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Building information modelling and building sustainability assessment: a review

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Abstract

Purpose – The construction sector is increasingly engaged to explore the potential application of building information modelling (BIM) for the sustainability of the buildings. BIM can be applied conjugated to certification methods to evaluate the sustainability of the buildings, and it is known as building sustainability assessment (BSA). This article aims to explore applications of BIM in the sustainability analysis of buildings, including five types of BSA.

Design/methodology/approach – A literature review from 2009 to 2020 considering a combination of search terms related to BIM and BSA complemented the analysis. The bibliometric analysis indicates an increase in the number of publications on this topic of study in the last five years. A peak occurred in 2015 and 2020, with 51 and 66 publications, respectively.

Findings – The results showed that BIM contributes to achieving part of the sustainability requirements from BSA, especially quantitative requirements that are related to material and resources. However, a complete analysis between BIM and BSA is still a challenge since part of BSA's have a lack information in their requirements and BIM softwares present interoperability problems that difficult an integrated analysis to extract information directly from the software to attend BSA's requirements.

Originality/value – The results contribute to analysing the evolution of studies about BIM and to understand the limitation in the applicability with sustainability rating systems. Future directions of research indicate the necessity to improve the use of BIM in the sustainability analysis of the buildings, but with a good perspective regarding the application of BIM in material and resources requirements, and waste management in construction sites.

Keywords Building sustainability assessment, Construction management, Building information modelling, Building environment

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1. Introduction

One of the most promising innovations in the architecture, engineering and construction (AEC) industry is building information modelling (BIM), a set of processes, tools and technologies that improve production, use and update the information of the building in a virtual model (Succar, 2009; Eastman *et al.*, 2014; Machado *et al.*, 2016).

At sustainability BIM is applied in studies related to energy efficiency, life cycle analysis, waste management and sustainability assessment systems known as "Green Building Assessments (GBA)", "Sustainability Rating Systems (SRS)", or "Building Sustainability Assessments (BSA)" (Krygiel and Nies, 2008; Berardi, 2012; Soust-Verdaguer *et al.*, 2017; Ansah *et al.*, 2019).

Building sustainability assessments (BSAs), the term adopted in this article, are types of environmental certifications to evaluate the sustainability of the buildings (Haapio and Viitaniemi, 2008; Kamaruzzaman *et al.*, 2016). Examples of BSAs are Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), Green Building Index (GBI), "High Environmental Quality" – *Démarche Haute Qualité Environnementale (*AQUA-HQE), Sustainable Building Tool for Portugal (SBToolPT) and "Leadership for Environment" (LiderA).

BSAs aim to provide comprehensive and quantitative assessments of building performance, considering aspects related to the project, such as site selection, energy performance, carbon emissions, water efficiency, quality of the internal environment and consumption of materials, including +) (Abdelhameed, 2017; Lambertz *et al.*, 2019).

New technologies like BIM have been adopted in construction projects to reduce the impacts of construction activities and improve the sustainability of buildings (Jrade and Jalaei, 2013). BIM contains multidisciplinary information that can support the credit assessment of BSA. However, this combination requires the integration of tools and adequate criteria to effectively contribute to the sustainability of the buildings (Jrade and Jalaei, 2013; Wong and Zhou, 2015; Lu *et al.*, 2017; Maltese *et al.*, 2017; Ansah *et al.*, 2019).

BIM is a trend in the construction industry with an increased number of studies that explore functionalities for the benefit of the buildings' management. The main objective of this article is to explore one of these applications with BSA. A literature review considering publications from the last decade complemented the analysis. The results from this preliminary study will contribute to a future analysis of the integration of the information required to meet BSA directly in the construction model. The development of functionalities integrated to BIM improves sustainability analysis in the building and facilitates measuring environmental impacts in construction and meeting requirements that are part of BSA.

This study was realized during the years 2019 and 2020, partly in Brazil and partly in Portugal, along an academic mobility period. To have a panoramic view of sustainability in construction from both countries, the authors selected the most representative BSA in each region: LEED and AQUA-HQE in Brazil; and BREEAM, SBToolPT and LiderA in Portugal.

The results from this study will complement next steps of the research that consists in the application of BIM to meet requirements related to construction and demolition waste management to minimize environmental impacts of the building.

