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BIM for energy certification in AEC industry: bibliometric analysis of four certificate cases

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The Architecture, Engineering, and Construction (AEC) industry is widely acknowledged for its substantial impact on energy consumption. Building Information Modeling (BIM), as a promising avenue to address the imperative of reducing energy consumption has been explored with sustainability frameworks but in specific areas, especially in its 6th dimension. Despite its potential, the literature shows that the connection between BIM and various environmental standards and certifications remains one of the least explored and utilized aspects. This study aims to identify commonalities in the application of BIM and environmental certifications, shedding light on both academic and practical gaps in the environmental management of buildings. To achieve this, a bibliometric literature review is conducted. Given the limited number of previous reviews, this study provides updated and original insights, serving as a foundational resource for future investigations into automated energy requirements. The research results reveal the four most widely adopted certifications, offering a substantial contribution to both the scientific community and AEC industry practitioners. The study provides a comprehensive and in-depth understanding of the current state of the link between BIM and Green Building Certifications (GBCs). Despite the restriction on the databases selected and focusing on the most common certifications, this study gives insight into the use of BIM with a certification that can be efficient when used in conjunction with another to better optimize environmental impact throughout the life cycle. Moreover, it underscores the low rate of automation in GBCs credits and requirements, emphasizing the necessity to incorporate new technologies like the Internet of Things (IoT) and blockchain into the field.

KEYWORDS

building information modeling, smart green building, green certifications, LEED, BREEAM

1 Introduction

The economic development of countries is closely linked to the performance of the Architecture, Engineering, and Construction (AEC) industry. Its contributions to the social growth of societies are tangible (Hatamleh et al., 2021; Idrissi Gartoumi et al., 2023a). This sector has taken the path of renovation by integrating the requirements of the 4th industrial revolution, which has brought new tools and approaches that have advanced this industry (Chen Y. et al., 2022). On another note, it is known for its high consumption of water

(Carvalho et al., 2019), natural resources, energy (Invidiata and Ghisi, 2016; Pacheco et al., 2012), and the generation of solid waste that infects the environment (Yeheyis et al., 2013; Li et al., 2021). This expenditure is not limited solely to waste construction materials left over from the act of building but also the quantities estimated in the design and engineering phase and not carried out due to lack of costing or failure to collaborate between stakeholders (Idrissi Gartoumi et al., 2022). The negative repercussions of CO_2 place the AEC industry at the top of the list of polluting industries and contributors to global warming (Feng et al., 2022a; Wong and Kuan, 2014; Wong and Zhou, 2015). With this in mind, the AEC industry is under intense pressure to reduce levels of polluting emissions (Mattoni et al., 2018). Construction professionals know the need to switch to ecological construction methods to minimize environmental impact, save building materials and earth resources, guarantee the health and comfort of occupants (Illankoon et al., 2017; Yılmaz and Bakış, 2015), and make the built environment more sustainable and resilient to achieve more Sustainable Development Goals (SDGs) (Opoku et al., 2024; Umar et al., 2024).

To overcome these barriers and enhance environmental performance, the AEC industry has concentrated on pivotal factors, particularly ambitious technological solutions (Bernardi et al., 2017; Wong and Zhou, 2015). This involves leveraging various tools, with Building Information Modeling (BIM) standing out as a prominent example (Pereira et al., 2021; Umar, 2021). BIM pilots the technologies recently integrated into the construction industry and are the most impactful technological development in the construction sector (Olawumi and Chan, 2018; Romano and Riediger, 2020). It is a new way of managing the construction life cycle from design to demolition (Wang and Chen, 2023). Essentially, BIM enables better modeling, estimation of construction material quantities, adjustment, and resolution of design faults and problems, evaluation of thermal comfort models, visualization of renderings, assessment of energy requirements, and facilitation of energy certification processes (Baarimah et al., 2021; Er-retby et al., 2022; Khalil et al., 2021; Ogunrinde et al., 2020; Osuizugbo, 2023; Wu and Issa, 2012).

Another crucial factor in addressing environmental concerns involves the adoption of energy transition frameworks (Braulio-Gonzalo et al., 2022; Cascone, 2023). Globally, numerous countries have developed building energy assessment systems and thermal regulations (Alyami and Rezgui, 2012; Lee, 2013). These systems aim to improve buildings' sustainability and life-cycle performance and mitigate their environmental impact (Illankoon et al., 2017; Liu et al., 2017). Ecological initiatives to solve energy consumption problems go a long way (Sun and Park, 2020). The Kyoto Protocol of 1997 catalyzed the formulation of framework agreements aimed at combating global warming (Azhar et al., 2011; Rosenqvist et al., 2003).

