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Recent progress on BIM-based sustainable buildings: State of the art review

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ABSTRACT

In recent decades, the planet has been negatively impacted by the construction industry due to the development of various infrastructures. Thus, it became one of the most polluting sectors that have required increasing the environmental awareness of public and private entities. Under these circumstances, there are urgent efforts required to mitigate these negative impacts. Different approaches have been made for sustainable buildings based on construction technologies, where sustainability must be included as the main premise from the initial stage of the project. Through a systematic literature review, different methodologies are analyzed such as Building Information Modeling (BIM), Life Cycle Assessment (LCA), and Building Energy Modeling (BEM) based on the existing regulations and standards of each country. The existing digital tools allow for the development of various low-carbon technologies, including sustainable materials and new integrations between them to find sustainable solutions and reduce carbon emissions from buildings. Several limitations exist as Building Information Modeling (BIM) software does not have all the green applications. Therefore, clear results are needed for effective indicators to help interested parties appropriate these technologies and invest time and money in projects based on Building Information Modeling (BIM) and learn a useful lesson for future projects from these technological tools.

1. Introduction

It is predicted that by 2060 the CO_2 emissions from construction material usage double up currently accounting for 9% of overall energy consumption globally (World Business Council for Sustainable Development, 2022). The built environment generated over 37% of global energy-related CO_2 emissions. From 2020 to 2021 the operational CO_2 emissions from the building sector increased by 5% (World Business Council for Sustainable Development, 2022). During the whole life cycle of construction, green buildings are created to protect the environment (Shafique et al., 2020; Shafique and Kim, 2017a, 2017b), maintain resources, and reduce pollution which can help to achieve sustainable development goals (Hossain, 2018).

The planetary crisis of climate change, pollution, and waste could be broader by 2050 if the building sector does not start the CO_2 emissions cuts. Decarbonizing this sector as well as other sectors is a priority for transitioning to a sustainable future (Azam et al., 2022a, 2022b; Cheng et al., 2022; Shafique et al., 2021a, 2021b; Shafique and Luo, 2022). This transition involves designing multi-beneficial material, the entire building life cycle, and a systems-thinking methodology. Stakeholders must take responsibility for their decisions about materials selection throughout the life cycle. (Hamilton et al., 2022).

One effective tool to calculate, improve and analyze the environmental impact of buildings during their life cycle is the Life Cycle Assessment (LCA), this method covers materials extraction, production of building components, and use and end-of-life (Cavalliere et al., 2019) and involves four phases according to the ISO Standard, objective and scope definition, life cycle inventory (LCI), and interpretation (ISO 14040, 2009).

Even though this method is being used in the construction industry for years, however, professionals find it very complex, and time-consuming. Creating the bill of quantities (BoQ) and finding the correct datasets in the building material Life Cycle Assessment (LCA) database, take extensive time. This procedure needs a great amount of data and is developed at the end of the design process when it is very complicated and expensive for the project to do changes in the decision-making (Álvarez Antón Díaz, 2014).

Building Information Modeling (BIM) is a tool that integrates building information, project management, and building performance analysis (Gao et al., 2019; Muller et al., 2019; Rahmani et al., 2015). Provide the necessary data transmission and storage methods, which can help improve green evaluation proficiency (Jiang et al., 2018). Yet the

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analysis of green BIM technologies during the design phase is inadequate. (Zhan et al., 2022).

Green building is the balance of usage and return in terms of resources and sustainable development of buildings to ensure long-term impacts on the environment. The development of green buildings as a principle must be (applicable, economical, and green) (Shafique et al., 2018) and have five aspects: standards, safety, durability, health, and comfort. Occupancy, convenience, resource-saving, and environmental liveability (Guo et al., 2021). Due to the large range of advantages of Building Information Modeling (BIM) applications on green buildings, this methodology has been investigated and is proven that is a powerful tool, which can be used for energy using simulation and lighting evaluation (Kamel and Memari, 2019; Najjar et al., 2019; Nilforoushan and Smith, 2015; Tushar et al., 2019).

