United Arab Emirates, among others, there are also some of the pioneering initiatives. In particular the Corenet project developed in Singapore since the 1990s for e-submission and recently transformed into one of those processes trying to adopt BIM technology for partial code compliance checking. Similarly, the Seumter digital submission system adopted by Korea since 2009 is recently undergoing implementations aimed at integrating BIM and Industry Foundation Classes (IFC) models in the partial automation of project compliance assessment [35].

In Europe, the state of the art is fragmented. The most fertile area seems to be the northern part of the continent, with Estonia, Finland, Germany, Norway, the Netherlands, the United Kingdom, and Sweden engaged in one or more projects targeting the development of DBP systems. It should be mentioned, however, that experiments along these lines are also taking place elsewhere, such as in France, Slovenia, Spain, Switzerland and Portugal.

In particular, one of the first attempts to evaluate the possibilities of translating the set of regulations in a computational sense, with a view to a possible automation of inspections related to building permits, was carried out in 2014 in England: in collaboration with Solibri and Butler & Young, the National Building Specification (NBS) developed a pilot to evaluate the tools currently available to perform automatic code compliance checking using a BIM model [36]. Among the most recent applications and attempts in this regard, the Finnish Kira-HUB platform [37] is gaining momentum, becoming one of the most interesting paradigms on the continent and beyond. The digital ecosystem that contains a three-dimensional environment, in addition to being used by both the private user for a compliance pre-verification and the public entity to monitor the compliance check process, is currently being used to incrementally characterize the very model of the three-dimensional space.

In general, there are some issues concerning the various projects and the state of the digital building permit in a global sense. Considering the evaluation parameters of the Building Smart International, many of the projects at the most advanced stage fall into level 2: hybrid, the BIM value is actively used in code checking, but some manual procedures may still be present. This is because level 3, the one in which "laws are readable by machines, open standards that do not depend on the software environment are used, and holistic code checking is performed" is difficult to achieve at the present stage, even for a context historically characterized by greater legislative and regulatory simplification [34]. This mainly depends on the difficulty of translating into a computational sense the entire apparatus of codes and standards, which by their nature are heterogeneous and ontologically different, but we will go further on this later. Among the few advances produced in this regard, many have been made in automating the extraction and transformation of rules directly from regulatory codes and documents. Artificial intelligence (AI) methods use natural language processing algorithms such as

text analysis, content monetization, automatic content classification, and text mining. These methods allow computers to automatically derive meaning from text and generate logic rules for checking purposes [38].

Definitely, the greatest common denominator among the cases, both the ones discussed and those which have been only mentioned here, is precisely the intention to produce a platform for the three-dimensional digital submission of projects and partial automation of compliance checking. Almost all of the projects focus on the goal of using BIM models, which highlights how BIM and GIS integration is still a complex road ahead.

4.2 The Implementation of DBP Systems: Three Open and Critical Issues

In parallel to applications and developments, it is essential to analyze the problems and major obstacles to implementing this type of system. To do so, we will once again draw on the literature reviewed so far, enlarging the reference discussion of one of the previously cited papers [27]. Indeed, the work highlights a series of subtopics corresponding to the different stages of progress of studies and experiments. By treating them as consequential problems, the study allows not only to delineate which aspects catalyze to a greater extent the efforts of experts, rather it allows to identify which are the most common issues and aspects to be implemented, with a view to DBP diffusion. Starting from this framework, we specifically highlight three macro-aspects that are most closely related to the orientation of our analysis.

Data Availability and Convertibility

The issue of data availability and convertibility touches several spheres with regard to the automation of DBP. First of all, the aspect of the translation of standards and codes into "computer-interpretable" and "computational objects" must be considered. It is plausible to argue that almost every particular context presents a code structure characterized by objects that can be easily translated in this sense, others less so and others not at all. In this sense, a 2015 study [39] classifies standards (in general terms) into three categories: those which are computer-interpretable (declarative) and those which are not (informative); finally, those which can be considered as unsuitable. Among operational developments, however, some hypothesize the use of NLP-based methods, which essentially involve implementing IFC to incorporate compliance checking-related information [40], while in the Netherlands, experiments are being carried out aimed at the storage of spatial planning information in 3D based on CityGML [27], a conceptual model and exchange format for the representation, storage and exchange of virtual 3D city models, promoted by the Open Geospatial Consortium.