2. Method

The first part of this work consists of a brief description of the five commercial BSA selected to be part of the study. Then, a literature review was realized to explore publications about BIM and BSA.

According to Kassem and Amorim (2015), one of the possibilities to measure the importance and popularity of BIM in construction sector consists of analysing the knowledge of the technical staff, based on academic production indicators. In this study, *Scopus* (https://

www.scopus.com) was selected as a database to find publications related to the topic about BIM and BSA. *Scopus* started operating in 2004 and has a detailed coverage of articles since 1996. The searches can be optimized with Boolean operators and search terms related to the topic of interest; this combination improves the results. *Scopus* indexes more than 18,000 journal titles, Open Access titles, conferences, web pages, patents and books, with a considerable coverage of science and technology magazines (Lopes *et al.*, 2012).

Scopus allows the use of Boolean operators to combine search terms related to the topic of study and limit the search according to what is desired and relevant to explore in publications. The search terms considered in this study are based on Mateus (2009), Succar *et al.* (2009), Eastman *et al.* (2014), Gaspar and Ruschel (2017) and Mueller *et al.* (2019). The terms considered not only the name or initials of each BSA selected to be part of the study, but also synonyms and other references used in BSA and BIM.

The combination of search terms used at Scopus database was: ((“BIM” OR “Building Information Model” OR “Building Information Modelling” OR “Building Information Modeling”) AND (“green building” OR “sustainability rating system” OR “certification system” OR “environmental certification” OR “building sustainability” OR “sustainable design” OR “LEED” OR “HQE” OR “Haute Qualité Environnementale” OR “Aqua process” OR “Aqua certification” OR “AQUA-HQE” OR “BREEAM” OR “SBTOOL” OR “LIDERA”)). The inclusion criteria considered only articles, journals and papers published in English, and that search terms appeared in the title, abstract or as a keyword. The temporal analysis considered the search from 2009 to 2020, for a better view of the evolution of studies about this topic in a decade. A bibliometric analysis to verify the origin of publications, main authors and keywords complemented the results.

Finally, an overview of the main findings is presented with a discussion about current practices in BIM and BSA and trends in the construction industry related to this application.

3. Overview of BSA

In Brazil, there are three BSAs that stand out in the construction industry: BREEAM, LEED and AQUA-HQE, with the latter two having the highest number of registered certifications, most of them in commercial buildings (CBCS, 2014). In Portugal, besides BREEAM, the other two BSAs most popular in the construction industry are SBTool for Portugal (SBToolPT) and LiderA (Fernandes, 2013).

3.1 LEED

LEED was created by the United States Green Building Council (GBC) in 1998 to establish strategies and standards for sustainable buildings. It is currently the most widely used method in the world to assess the environmental performance of buildings and provides owners and operators with a concise framework for identifying and implementing projects, practical and measurable green building operation and maintenance solutions (Kamaruzzaman *et al.*, 2016; Solla *et al.*, 2016).

According to GBC (2019), China leads the ranking with the largest certified area, 68.83 million square metres. Brazil obtained approximately 17 million square metres certified in 2018 in more than 530 projects. The most popular LEED certification is LEED for design building and construction for new constructions, that is, LEED BD + C: NC.

3.2 AQUA-HQE

AQUA-HQE emerged in Brazil in 2008, based on an adaptation of the French method HQE (*Haute Qualité Environnementale*), to meet the culture, climate, technical standards and regulations present in Brazil. AQUA-HQE aims to control the impacts of a constructive or rehabilitation project on the external environment, comfort and health of users along the pre-project, design and execution phases (Fundação Vanzolini e Cerway, 2018). Since the AQUA-HQE started in Brazil, 502 projects have been certified (Fundação Vanzolini, 2019).

3.3 BREEAM

BREEAM emerged in 1989 in the United Kingdom and is considered the oldest and the most used BSA, with more than 500,000 certified enterprises in 85 countries (Building Research Establishment, 2020). Most of the certified buildings are in Europe. Portugal has 38 projects registered by BREEAM. In Brazil, there are only four projects with this certification (Kibert, 2016; Building Research Establishment, 2020).