The most important idea is that the model should be flexible and adjustable, allowing it to be applied in different regions. (Guo et al., 2021). The BIM-LCA integration is a strong approach, to performing green buildings during the complete design process (Soust-Verdaguer et al., 2020) from Level of Development (Building Information Modeling LOD) 100 to LOD 500 in most cases the Life Cycle Assessment (LCA) only is applied in one of the stages, is ideally recommended to apply the BIM-LCA in all the LOD from structural elements to the construction phase (Cavalliere et al., 2019).

Different studies (Carvalho et al., 2020, 2021b; Cavalliere et al., 2019; Lee et al., 2015; Naneva et al., 2020; Onososen and Musonda, 2022; Röck et al., 2018; Schwartz et al., 2016; Soust-Verdaguer et al., 2020; Wong and Zhou, 2015; Yang et al., 2018), prove the importance of the dialogue between LCA and Building Information Modeling (BIM) when it comes to sustainable construction but one of the problematic points is the complexity of Building Information Modeling (BIM) models. Other i.e., the lack of computer tools also the big amount of data that is needed for more effective low-carbon management. Moreover, in the future, the green Building Information Modeling (BIM) tools must include the three R's concept (reduce, reuse, and recycle) in all the sustainability analyses for new projects and retrofitting projects.

Building Information Modeling (BIM) should be extended to the entire lifecycle of a building, including when it is occupied, repaired, and demolished. To achieve sustainability goals, green BIM should be a model-based process that is consistent and coordinated. Maintenance manuals should be provided to monitor the building's full life cycle. (Wong and Zhou, 2015).

As summarized, even though a high number of studies (Ansah et al., 2019; Carvalho et al., 2020, 2019; Castro-Lacouture et al., 2009; L. L. Chen et al., 2022; Chi et al., 2020; Ferrari et al., 2022; Hossain, 2018; Jiménez-Roberto et al., 2017; Lee et al., 2015; Li et al., 2021; Liu and Wang, 2022; Maskil-Leitan et al., 2020; Mustaffa et al., 2021; Naneva et al., 2020; Porsani et al., 2021; Wong and Zhou, 2015; Wu et al., 2019; Zhan et al., 2022; Zhang et al., 2017) focus on green building performance there is a lack of a range of sustainable materials in the design and construction phase which must have further research and appliance.

Building Information Modeling (BIM) and LCA methodologies have been investigated for several years, but further green BIM development is needed to optimize models and appliances in the construction stage. This could provide designers and stakeholders with better tools to optimize the models and appliances. However, there are still gaps in the practice and understanding of these concepts. This study reviews the current literature on green BIM in buildings and investigates the current trend and application of BIM-based sustainability building around the globe. It focuses on the lack of Building Information Modeling (BIM) and sustainable-based models in the practice which can provide multiple benefits that bring sustainability approaches to this industry. Further studies based on the existing green Building Information Modeling (BIM) articles will provide the research directions to explore its full potential and recognize which areas need further research. This would enable the construction industry to use all the different sustainable tools such as BIM-LCA and achieve the sustainable worldwide goals needed for the environment and the planet. The overview structure of this study is as follows: section 2 provides the overview of the search methodology, whereas section 3 gives up-to-date literature. Whereas section 4 provides results and discussion, section 5 gives an overview of the research gap and future research direction; finally, the conclusion is presented in the final section.

2. Research methodology

This research intended to achieve a methodical literature review on Building Information Modeling (BIM) resources, concerning the construction, sustainability, and eco-resilient materials used during the designing and construction phases of green buildings. A systematic review permits authors to familiarize themselves with the ideas recovered in the screened articles and enables them to have an understanding of the approaches and of the significant findings that must have deeper researched in the future (Hoang et al., 2019).

To achieve the above-mentioned target were conducted three phases as explained below.

1. Phase 1: Establish the search criteria and keywords. Web of Science and Scopus were established as the databases in this research. The keywords were concluded "BIM construction", "BIM sustainability", and "BIM building".
2. Phase 2: In this phase, was developed article screening over the search series, including review articled and research articles excluding conference papers and proceeding papers. Non-English articles and articles published five years before 2022 were also excluded from the search process.