In general, the topic is crucial, but developments are still isolated and strongly context-specific.

Standard and Interoperability CityGML/IFC

Another aspect refers on the one hand to the conversion of normative data into spatial format (in terms of IFC models), and on the other hand to how BIM data in IFC format can be converted into 3D geodata [41], in order to support an uninterrupted digital data

flow and consequently enrich the system incrementally, while continuing to record the transformation of current conditions.

In fact, rather than the issue strictly related to the accessibility and quantity of information available, which is certainly fundamental but concerns local policies and actions for the implementation of databases, the most urgent issue at the methodological level concerns how to make information, or rather geoinformation, reliable but above all interoperable data. This can only pass through standardization and conversion: to date, the most suitable system seems to be CityGML, (especially in relation to general urban rules such as zoning) [42].

The few works focusing on possible solutions to the issue point out that, although there are tools that would already support the conversion and georeferencing of data, a clear definition of the necessary requirements for conversion is still lacking, and this affects the coherence of the results. The GeoBIM benchmark 2019 – funded by ISPRS and EuroSDR [43] – had as its aim precisely the evaluation of implementations of coherent conversions between 3D city models and BIM, also involving external experts [29]. It emerges precisely how the issue of checking the coherence and truthfulness of geometric and semantic information is considered the most critical [29, p. 12], so much so that a further manual check of the conversion still remains necessary.

Other works are attempting to deal with the problem from a strictly technical point of view, and trying to evaluate advances, net of the aforementioned difficulties. Still starting from the general assumption that "municipalities invest a lot of time and person-hours into manual building permit checks" [44, p. 529], and that the implementation of DBP systems could guarantee an improvement "of both the efficiency and transparency of building permit checks" [44, p. 534], a team based at Tu Delft is trying to convert data corresponding to a set of regulatory parameters and constraints, extracted mostly from zoning documents, into JSON formats, in order to immediately explore the possibilities of web interaction of a partially automatic check-compliance system. The reference case study is the aforementioned Rotterdam project and involves investigating the possibility of a system running on an online server. The hypothesis is to load and display IFC files directly on a browser, and then convert them into glTF files to be finally displayed with BIMSurfer2 [44]. But beyond exquisitely technical aspects, this research also highlights the limitations with regard to the truthfulness of the output, leading to the conclusion that the generalization of standards and other parameters to be converted, and the construction of a common basic ground upstream of the process, are unavoidable aspects.

Back on a more general level, this problem also relates to the preliminary analysis and evaluation phases of planners (both private and internal to public facilities). In other words, the issue of converting data into CityGML models, or other related systems, concerns both the evaluation and check-compliance of a project in relation to its enabling and the preliminary analyses to its development.

In this case, several solutions are explored, including: automated methods to extract design information from BIM models in IFC to insert it into a semantic logic-based representation, aligned with a corresponding semantic logic-based representation of normative information [27] (a modality proposed for example by [40]); another more popular and well-known system is the use of Solibri Model Checker (SMC), "to validate the information content of BIM models prior to code checking" [27]; or, again, one

avenue evaluated in the aforementioned Korean KBIM case is that of "a design quality control process whereby architects create OpenBIM data using specific guidelines and previously developed BIM libraries" [27]. But even in this case, implementations are still numerically very limited.

GeoBIM Automation

In general, the issues outlined concern the automation of building-related permits, while on a more specific level can be all referred to a field that is indicated as GeoBIM - although, as above mentioned, this definition has only recently begun to spread. The basic problem can be summarized as follows: the need to place the designed building (BIM) in its geographical context (GIS).

Linking this to the theme of translatability and computer-interpretability of standards, it should be considered that the BIM model must be examined against specific requirements defined by codes and regulations. Recently, there has been an increase in studies and research in this direction, many of them concentrated in the Netherlands [41] and the Scandinavian area [45] but also in other geographical areas, as highlighted above through the state-of-the-art analysis of real-world applications.

Eventually, the reason why these aspects are the most relevant for us is that they are closely linked both to the topic of assessing the sustainability of an intervention (and its inclusion among the objectives of the automation of building permit procedures) and, more generally, to the effects such automation would generate on coding in general. The pivotal question in this regard is: how, in view of the possible need to make standards computational, could the norm-making paradigm change?