Under the Protocol, several countries have committed themselves, and other decrees describing energy efficiency targets have been established that must comply with the Kyoto Protocol or "20-20-20" (Laski and Burrows, 2017; Zuo and Zhao, 2014). For example, LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN (LEED) is one of the most widely recognized and deployed systems for designing, constructing, and operating green buildings. Originating in the United States, LEED, like other energy certification protocols, provides the criteria needed to evaluate, measure, and build ecologically and sustainably (Altomonte and Schiavon, 2013; Kang, 2020; Potbhare et al., 2009; Ur Rehman et al., 2022). BUILDING RESEARCH ESTABLISHMENT ENVIRONMENTAL ASSESSMENT METHOD (BREEAM) is another example of certification first used in the UK and now launched for use internationally in 2016 (Alyami and Rezgui, 2012; Chen et al., 2015; Lee, 2013; Pauža, 2023). In Japan, the COMPREHENSIVE ASSESSMENT SYSTEM FOR BUILDING ENVIRONMENTAL EFFICIENCY (CASBEE) was developed in 2001. The CASBEE system evaluates and certifies the environmental performance of various types of projects in Japan based on life cycle assessment (Alasmari et al., 2022; Haapio, 2012; Seyis, 2022). In addition, others are joining the Green Building Certifications (GBCs), such as the GERMAN SUSTAINABLE BUILDING COUNCIL (DGNB) (Bahale and Schuetze, 2023), Green Star NZ (Abdelaal et al., 2022), Australian Green Star (Doan et al., 2021), and GLOBAL SUSTAINABILITY ASSESSMENT SYSTEM (GSAS), and ESTIDAMA developed for Gulf countries (Azzam et al., 2022; Lei and Cui, 2022).

The linkage between BIM and GBCs creates a real opportunity to support the environmental and ecological transformation of the AEC industry (Ryu and Park, 2016; Wong and Zhou, 2015). Implementing BIM facilitates compliance with GBCs regulatory requirements by integrating the necessary information throughout the building's life cycle (Mohanta et al., 2021; Žurić et al., 2022). This information from energy regulations is analyzed and simulated before the project is delivered (Motalebi et al., 2022). In a significant portion of the literature, green buildings, characterized as the ecological counterpart of GBC-based buildings, have been summarized and analyzed (Cao et al., 2022; Chen L. et al., 2022; Meena et al., 2022; Olanrewaju et al., 2022a). On another register, studies analyze the different links between these certifications and others on the viability of using BIM in conjunction with some certificates and mainly LEED (Ariono et al., 2022; Caldas et al., 2022; Nairne Schamne et al., 2021).

BIM linked to GBCs has only been the subject of a few literature reviews. In the context of the relationship between parametric design and sustainable development (Cascone, 2023), reviews the state-of-the-art different methods of integrating LEED and BIM at the early design stage. This recently published paper recommends that future research should include the other certificates. Their studies (Alves Tenório de Morais et al., 2023), focus on the integration of the REVIT tool as BIM software can make GBCs processes more agile and standardized. In addition, BIM can address the complexities of building structures to correctly apply to build life cycle assessment and ensure better environmental performance of a building (Feng et al., 2022b). In terms of linkage, on the one hand (Mohammad et al., 2020), detail the applications of BIM from the point of view of contractors in Malaysia whose use is found with LEED certification. On the other hand (Sanhudo and Martins, 2018), establish a link between BIM and LEED via an application for stormwater credits for all types of buildings.

At this stage, it appears that previous work has either explored the concept of BIM as a tool for the effective deployment of GBCs or has established practical integration of BIM with LEED certification. However, these previous works have mainly focused on analyses limited to LEED certification without having a deeper, broader understanding of the research domain and including other certification schemes. In addition, many of these analyses have considered BIM-GBC studies, without focusing on a particular aspect or using a bibliometric approach to the analysis of a large dataset. Besides the insufficiency of discussion about automation in green certification applications and few studies of integrating advanced technologies like BIM.

To this end, there is a lack of knowledge about the applicability and use of BIM with the energy certifications most cited in the literature. There is therefore a need for a bibliometric literature review, to understand and organize all information relating to the application of BIM and current energy efficiency processes through BIM, including remaining limitations and feasible future improvements.

Furthermore, with the remarkable growth in the adoption of BIM, and the particular attention reserved by recently published studies to the subjects of energy certification with BIM, there is a need for a system that maps the existing and shows the strong links between BIM and all types of GBCs in all countries of the world and the context of use.

In the absence of a bibliometric analysis of the literature to our knowledge, this document is proposed as a preliminary work to map existing research through a scientometric analysis and to provide useful information on existing and future research to guide the scientific community and professionals in this context on how to proceed in the future. To extend the discussion on all common aspects of the application of BIM with the different certifications, the specific objectives are guided by the following research questions:

RQ 1: What certifications have been adopted with advanced technologies like BIM?
RQ2: How and when is BIM being deployed to meet environmental requirements?
RQ3: What are the trends and outcomes of BIM deployment with Certification for Green Building?

This article is essential for professionals and researchers as it helps to improve sustainability requirements and facilitates the adoption of energy certification. It is presented in 4 sections. After the first introductory section, the methodology is detailed in Section 2. The third section presents the main results of the bibliometric and scientometric analysis and, before concluding in Section 4, discusses and draws the main conclusions.

2 Research methods

To address research questions RQ1, RQ2, and RQ3, the bibliographic literature underwent analysis using bibliometric techniques. This method is employed to identify and map areas of knowledge by discerning research models. Widely utilized, bibliometrics has proven effective in detecting emerging research areas and technologies within the AEC industry (Wang et al., 2023). This analysis had a dual step. Firstly, visualize the extent and present the qualitative parameters of the data collected to understand the key aspects of research on the link between BIM and GBCs. Secondly, bring out the research map of themes. Via a rigorous exploration of the text and content of articles.