The early article explore was carried out in November 2022. In this procedure, 774 articles have being found from WoS and 667 from Scopus. Then, 208 articles were removed by the publication year. In the end, 1233 articles stayed later further qualitative analysis as shown in Fig. 1.

3. Phase 3: The qualitative consideration explained in Fig. 1 was achieved on the 1233 continuing articles and the literature review was developed with 107 papers based on the second phase inclusionary and exclusionary criteria. (Stated in Table 1). Furthermore, these articles were studied manually to identify further research in the significant findings or conclusions. Also, the articles should include information on Building Information Modeling (BIM) tools and aspects of sustainability in construction and how each of the countries where the case studies are situated, manages green buildings based on their legislations and any significant environmental index that must be improved and from the construction industry solutions can be provided.

3. Literature review

This section assesses exploration performed on BIM Sustainability, and technological tools used in buildings to enhance environmental solutions. The review is given using a systematic literature review and is presented in the two tables below (Table 2) and (Table 3).

Table 2 shows that the quantity of research papers related to the integration of Building Information Modeling tools and LCA has been getting higher over the past five years, representing the importance of integrating technology tools into sustainable solutions. The earliest article was published in 2017, which denotes the importance of the (BIM) application over the past years. Most of the articles provide information about the Building Information Modeling application as a sustainable method, catalogued in different approaches, the most prevalent ones the BIM-enabled LCA method, Green BIM framework, Selection of software for (BIM), integration of (BIM) and BSA methods, BIM-GWP, and other methods, such as online questionnaire, interviews, workshops. A significant finding is an integration of Building information modeling technology and Life Cycle Assessment (LCA) could be