4.3 GeoBIM and Urban Indicators

The three highlighted macro problematic aspects – data availability, interoperability and automation – are correlated to some difficulties with respect to the operationalization of indicators for urban sustainability [20, 49–53].

Regarding the national context [53], data are often unavailable because they are obsolete or linked to episodic collections, and/or the databases are difficult to consult. Moreover, existing data are often not homogeneous in terms of spatial scale, reference time span and disaggregation levels. Consequently, potential interoperability between databases is not feasible, because partial information does not allow cross-queries, e.g., between statistical and geospatial information. In line with these issues, the possibility of supporting an uninterrupted and incrementally enriched flow of digital data clashes with non-open or non-standard technologies [48, 53], making even real-time and automatic updating complex. In this sense, a political discussion and local action for the implementation of accessible and integrable databases [46–48] and related codes and regulations [20] is more urgent than ever.

With respect to the need to measure the sustainability of projects, in the context of building permits, urban indicators could allow for both quantitative and qualitative assessments that are not only statistical but visualizable and spatialized [20, 48, 54, 55] thus a GeoBIM integration would be a key support for the spatialization of sustainability measurement. Furthermore, since observing one indicator at a time, rather than their relationship to each other, limits the possibility of capturing multiple and interrelated

implications of urban transformation processes, GeoBIM could guide the process from measurement and monitoring to the actual evaluation of project performance [56].

The use of GeoBIM models can help to make more informed decisions by making use of several key indicators that can lead to better and more reliable results through a multi-criteria approach [57, 58]. BIM makes it possible to quickly extract data and information from the components of a project and aid in the evaluation [58], mainly due to the potential offered by the IFC file format, while GIS integrates such assessments into the broader urban decision-making by incorporating multiple location and environmental information and criteria – as social, environmental and economic indicators – thus bringing GeoBIM technology to potentially more effective use in multi-criteria decision-making [59, 60].

5 Discussion and Conclusions

The analysis of the literature and ongoing experimental projects developed in the previous sections brought to light both potentials and criticalities in the integration of BIM and GIS systems for building permit issuing.

The results of the analysis show, on the one hand, the potentials offered by GeoBIM systems in this respect. Some elements, particularly critical in the measurement of sustainability in urban transformation processes, are worth highlighting. First, the integration of BIM and GIS systems could foster greater integration and uniformity of measurements and reference systems at all scales – from the building to the territorial one – through the introduction of common interoperability standards. Second, the implementation of three-dimensional digital urban models could make it possible to localize and spatialize measurements that are usually solely statistical, laying the foundations for a quanti-qualitative evaluation of urban transformation processes. Thirdly, GeoBIM technologies pave the way for extending the scope and time of urban sustainability assessment, providing a constantly updatable platform for the systemic measurement and monitoring of a wide variety of indicators over a period of time covering the entire design process and project life cycle.

On the other hand, the literature review also shows how, for these perspectives to become operational, a number of limitations must still be overcome. More specifically, technical issues concerning the integration of GIS and BIM systems, widely discussed in the literature, are traced back in this paper to three issues particularly critical for addressing GeoBIM implementation for digital building permit: (i) data availability and convertibility; (ii) standard and interoperability; and (iii) automation. Nevertheless, other cultural and social aspects raised by the spread of GeoBIM systems are still understudied, highlighting a gap in the literature in this respect. Among the most relevant social issues are, for example, the lack of technical skills and structures within technical offices and design agencies; the inertia of cultural and professional working contexts; the change of perspective and role required to public and private actors operating in the building sector; the ethical problems related with the acquisition and storage of personal data; etc. In addition, most of the studies developed on this topic do not explicitly address the implications of adopting GeoBIM systems – and in particular automated check-coding systems – on the overall regulatory paradigm. Indeed, the partial automation of

building compliance verification processes opens new possibilities for the streamlining and updating of administrative procedures on the one hand and for the implementation of data-based multi-criteria decision-making processes on the other.

In conclusion, the paper envisage the potential of GeoBIM systems for disseminating urban sustainability measurement in ordinary building processes. It also suggests, however, the need to develop further research from at least three understudied perspectives: (i) the actual potential of developing sustainability assessment tools and methods through GeoBIM systems; (ii) the socio-cultural limitations related to GeoBIM operationalization for digital building permit; and (iii) the possibilities it opens up for a more comprehensive process of re-coding and revision of current regulatory frameworks.

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