A rigorous content analysis of the selected articles allows us to summarize previous contributions. Then study current and future integration and present recommendations for successfully linking BIM and GBCs and ensuring energy efficiency. Figure 1 illustrates the research method, focusing on the quantitative results obtained.

2.1 Data collection

The content was extracted from the Scopus database. This database is widely chosen by a myriad of researchers (Baas et al., 2020; Newman et al., 2020). Because of its high coverage of predominant journal articles and a wider range of peer-reviewed journals, but also because of its automated analytical capabilities. In addition, this renowned database is a documentary source recommended by many academics and researchers as a wide-ranging source and includes more journals, articles, and papers (Ababio and Lu, 2023; Zhao et al., 2019). Another strong reason for choosing Scopus is that it is one of the main sources of data for Vos Viewer, which is the main tool for conducting bibliometric analysis in this study (van Eck and Waltman, 2010). For a clear, original, and exclusive view of the subject the selected article base was enriched with publications that closely align with the research objective, sourced from Emerald Insight, IEEE Xplore, and ISARC proceedings. To ensure a consistent analysis with VOSViewer, the Web of Science data was manually added to the CSV file extracted from Scopus, after checking that most of it was present in Scopus. Therefore, other documents from the WoS and the other sources mentioned above were also integrated.

To cover the scope of this study, the documentary search was carried out using keywords combined in the TITLE, ABS, KEY strings as follows:

i. ("Building Information Model*" OR BIM) AND ("Environmental certification" OR "Energy certification" OR "Green Building Certifications").
ii. ("Building Information Model*" OR BIM) AND (LEED OR BREEAM OR CASBEE OR DGNB OR GSAS OR ESTIDAMA OR HQE OR OSMOZ OR "Green Star").

Using the specified search terms, a total of 239 publications were collected from the databases and subsequently archived in library manager software.

2.2 Screening

Before moving on to the bibliometric analysis, exclusion criteria were applied, exclusion criteria were applied in three stages. Double publications were eliminated. This step resulted in the exception of 17 references from the library created. Secondly, careful reading of titles, abstracts, and keywords was adopted to focus on papers closely related to the intersection of BIM with energy or environmental certification. Documents outside this context were discarded (34 records). The third and final stage consisted of a complete and detailed reading of the remaining articles and resulted in the exception of 12 references. The total count of publications incorporated in the subsequent sections of this document is 176. It is worth noting that all types of publications were included (Research articles, conference proceedings, and book chapters) and only papers in English or transcribed in English were evaluated.

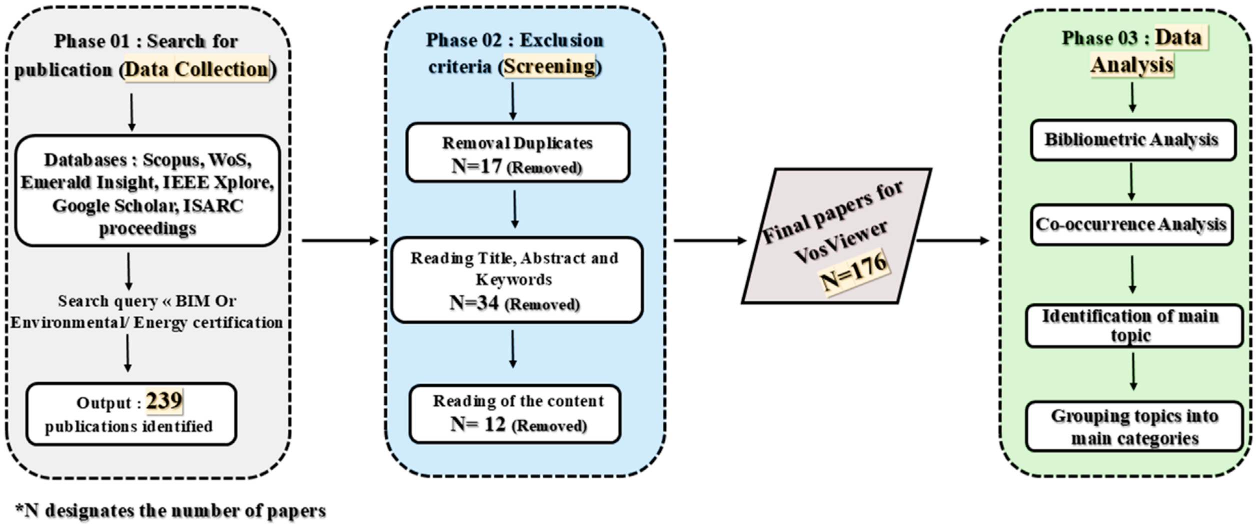

FIGURE 1
Flowchart of research design.

2.3 Data analysis

No restrictions on the publication period have been applied; all documents up to the end of 2024 have been considered. The document base was then exported to the commonly accepted tool suitable for scientometric analysis, VOS Viewer (Moral-Munoz et al., 2019; van Eck and Waltman, 2010). The data within VOS was represented by bibliographic linkage and total strength (Zhu et al., 2021).

The data sources obtained at the end of the process were analyzed according to the bibliometric parameters that specify the current state of research, using the following parameters: links between keywords, number of citations, number of documents, the average year of publication and average standardized citations (Idrissi Gartoumi et al., 2023b; Li et al., 2017).

The final selection of 176 papers is well aligned with the research questions and objectives. In fact, the selection allows a representation and a comprehensive understanding of BIM-GBC spectrum knowledge and gives relevant recommendations in the era of emerging advanced technologies for automation GBCs.