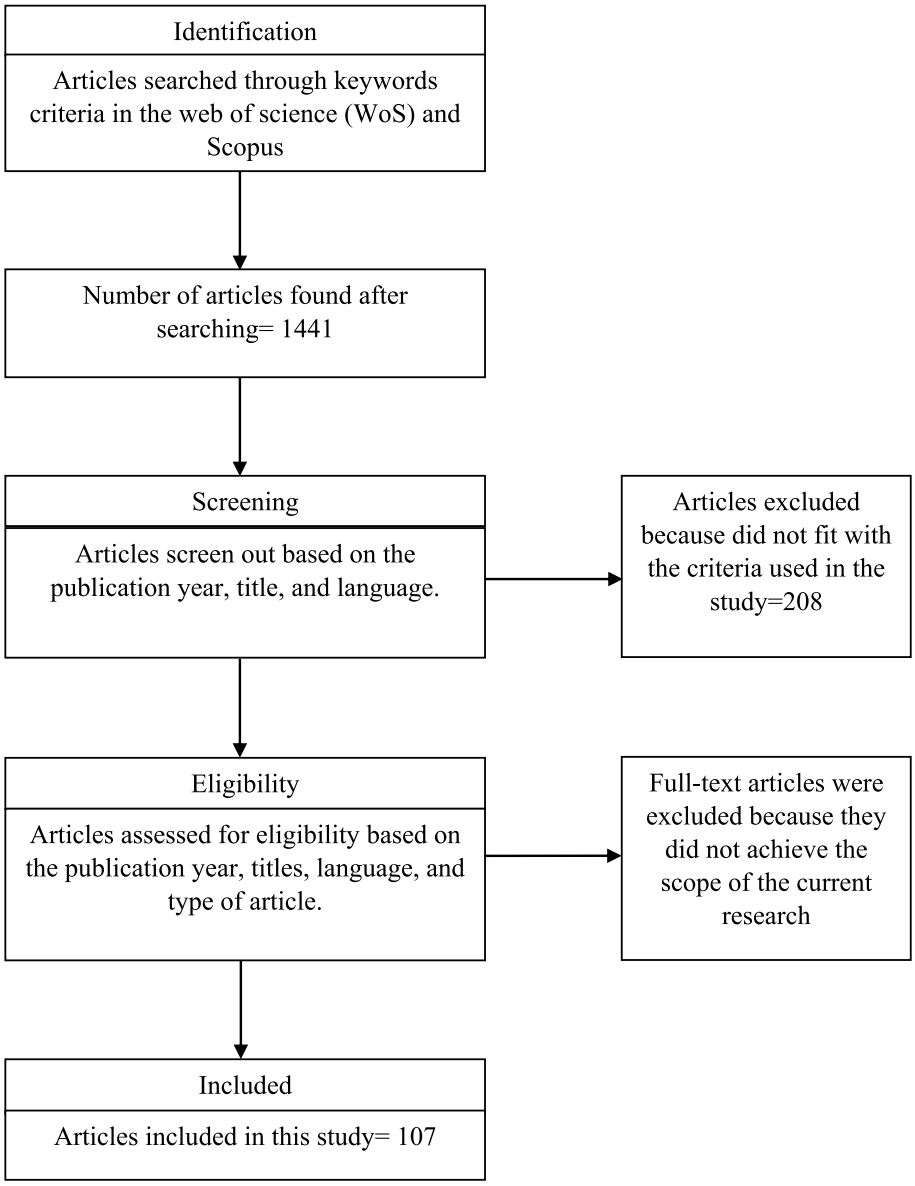

Fig. 1. The flowchart diagram for screening articles for this review.

used in different phases of the project. First in the design stage (Lim et al., 2019), in the entire building process (Naneva et al., 2020), In the renovation process (Lasarte et al., 2021), in the construction stage (Zhan et al., 2022), during the selection procedure (Liu and Wang, 2022) in the material recycling process (Zhang and Jia, 2021).

These articles have included case studies in 18 countries and 6 continents of which 5 of the articles were from China reporting the largest influence. A country that has promoted environmental protection and also has set a variety of green building standards (Guo et al., 2021). The building typologies of this case are mostly medical, educational, and commercial. The materials are also well-varied, such as reinforced concrete, metallic structure, brick wall, wood, prefabricated elements, granite, masonry, and glass. This detailed information is provided in the third column of Table 2.

The most used software for Building Information Modeling (BIM) modeling is Autodesk Revit this tool is known for enhancing decision making processes and achieving environmental goals in projects (Wang et al., 2022) (Engineering, architecture, and MEP), and also ArchiCad. To develop the environmental ideas the tools that were used are, Design-Builder; Energy Plus Eco designer STAR, Cype software, Ecotect, Dynamo, Navisworks All plan, Tekla, Solibri, MicroStation, Bentley, and Synchro. The potential advantages of integrating Building Information Modeling into the interoperability of different analysis (Changsaar et al., 2022), using the software included in Table 2, are summarized in the majority of the articles, demonstrating improvements to a building's sustainability. Based on some design alternatives such as photovoltaic cells to improve renewable energy generation, sensors to automate lighting, and the use of greywater to decrease water consumption (Changsaar et al., 2022). As considered above, many researchers around the world suggest that Building Information Modeling (BIM) indeed can successfully improve Life Cycle Assessment (LCA) performance continuously over the entire building process (Naneva et al., 2020) and can provide improvements in the green performance of the building in a shortened way.

As shown in Table 3, the future prospects are mostly based on the investment that should be done in the Building Information Modeling (BIM) applications from the stakeholders this would provide further findings about materials and their characteristics. Different tools improve data transfer from one process step to the next and interoperability between digitalization and the construction area.

Table 1
Key Searching criteria.