BREEAM aims to minimize the life cycle impacts of buildings on the environment and be a reference to stimulate demand and creating value for more sustainable buildings, construction products and supply chains (Building Research Establishment, 2017).

3.4 SBTool^{PT}

The Portuguese method SBToolPT emerged in 2009 by an adaptation from the Green Building Tool (GBTool) from 2005. It presents a generic structure to classify the environmental building performance, assigning scores to credits from different areas based on benchmarking references (Mateus and da, 2009; Fernandes, 2013; Larsson, 2015; iiSBE, 2020). The parameters are evaluated based on measurements and reference values from Portuguese constructions (Mateus and da, 2009; Mateus and Bragança, 2011).

3.5 LiderA

LiderA, an acronym translated as Leading the Environment for Sustainable Construction, was created in Portugal in 2005 to evaluate and certify buildings in the design, construction and operation phases (LIDERA, 2019). It covers six aspects: local integration, resources, environmental loads management, quality of service and resilience, socio-economic experiences, and sustainable use. The latest version of LiderA is 4.0, revised in 2019 (LIDERA, 2019).

4. BIM and BSA

4.1 Bibliometric analysis

The research studies on the topic of BIM and BSA have increased over the years. According to Figure 1, the publications practically doubled in the last five years compared to the

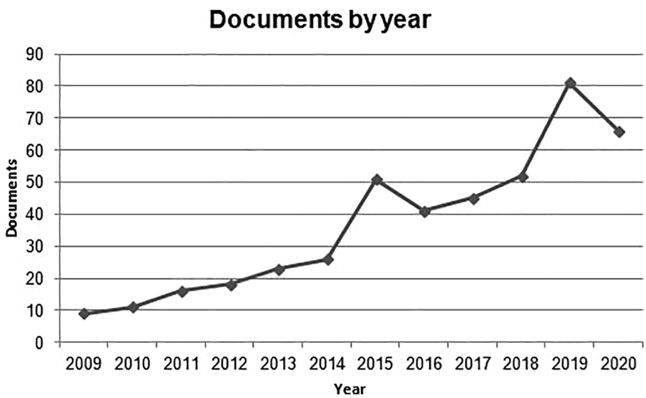

Figure 1.
Number of publications about BIM and BSA from 2009 to 2020

beginning of the series; this highlights the relevance of the theme over the years (Figure 1). A peak occurred in 2015 with 51 publications, and then in 2020 with 66.

The increase in publications may be the result of new environmental certifications launched in the market and the improvement of existing ones. In addition, there is also the dissemination of the concept of sustainable development in constructions, with updated norms and environmental legislation and the use of more complete tools like BIM to contribute to the management of the buildings in a collaborative way.

Regarding the authors (Figure 2), the five authors that published the most during the analysed period were A. Jrade with nine publications, followed by F. Jalaei with eight publications R.R.A. Issa and W. Wu with seven publications and P.H. Chen with six publications.

As for the origin of publications, the top five countries that published on BIM and BSA were the United States, China, the United Kingdom, Malaysia and Canada (Figure 3).

A map was created using *VOSviewer t*o complement the bibliometric analysis and detail the keywords that occurred at least ten times in publications from 2009 to 2020 (Figure 4).

Among the keywords highlighted in Figure 4 are "architectural design" with 292 occurrences, "sustainable development" with 183 occurrences, "building information model–BIM" with 131, "information theory" with 108, "buildings" with 105 and "green buildings" with 85 occurrences.