The methodology provides a clear view and maps the relationship between GBCs and BIM. Thanks to the scientometric and thematic analysis, the subject is exposed transparently with a clear way to conduct relevant future studies.

3 Results

This section initially focuses on examining various bibliometric characteristics of the subject based on the gathered articles. Subsequently, it organizes and classifies the integration of GBCs with BIM in the AEC industry.

3.1 Part 1: trends and bibliometric parameters

The presentation of the research results unfolds in stages. In the initial stage, the focus is on describing trends and quantifiable bibliometric indicators associated with the utilization of BIM in conjunction with energy certifications. This includes an exploration of the evolution of publications per year and citations per year.

The subsequent stage widens the literature's scope through the creation and analysis of metric networks. The key findings have been identified and categorized, facilitating the structured presentation of information. A total of 176 publications spanning from 2007 to 2024 have been identified. The earliest publication dates to 2007, comprising 85 articles (48.30%), 78 conference papers (44.32%), 6 reviews (3.41%), and 7 book chapters (3.98%). The annual distribution of publications is summarized in Figure 2.

The trend in publications exhibits variability, characterized by intermittent increases and decreases. The first notable spike occurred in 2011 (n = 7) and continued into 2012 (n = 7), showcasing remarkable variation over the period spanning from 2007 to 2012. Subsequently, after 2012, the trend experienced a decline, with only four publications in 2013. The pace of publications picked up again between 2014 and 2016, culminating in the second peak of 15 documents in 2016. However, the trend resumed its descent, reaching a low of 8 publications in 2018. Over the last 5 years (2019–2024), the pace of publications did not exhibit a continuous increase and, notably, experienced a decrease in 2021 following the first peak (n = 19) in 2019. The upward trajectory then gradually resumed in 2023. The most substantial number of publications (n = 20) was observed in 2023. This indicates the extent to which the subject is new and is attracting the interest of researchers on an international scale. Due to obligations, the need to conserve resources, and sustainable governance of buildings, this subject will receive more attention.

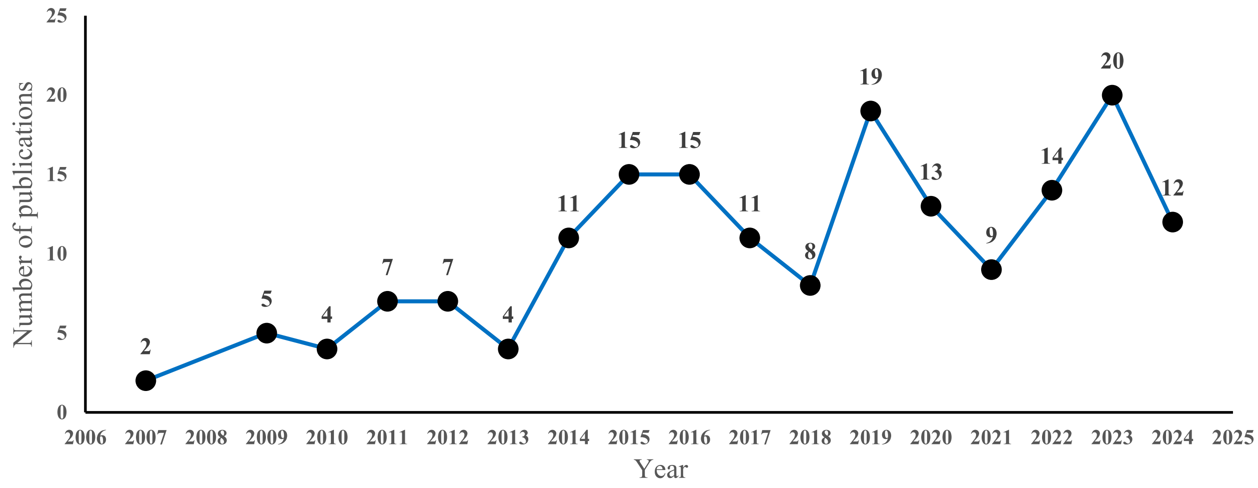

FIGURE 2
Breakdown and annual trend in publications.

In the pursuit of practical solutions for achieving necessary optimizations in energy efficiency, each country worldwide, driven by its unique context, is actively exploring avenues. One notable solution involves the integration of (BIM) with (GBC). To gauge the extent of response to this adoption, the identified publications have been linked to their respective countries based on the corresponding author's institution. This approach not only offers insights into the global landscape of research contributions but also opens opportunities for collaborative initiatives among research bodies with shared interests. Collaboration can facilitate obtaining funding assistance and support for addressing pressing issues. Leveraging VOSviewer, country contributions have been identified and categorized, employing criteria of a minimum of 5 documents and 5 citations per country. The results are depicted in Figure 3.

According to the threshold, 11 countries are leading this discussion and have published at least 5 documents. Out of a total of 44 countries from all continents contributing to this research issue, the United States is ranked first, followed by the United Kingdom and Malaysia (Figure 3a). Based on citations, which indicate the importance of the studies carried out, the ranking underwent a remarkable change, placing Canada and Egypt in second and third place, respectively. Analyzing the strength of the total linkage, which reflects the links established between institutions, countries, and researchers with others, it is clear that this linkage remains weak but promotes future cross-country collaboration.