Key Criteria		Resulting Criteria	
Inclusionary	Exclusionary	Inclusionary	Exclusionary
Review articles that could be found on the Web of Science and Scopus	Conference papers	Papers with a global Case Study	Papers that do not include a global case study
Journal articles that could be found on the Web of Science and Scopus	Replicated papers	Articles published within the last 5 years	Articles published before 2017
Articles and papers published in English	Non-English papers or articles		
Articles and papers that are accessible and the full text in PDF is available for researchers	Hard access papers through the institution		
		Articles that provide prospects and the necessity of deeper future research	Articles with only conclusions about the introductory topic

Most of the research areas are Construction & Building Technology, Science & Technology; Engineering; Environmental Sciences & Ecology, from this, is concluded that sustainable construction is tied to environmental sciences, and ecology and the importance that in the later years the researchers have been given to the environment. The actual and future development of the construction industry is based on the adoption of green and sustainable construction strategies which helps to decrease carbon dioxide emissions and the utilization of renewable energy sources (Alireza et al., 2017).

Wong and Zhou (2015) analyzed the innovation of building sustainable performance based on monitoring and managing the environmental impacts of the project founded on the utilization of Building Information Modelling (BIM) furthermore consider that future Building Information Modeling (BIM) tools must enhance the three R concepts (reduce, reuse and recycle) in their environmental assessment for existing and new projects. Similarly, Chi et al. (2009) (Chi et al., 2020) implemented the analysis of construction waste minimization as an important sustainable goal in green buildings, and the application of regulations, innovative technologies, and public perception to evaluate the impact on building energy and achieve better waste minimization due to the variations across countries. Involving worldwide regulations, Carvalho, Schmitd and Bragança (Carvalho et al., 2021b) are concerned about environmental goals in the construction industry, they include research developing a BIM-based decision-making tool for construction professionals to estimate the environmental, economic, and operational performance of buildings.

4. Results

4.1. Descriptive analysis

Following the exploration and the assessment conducted in the methodology, 774 articles Web Of Science (WoS) were included in the systematic review. The year publication of the revised papers is described in Fig. 2. Corresponding to Fig. 2, the initial publication of these reviewed articles is in 2008. From 2008 to 2014, the research on Building Information Modeling (BIM) abilities in sustainable construction was still in the beginning stage. From 2015 to 2022, the amount of research papers in these areas indicates increase, similarly, the quantity of articles shows growth.

Fourteen of the articles were published in 2014, and the research about Building Information Modeling (BIM) utilization in green buildings was becoming more widespread. From 2016 to 2022, Building Information Modeling (BIM) usage in the construction sector had turn into a major field and obtained broad and considerable consideration from researchers. From 2018 to 2022, Throughout this time, the number of articles published climbed progressively, by more than 30 every year. The number of published articles in 2022 is still increasing, which indicates this field is still vital for the construction industry.

From the perspective of countries' case studies, these 774 articles develop the research using case studies around the world. As is shown in Fig. 3 most case studies are situated in China. Considering the volume of articles situated in all country, the rank of countries is presented below: *China (181), England (116), Australia (89), United States (77), Malaysia (70), Italy (42), Spain (39), South Korea (35), Canada (35), Brazil (22), Germany (28), Portugal (18), Egypt (21), Iran (17), Netherlands (15), Singapore (16), Turkey (18), New Zealand (13), Austria (14), South Africa (13), Taiwan (11), Czech Republic (11), Denmark (11), Sweden (10), Indonesia (9), Pakistan (11), Poland (9), Slovakia (9), Switzerland (10), Nigeria (10), United Arab Emirates (9), Chile (8), India (7), Saudi Arabia (7), United Kingdom (9), Slovenia (7), Finland (8), Lithuania (6), Belgium (6), Colombia (6), Cyprus (5), France (5), United Kingdom (5), Ireland (4), Luxembourg (4), Norway (4), Ghana (3), Israel (3), Sri Lanka (3), Croatia (2), Iraq (4), Morocco (2), Northern Ireland (2), Qatar (2), Vietnam (2), Algeria (1), Brunei (1), Cameroon (1), Estonia (1), Ethiopia (1), Greece (1), Hong Kong (1), Japan (1), Kazakhstan (2), Kenya (1), Kosovo (1), Lebanon (1), Libya (1), Republic of North Macedonia (1), Mexico (1), Oman (1), Peru (1) Russia (1), Sudan (1), Thailand (2), Wales (5), Uruguay (1)*. The number of articles according to the number of case studies in each country is demonstrated in Fig. 3, the countries within only 1 article is not included in the figure.