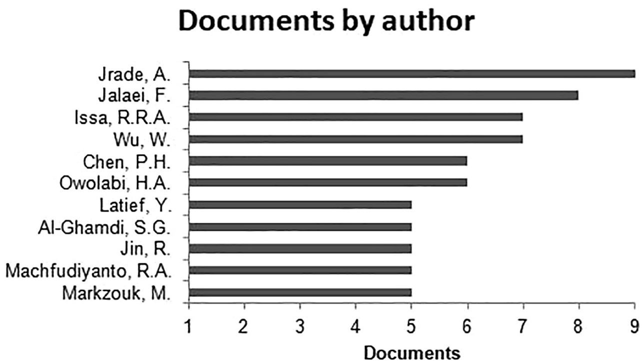

Figure 2.
Authors of BIM and BSA from 2009 to 2020

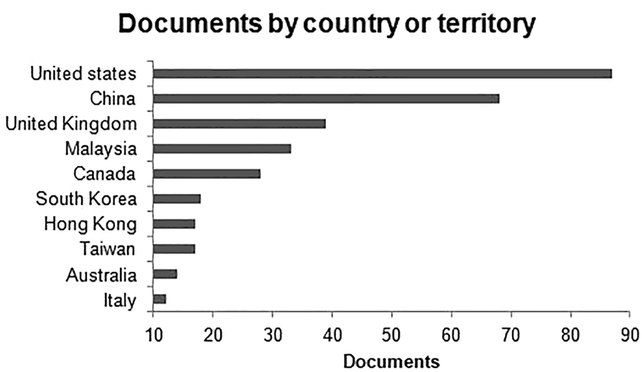

Figure 3.
Origin of publications for BIM and BSA from 2009 to 2020

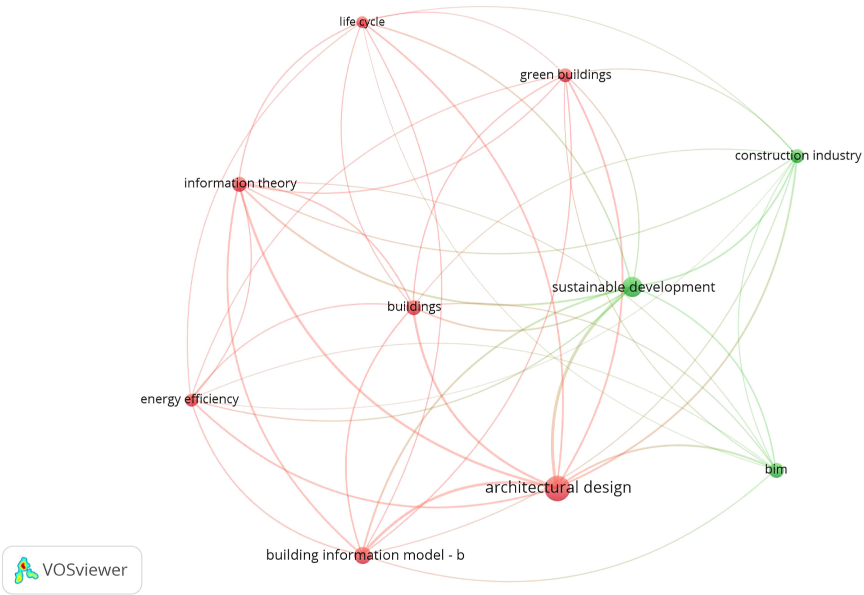

Figure 4.
Co-occurrence map of keywords for BIM and BSA from 2009 to 2020

4.2 Overview of findings

After the bibliometric analysis, a thorough analysis of publications was done to select articles more aligned with the theme and future directions of the study. The selection considered only complete published articles from journals or conference proceedings in which the title, abstract or keywords were directly related to the application of BIM with one or more of the BSA selected to be part of the study. The preference was to explore the highest cited articles that use BIM to evaluate the sustainability of the buildings. A better reading of this selection resulted in the overview, with the main findings stated in the following paragraphs.

Azhar *et al.* (2011) developed and validated a conceptual framework to establish a connection between the data collected for BIM and the data necessary to get LEED certification. The scope of the research was limited to non-residential construction projects. The authors carried out a literature review and interviews with professionals from the AEC industry. The study indicated that some of the parameters required for the sustainability assessment could be obtained through the Revit® and IES VE software, simplifying the LEED certification, saving time, costs and resources. The results showed savings of 20% over ten years in the total cost of the project.

Jalaei and Jrade (2015) integrated BIM with LEED-NC to automatically calculate credits for two categories: Energy and Atmosphere and Materials and Resources. The authors also created a feature in Revit® to calculate the respective fees necessary to register and obtain LEED certification for the proposed construction. Google Maps helped calculate the distance between the location (source) of the material suppliers and the construction place (destination). Although the integration of BIM and LEED was feasible, the authors identified some barriers like difficulty by the system to estimate the costs associated with different materials or the integration of other tools to reach each credit or point.