Table 1 explores other bibliometric parameters. The first is the Avg. Pub. Year. This indicator shows the average year of publication for each country. The countries' output is almost brand new and varies between 2015 and 2021. This study deploys two other indicators. The first is normalized citations, which equals the division of a document's total number of citations by the average number of citations of all documents published in the same year. This parameter calculates the average normalized citation score by dividing a research unit's total normalized citation score by the total number of documents published during the same year. This indicator highlights the importance of studies carried out in different countries. According to Table 1, the United States has the highest normalized citation value (13.58). Finally, academics from Canada had the highest average normalized citation value, followed by academics from Egypt, China, and the United States. This last result shows the existence of global competition to produce significant studies and contributions. As well as the diversity of certification tools countries deploy in response to environmental challenges.

3.2 Part 2: certification incorporated with BIM

To answer this second research question, we carried out a co-occurrence analysis to find the most discussed and targeted content and the most emphasized keywords. Some documents contain and present more than one green certification or environmental approach used with BIM in the AEC industry, all aimed at promoting the sustainability of this sector. To identify and pinpoint the strongest collaborative links between BIM and energy certifications, the study uses a threshold of at least four co-occurrences in the GBCs literature. This ensures the identification of the most applied, adopted, and recognized certifications within the scientific community. Figure 4 illustrates the research trends toward BIM and GBCs applications.

According toFigure 4, since 2018 BIM has been able to create links with various environmental components such as certification, sustainability, and energy performance. At the beginning of 2019, these trends will reach a new turning point with the appearance of a new theme: the automation of sustainable design using BIM.

Based on the threshold chosen, the keyword analysis highlights two clusters related to energy certification. The first concerns green design based on BIM and LEED certification (avg.pub.year 2016,5) and the second concerns BREEAM and BIM (avg.pub.year 2017,5). The recent keyword in this analysis is Life Cycle Assessment (LCA) with an avg.pub.year of 2021. As mentioned in several studies, BIM is a technology designed to introduce the various aspects of sustainability via green building certification (Nocerino and Leone, 2023), sustainable design (Shin et al., 2016),

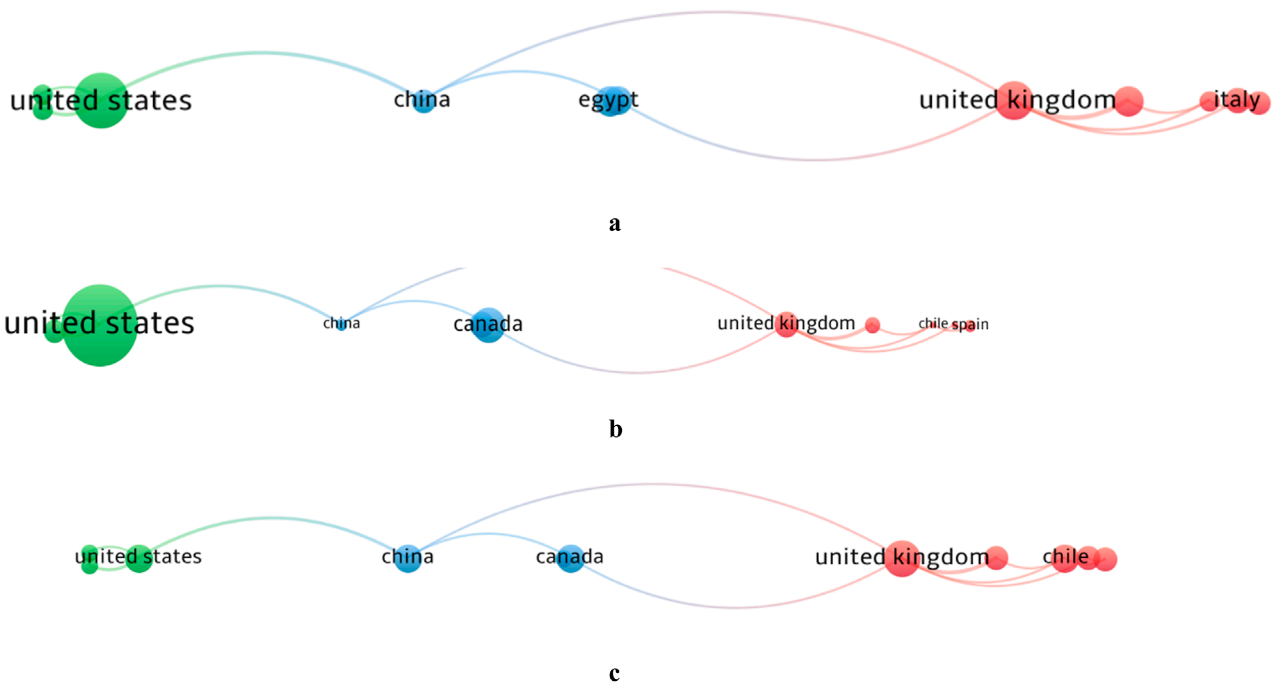

FIGURE 3
(a) Countries Network (based on documents). **(b)** Countries Network (based on citation). **(c)** Countries Network (total link strength).

TABLE 1 Countries engaged in BIM and GBCs research.