The perspective of research areas, the 774 articles were categorized into three main areas, *Environmental and Science Ecology (284), Science Technology (277), and Construction building technology (213)*, Fig. 4, is concluded that the total articles are included in Environmental, science, and technology even though the articles are based on construction the importance of the environmental aspects are relevant to the research and problem-solving areas in the actual situation of the construction sector. This might be caused by the challenges that the construction sector is facing, two of these significant challenges which include diminishing the environmental impact of projects and improving the efficacy of the construction processes by providing technology and wide solutions for applying sustainability in each stage of the project development (Jiménez-Roberto et al., 2017).

4.2. Results analysis

Within the architectural design, planning, management, maintenance, and recycling, the implementation of Building Information Modeling (BIM) is considered the main technological tool to add the entire infrastructure sustainability process to the project and be able to show efficacy in the sustainable development results. Regardless of its potential advantages, this methodology is still having difficulties with its implementation. The decision making from governments, policies (Aksenova et al., 2019), and stakeholders in the private sector is essential to develop a successful BIM-based Life Cycle Assessment (LCA) view for the construction sector (Onososen and Musonda, 2022).

In this analysis, 774 articles were involved in the methodical review and study by the sources. Past this analysis, the Life Cycle Assessment (LCA) and Building information modeling (BIM) advantages and disadvantages are reviewed according to their case study, materials, and tools. Also, the future research prospects analyzed by each author are highly important for the reviewed studies.

4.2.1. Construction material recycling

Globally it demonstrated the potential of Building Information

Table 2
Recent literature on Eco-resilient BIM Based Building studies.

Authors	Location	Selected Materials	Methods/Tools	Evaluation Indicators	Function Unit	LCA Phase	Significant Findings
Maglad et al. (2023)	Pakistan	Concrete, concrete block, gypsum board, tile or vinyl, metal, single and double glazed windows, wall: 228 mm brick work and 50 mm of plastering material.	Revit, Insight 360,	R-value, CUI-ATD, (EUI) in kWh/m2 per year, (ACH),	Hotel Building	Cradle-to-Gate	The greatest strategies for AEC are building energy analysis methods using Autodesk Revit and Autodesk insight at the crucial stage of a project.
Soust-Verdaguer et al. (2020)	Uruguay	bricks and concrete blocks	BIM and Archi CAD; Excel; Design- Builder; Energy Plus Eco designer STAR	GWP, freshwater aquatic ecotoxicity, human toxicity, ODP	Single-family houses	Cradle-to-grave	Some materials as wood are more environmentally friendly, but at the same time, their life cycle can be difficult. It is important to have into account the impact of the materials and their performance.
Bueno and Fabricio (2018)	–	Concrete blocks masonry original clay tiles	Visual programming routine; GaBi; Revit; Excel	–	1 m2 of the non-structural shell	Cradle-to-grave	The lack of expertise in LCA is not an issue when the building design is developed using BIM tools, which simplified the integrations of building components and data.
Yang et al. (2018)	Chongqing, China	Cement, pinewood, hot rolled steel bar, steel plate, steel bar, concrete brick; aluminum alloy, sheet glass	BIM-enabled LCA method; Autodesk Revit 2015; Design builder	GWP	Village building	Cradle-to-grave	The giant potential of using BIM to know the life cycle of a building and development of the low carbon design
Schwartz et al. (2016)	United Kingdom	Included 35 different object properties	Examined the application of semantic rules on BIM models through the RFC XML protocol by using Semantic Web applications; Revit; Pellet 1.5.2	Embodied CO2 emission	Buildings material	Cradle-to-site	The collaborative work, between the design and the construction team, and the knowledge of the data from the BIM model, lead to improving the environmental performance of the building
Lee et al. (2015)	Korea	Ready-mixed concrete, glass, concrete block, insulation material, and gypsum board	Extracted the quantity takeoff; then performed an evaluation; Revit	GWP, ADP, EP, ODP, PP	Material levels	Cradle-to-grave	Each level of detail in the BIM-Based model provides different information for the life-cycle assessment (LCA) also, and the performance materializes in each LOD stage.
Mésároš et al. (2021a)	Kosice, Slovakia	Masonry, reinforced concrete,	Building selection; Selection of software for BIM; Selection of software for formwork design; Design of the formwork project in the BIM environment; ArchiCAD; Revit; BIM6x	Changing lighting conditions, ventilation, heating, and temperature during the design of the building.	Building renovation; demolition; reconstruction	Cradle-to-grave	Having the 2D and the documentation of the building, creating create the 3D model using BIM 3D Tools, make it easier over time the renovation process gives multiple benefits to the design and adaptive architecture
Carvalho et al. (2021b)	Porto, Portugal	Brick; EPS insulation; mortar; concrete; XPS insulation; waterproof membrane; ceramic tile; hydraulic tile;	BIM, new parameters Dynamo, LCC, LCA; Revit, Dynamo, Excel	ADP, GWP, ODP, AP, POCP, EP, ENR	One-level residential building	Cradle-to-site	Construction solutions with low environmental impact material and low-maintenance materials are two of the main before for sustainable buildings
Onososen and Musonda (2022)	–	Concrete elements	BOQ; BIM Software; Refinement of variables with academics in BIM LCA Thematic area; Data Aggregation based on the rule of the majority; Develop initial reachability matrix	SSIM; MICMAC	Building data	Cradle-to-grave	Lack of data, interest, training, expertise, BIM technology limitation, and information lead to modelling errors. The importance of getting over these barriers adopting opt BIM allows to have complete