Nguyen *et al.* (2016) created a feature in Revit® to score the LEED certification credits in the Location and Transport category. The BIM and LEED integration used an algorithm that extracts the relevant data from the BIM model and then checks the conditions of the requirements to calculate the score. Geometry data (dimensions, areas, volumes, etc.) from Revit®, new parameters and elements, and additional user information in the model for the automatic evaluation of LEED were necessary to operate the algorithm. After modelling the algorithm in Revit®, a classification tool was created, with an interactive interface in which the user can access the evaluation data and extract reports according to the standard adopted by LEED professionals to support certification. The survey results raised the potential for applying BIM to automate tools for assessing the performance of construction projects.

Chen and Nguyen (2019) conducted research similar to Jalaei and Jrade (2015) and Nguyen *et al.* (2016). The authors created a plug-in in BIM to calculate the distances and estimate the cost of transportation between the location of suppliers of materials and the construction sites. The tool could help the manager to attend the requirements of LEED certification. In addition, the plug-in could improve the selection of the materials according to the stage of the project, budget and time available.

Wu (2010) analysed the needs, gaps and expectations of the construction sector regarding the integration of LEED with BIM. Initially, a questionnaire was applied to AEC specialists to assess knowledge about LEED, BIM and the impacts on the certification process. Then, the author created a generic integration structure to evaluate the features of Revit® and supplementary software applications. Finally, a BIM-LEED model was developed in two modules, one for project assistance and the other for certification management. The model was applied in a case study to assess the requirements of LEED, Materials and Resources category. The author identified some restrictions in the model related to the functionalities from Revit®, such as the absence of a GIS connection, lack of material library that captures data from industrial products and immature support for interoperability at the database level. There were also restrictions due to the inherent characteristics of some of the LEED requirements that do not apply to BIM integration (Wu, 2010).

Carvalho *et al.* (2017) and Carvalho *et al.* (2019) studied interoperability between BIM and SBToolPT for homes to verify how the requirements could be met based on data obtained in the BIM project. Initially, all requirements were analysed and the data for evaluation identified, as well as which BIM software could be used to collect this information. The authors found that 80% of the requirements could be obtained directly or indirectly with BIM resources in the initial phase of the project and that Revit® is the BIM software best suited to assist in the SBToolPT assessment for homes in Portugal. In the end, an integrated structure was proposed, considering the capacities and restrictions found in the analysis.

Wong and Zhou (2015) analysed the application of BIM in green buildings. According to the authors, BIM tools should consider the concept of 3R's (reduce, reuse and recycle) in the sustainability analysis of new projects and the modernization of existing ones. New solutions should be able to predefine or generate strategies that help project teams to avoid lost materials or impacts over the life cycle of the building. The tools must be more practical to achieve the requirements from BSA and improve innovation in construction.

4.3 Discussions

Although BSA intends to determine the level of sustainability in buildings, the criteria established in BSA are not always objective or represent the reality of the place evaluated. The difficulty in meeting the requirements is due to the particularities of the construction and the interpretation of requested information to validate them.

The five certification methods differ in several aspects as to how the requirements must be fulfilled, which parameters and indicators represent each category of evaluation, what are the units of measurement to qualify or quantify the indicators, the different interpretation on how to consider the sustainability at the construction site, among others.

The information in LEED and BREEAM is more detailed regarding what facilitates the interpretation and the meeting of requirements. In general, the fact of these certifications being older, better known and applied worldwide had improved them over the years through various updates, which have made them more complete and widely disseminated.

In the AQUA-HQE, despite originating from a French certification, the method was adapted to Brazilian buildings to meet current CDW management guidelines in the country. On the other hand, in the Portuguese certifications that use benchmarking data, it is necessary to ensure that the reference data are reliable; otherwise, there is scope for misinterpretations, which can influence the level of more or less sustainable practices in construction.

The reflection of the popularity of LEED was identified in the literature review. Most articles present the application of BIM to attend requirements from LEED. The BIM model at Revit® helped develop functionalities to extract information from BIM to attend requirements related to energy and atmosphere, transportation, and materials and resources.