Country	Total link strength	Documents	Total citations	Avg. Pub. Year	Avg. Citations	Norm. Citation	Avg. Norm. Citations
United States	5	44	1341	2015	30,48	13,58	1.12
United Kingdom	7	20	317	2017	15,85	3,21	0.58
Malaysia	4	13	172	2018	13,23	1,74	0.68
Egypt	1	12	308	2018	25,67	3,12	1.92
Canada	3	11	468	2017	42,55	4,74	2.04
China	4	8	115	2018	14,38	1,16	1.56
Italy	2	9	45	2019	5,00	0,46	0.58

sustainable assessment (Abouhamad and Abu-Hamd, 2021) and energy efficiency (Nemati et al., 2020). Figure 4 also maps this finding and shows that sustainable design is the most recurrent cluster with the high total strength of link.

Table 2 shows the 4 highest-ranked certification systems covered in scientific publications up to the end of 2024.

4 Discussion

In response to concerns about the negative impact of the AEC industry on the environment, research into the regulation of building consumption has been carried out via a collaborative application of BIM with energy certifications. According to the table, 4 certifications deal with this subject. LEED certification is ranked first with 32 occurrences, followed by BREEAM in second place.

These certifications also reflect the extent to which countries have embraced BIM. On this subject, many studies have emphasized the differences between countries in the implementation of strategies to promote BIM. Like BIM, the emergence of energy certification is also linked to regional disparities and the presence of regulatory policies. In this sense, countries with green strategies are the first to implement energy certificates, explaining the dominance of LEED and BREEAM.

Both certificates, as pioneers, have focused on environmental sustainability, thus these authors are working on an improvement

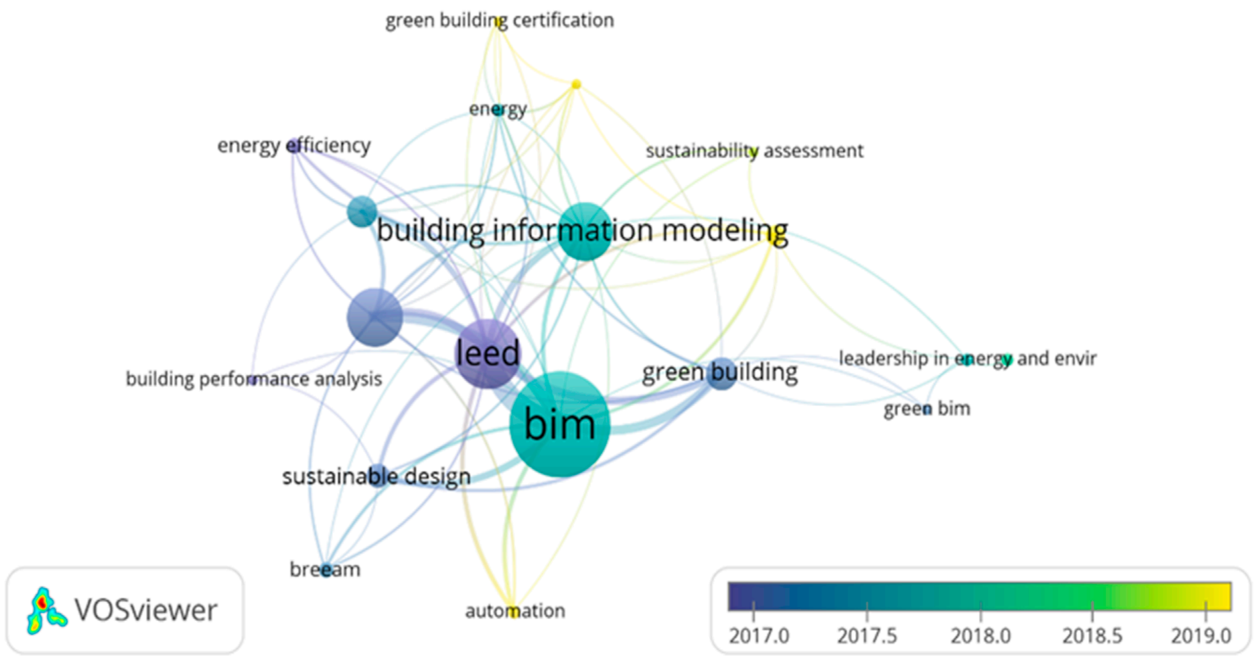

FIGURE 4
BIM interaction with green certification.

TABLE 2 Top-ranked Green BIM certification systems.

Certification	Occurrences	Total link strength
Leadership in Energy and Environmental Design (LEED)	38	92
Building Research Establishment Environmental Assessment Method (BREEAM)	6	16
National Australian Built Environment Rating System (NABERS)	2	8
Net Zero Energy Building (ZEB)	2	8

of social (Olakitan Atanda, 2019; Stender and Walter, 2019) and economic (Seinre et al., 2014). On the contrary, the NABERS and ZEB certifications are present with only 2 occurrences.

4.1 BIM certifications identified

4.1.1 NABERS

The National Australian Building Environmental Rating Standards (NABERS) allow energy performance ratings to be generated once the installation is in service (Doan et al., 2019). The link between NABERS and BIM appears in only two articles. In the first Tuohy and Murphy (2014), predict that NABERS is one of the building industry initiatives most likely to achieve the desired performance in practice provided it is supported by BIM (Tuohy and Murphy, 2014). In a second paper, these authors conclude from an analysis of energy failures in the construction industry that the correct use of a BIM approach based on NABERS regulates the actual performance of an occupied building (Tuohy and Murphy, 2015).

4.1.2 NZEB

The introduction of Nearly Zero Energy Buildings (NZEB) in construction projects has called for precise coordination, which can be achieved using BIM (Zhang et al., 2021). Indeed, the creation of a low-energy building is part of the BIM concept because of the need for precise analysis right from the conceptual phase (Kim et al., 2015). In the second study on this subject Sergio Gómez Melgar al. (2018), in a case study integrated all the stages of the NZEB (ZEB and +ZEB) to achieve a minimum energy building. This study, based on the actual behavior of the building, used BIM throughout the lifecycle, from architectural design to operations management (Melgar et al., 2018).

4.1.3 LEED

With the USA winning the most articles, LEED certification as shown features prominently in previous discussions. A previous review system (Ansah et al., 2019) found that LEED was the most frequently used certification (Olanrewaju et al., 2022b). Reveals that

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LEED possessed the highest representation of 35% in multi-criteria green building certification systems.

The integration of BIM and LEED was cited 38 times in the keywords of previous studies. These studies have looked at the possibilities of integrating BIM and LEED. One of the first studies dealing with the integration of BIM into the LEED certification process in 2011 proposed the BIM methodology to analyze two LEED prerequisites and 5 credits (Azhar et al., 2011). In principle three ways were revealed; data exchange between BIM software (Cascone, 2023), the BIM cloud (Mellado et al., 2020), and extension programming (Tagliabue et al., 2018).

Recently, LEED has become the focus of BIM-related research through Building Energy Modeling (BEM), counted as a derivative of BIM (Hosseini et al., 2018). In practice, previous studies show that there are no appropriate BIM tools to automate LEED certification, however, Insight 360 remains feasible to determine some LEED (Reeves et al., 2015). Thanks to the interoperability between the different BIM tools, the transfer of data such as the estimation of construction materials and light analysis is guaranteed, which reduces the time needed to verify LEED credits and categories. However, it is necessary to facilitate the certification process by developing new BIM creation tools other than REVIT (Alves Tenório de Morais et al., 2023). LEED automation is one of the facilitations proposed thanks to the BIM cloud (Wu and Issa, 2011), the development of credit calculation tools (Jia et al., 2012), the development of software and databases to store country parameters (Sanhudo and Martins, 2018).

Implementing LEED through BIM remains a cost-effective and efficient framework for sustainable construction (Idrissi Gartoumi and Koumetio Tékouabou, 2023). It is of course applicable in the building design and engineering phase (Sampaio et al., 2021). Thanks to the collaborative management offered by BIM, this framework could be extended to the construction phase by opening to other approaches to sustainable construction management such as Lean Construction (Idrissi Gartoumi et al., 2023a; Patel et al., 2023).

4.1.4 BREEAM

BREEAM, first launched in 1990 in the UK by the Building Research Establishment (BRE), seems to be fully adapted to certain countries thanks to cooperation agreements with local institutes (Bonna et al., 2019).

The mapping of GBCs supported by BIM puts the Building Research Establishment Environmental Assessment Methodology (BREEAM) in second place as shown. Previous studies validate and propose sustainability frameworks for the use of BIM with BREEAM. BIM can be implemented in the definition of BREEAM requirements for different phases (Carvalho et al., 2019), data transformation through interoperability (Idrissi Gartoumi et al., 2023c), creation of the model with the required parameters (Jalaei and Jrade, 2014), simulating and evaluating BREEAM requirements (Kasim, 2015). It can also help to identify preferable renovation solutions by enabling a comparison between the performance of the existing building and the performance expected after certain changes (Pereira et al., 2021).

This certificate has become popular thanks to its flexibility to be adapted to the local scale and requirements of each country (Sánchez Cordero et al., 2020; Carvalho et al., 2020) estimate that 24% of BREEAM credits have been linked to BIM, compared with 67% for LEED, and that the automation of BREEAM mentioned earlier has been achieved using REVIT, Dynamo, Energy Plus, Green Building Studio, and Visual Studio (Simhachalam et al., 2021). Have developed a framework for automating BREEAM certification adapted to the Netherlands context. This study shows that the BREEAM automation process depends largely on the level of BIM maturity of an organization.

Dubljević et al. (2023), led a process to automate the achievement of BREEAM credits for the renovation of an existing building. In addition (Rodríguez, 2023) set up a case study of a 3D building in Seville based on BIM. In this study, the author analyses the BREEAM indicators that can be integrated into BIM and concludes that the indicators associated with the geometric and spatial definition of the building are the most influential in advancing sustainability in the initial design phase.

Given the urgency of energy consumption in buildings and the impact on the environment, it makes sense to develop tools that can help and facilitate the assessment process. However, existing automation problems mean that manual and semi-automatic methods must be used (Eadie et al., 2013). In addition to the weak inclusion of regenerative credits such as biodiversity, water, land use, and ecology, socio-economic and acoustic aspects are less integrated into sustainability assessment models Olanrewaju O. I. et al. (2022a). Faced with this situation, using emerging technologies to enhance BIM and improve sustainability is essential. (Chen et al., 2023), conducted a comprehensive study on BIM-IoT integration for sustainable building. This study illustrates the added value of IoT as an "auxiliary plug-in" to join the BIM platform.