Although BIM contributes to the development of buildings in a more sustainable manner, some barriers were identified during its application. Research indicates that the data available in BIM are not enough to analyse all quantitative and qualitative sustainability requirements (Azhar *et al.*, 2011; Liu *et al.*, 2015; Kamaruzzaman *et al.*, 2016). Ansah *et al.* (2019) and Muller *et al.* (2019) identified weak interoperability between applications, lack of support and standards for the construction and operation of green buildings, few studies that explore best practices in Green BIM projects, low acceptance of industries by available applications and low precision and detailed in the models.

For Mueller *et al.* (2019), technological innovation has been represented by the advancement of studies in BIM and interoperability. However, considering aspects such as services and business, it is observed that these topics are still on the rise. Interoperability is the field that can connect and improve the life cycle and sustainability, opening doors to innovative, economical and sustainable constructions.

Considering that the application of BIM in the AEC industry is a trend, certifying institutions must be attentive and prepared to update all BSAs and keep up the innovation of projects through digital modelling. At BIM model adaptations, complementary tools and a reliable database would help in the process, as the development of tools to supply this demand and cover more parameters and aspects related to sustainable issues, such as the inclusion of a set of requirements for assessing the sustainability of buildings directly at a BIM platform as mentioned by Chong *et al.*, 2017. However, the parameters and credits should be adapted to be met based on the information extracted from the model in BIM, which helps the building designers to meet certain BSAs without many changes in the project.

Besides the adaptation of BSA to be attended by BIM model information, it is also possible to create new tools or methods to measure the sustainability of the buildings, with parameters and indicators more adequate to the BIM platform. The digital transformation of the construction sector requires innovations to contribute to the sustainability analysis along the life cycle of the building.

The results from this paper point out opportunities for research regarding the extraction of information from the BIM model to attend sustainability requirements from any BSA in the market. The study also highlights the opportunity to develop other environmental indicators to help in the sustainability analysis of the buildings considering data are available in BIM. Studies revealed good perspectives to use BIM information to meet requirements related to material and resources. So, a future direction of search is to explore the direct application of BIM to meet these types of requirements. New functionalities can optimize the quantification of materials in construction and measure the impacts in construction sites caused by CDW generation that resulted from these materials.

5. Conclusions

This article proposed a literature review considering the academic database *Scopus* and a combination of search terms to explore the main applications of BIM and BSA, in the period of 2009–2020, and five commercial BSAs most popular in Brazil and Portugal. Through the literature review it was possible to identify the main applications of BIM in sustainability assessments and which requirements were better met by BIM information. In the last decade, the publications about BIM and BSA have seen a considerable growth, mainly in the last five years. The advancement of digitalization in the AEC industry and the discussions around the future of the planet about sustainability, circular economy and the search for minor impacts in the environment have contributed to more sustainable, smart, healthy and safe buildings, which demonstrates the relevance of the topic for future studies.

It was concluded that the use of BIM to get BSA certification is possible, but some adaptation is needed to allow a simultaneous analysis and to get better performance with this integration. The study revealed most applications of BIM with LEED, and to attend requirements related to resources and materials. Also, the studies showed better results with BIM in the meeting of quantity requirements than quality requirements. The data related to materials, volume, area and quantity are available for the model in BIM, which makes it easier to adapt to attend estimated values like generation of waste, materials used, carbon rates and so forth. Future directions indicated the necessity to improve the use of BIM in the sustainability analysis of the buildings, but with a good perspective of study regarding material and resources requirements, an opportunity to use BIM in waste management, for example.

One limitation of the study is that the publications evaluated were just from *Scopus* database; future studies should explore other types of scientific bases like Web *of Science, Sage, Scielo, Google Scholar* and compare the findings. However, as a preliminary study, the literature review enabled a discussion of the current state of sustainability assessment in the construction sector, a review of current BIM practices and a preview analysis of the main barriers in the operations. The limitations identified were interoperability problems among tools, the complexity of requirements from the BSA and the lack of information in the certifications to meet the requirements.

For a better extraction and use of information from requirements through BIM, it is necessary to map the process and create databases before using the model in order to effectively contribute to achieving the sustainability of the building and measure specific indicators. Future opportunities on this topic of study can include the development of new tools or functionalities that overcome problems with data interoperability between tools, loss of information or extraction of information during operations.

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