Blockchain integrated with the BIM process for intelligent energy management is proposed as a strategy in sustainable construction management. (Liu et al., 2019), reveals that blockchain can overcome challenges that prevent BIM in sustainable design.

Emerging technologies like BIM help create more sustainable built environments and implement the GBCs credits. However, each certification has its advantages and challenges. In the light of the paper, combining more certification systems helps to enhance the sustainability of the built environment and overcome challenges related to regulatory policies.

In this context regrouping technologies and creating workflows between BIM, IoT, and Blockchain allows transparency in collecting, measuring, mentoring, and assessing GBCs credits. For example, implementing LEED follows a process characterized by four stages: LEED pre-assessment (Feasibility stage, Pre-Certification (Design stage), Construction review (Construction stage), and Credit appeal (post-construction stage). In each stage, advanced technologies create an opportunity to collect and exchange data in transparency, security, and integrity in one BIM platform.

The importance of BIM lies in its ability to align with other new techniques and environmental approaches. In recent discussions, new local certifications have been discussed. The coherence between these new certifications and approaches like Green Globes, Living Building Challenge (LBC) and SBToolCZ could be the subject of future research (Anjamrooz et al., 2024; Federla and Korytárová, 2024).

5 Conclusion

This paper furnishes a contemporary and comprehensive perspective on the digitization of green building certification facilitated by the deployment of Building Information Modeling (BIM). The study delves into the interactions catalyzed by BIM in the context of energy certifications, specifically focusing on instances where less than one energy certification is involved. Motivated by various considerations and obligations, the bibliometric literature review successfully identified four certifications central to discussions on credit automation through BIM. As of the end of 2024, LEED and BREEAM certifications have emerged as predominant players, taking the lead in discussions and occupying prominent positions within the framework established with BIM for the creation of green buildings. The study is part of a worldwide effort to automate the deployment of energy certification. It highlighted the growth of this subject and identified the development needed to overcome energy challenges.

The structuring of updated knowledge arising from the results found can be presented in three blocks of knowledge: knowledge domains, knowledge evolution, and knowledge capitalization. This last block summarizes the solutions that need to be adopted alongside BIM for better application and realization of energy certification credits. These solutions are largely technological solutions resulting from the technological revolution. Through analysis of occurrences and previous studies, BIM can be armed with other technologies such as blockchain and IoT. Exploring these two technological tools requires a scientific effort.

Researchers and practitioners can deepen energy certification practices and measures by extending the scope of BIM and deepening its application across the entire lifecycle of construction. In addition, think about frameworks that include IoT and Blockchain with BIM to ensure systematic automation and inclusion of energy certification. The benefits of this study can be exploited even at the level of the choice of certification, especially in countries considering the creation of thermal regulations, and it offers a clear view of the tangible prospects and the quick wins to be implemented.

The bibliometric results highlight a worldwide classification of this subject. The first category comprises countries that have already started designing and building with one of the energy certifications. The second is at the stage of thinking about or researching the local adaptation of an energy certification. The study shows that developed countries are paying particular attention to this issue. In this respect, developing countries could take this paper as a preliminary study to create local standards and adopt technology to facilitate the application of energy certification.

In this study, we have delved into numerous opportunities, perspectives, and challenges inherent in the application of GBCs within the framework of projects developed using BIM. Our aim is that this exploration proves valuable and comprehensive, providing researchers with insights to digitize the BIM application process and harness the benefits of modeling and monitoring through BIM. Having synthesized the findings and identified current research gaps in this domain, we offer the following recommendations:

- Put BIM at the center of the digitization of credits standardized by energy certificates.
- Include BIM 6D tools and analyze their interactions with GBCs throughout the construction lifecycle.
- Study the feasibility of introducing recent technologies such as the Internet of Things (IoT) to simplify the design, quantification, and monitoring of thermal and environmental indicators.

The study was based on solid scientific studies from indexed journals, including recent papers. Results allow stakeholders a better visibility of the relationship between BIM and GBCs. Considering this study, the academic community must explore more advanced technologies and relationships with GBCs. For the stakeholders and professional community BIM 6D constitutes the first action to align construction with energy certification measures. Then developing other workflow based on BIM, IoT, and Blockchain enhances the efficiency of GBCs implementation.

However, only two databases were consulted to gain a better understanding of the subject. Furthermore, being limited to a literature review, this study does not consider a practitioner's perception or an in-depth examination of a successful country. Other limitations are related to the fact that we only considered articles published in English and that we ignored other languages such as French where French-speaking countries publish locally their efforts in terms of environmental certification.

To strengthen the analysis, it is recommended that an in-depth comparison of the criteria used by various certification systems be conducted to better highlight their unique features and implications. By incorporating references such as the Whole Building Design Guide (WBDG), it would be possible to establish a workflow with BIM, assess the outputs of digital mock-ups from the perspective of each certification, and identify differences in calculation methods and rating systems. This would enhance the recommendations for professionals and create a robust decision-making platform. Therefore, this comparative approach could serve as a focal point for future work.

Author contributions

KIG: Conceptualization, Formal Analysis, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review and editing. HR: Funding acquisition, Project administration, Resources, Supervision, Writing – review and editing. LE: Conceptualization, Supervision, Validation, Visualization, Writing – review and editing.

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Conflict of interest

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