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Table 2 (*continued*)

Authors	Location	Selected Materials	Methods/Tools	Evaluation Indicators	Function Unit	LCA Phase	Significant Findings
							information management and avoids extra costs.
Maskil-Leitan et al. (2020).	Israel	–	Research Sections; Workflow steps; Illustrating stages;	BIM application adapted to the IPD method and quantified by SNA	Municipality Project; Government project	Cradle-to-grave	Knowledge of the information from all those involved in the green design building. Allows social benefit; Effectiveness and a sustainable project
Carvalho et al. (2021a)	Porto, Portugal	A slanted roof with ceramic tiles, a prestressed slab, and windows with wooden frames; a double-brick wall with a flat roof, lightweight block and beam slab, and aluminium window frames with a thermal break.	Integration of BIM and BSA methods; Portuguese thermal regulation (REH); Autodesk Revit; SBTool; Cypetherm REH; Cype software; Portuguese Directorate-General for Energy and Geology (DGEG)	P7, P8, (Nic), (Nvc), (Ntc), DHW (Qa and Nac), (REH)	Single-family houses, (3-bedroom) and floor area (less than 100 m2)	Cradle-to-Use	Parameters such as building location, building typology, interior height, altitude, are indispensable to developing and evaluating the energy performance of the buildings.
Lim et al. (2019).	Johor Bahru, Malaysia	–	The use of computational building information modeling (BIM) to automate the process of design decision-making for building envelope sustainability optimization. Dynamo, Revit, and MOO in Matlab	Overall thermal transfer value (OTTV)	Non-residential building	Cradle-to-Use	BIM is not only a technological tool is also a methodology that leads the process to results, in this case, getting the information for an optimal building envelope design
Manzoor et al. (2021)	Malaysia	–	BIM implementation in high-rise buildings by integrating the exploratory factor analysis (EFA) and structural equation modeling (SEM) approaches. KMO test	computer simulation techniques for CSFs	High-rise Building	Cradle-to-Use	Is highly significant for the high building design to study these five factors, productivity, visualization, coordination, sustainability, and safety
Carvalho et al. (2020)	Porto, Portugal	Brick wall, Concrete slab, Aluminium frame, Wooden doors	BIM-based LCA into BSA. Autodesk Revit, Cype software	Cypertherm REH, GWP, ODP, AP, POCP, EP, FFDP	Single-family dwelling	Cradle-to-grave	The analysis of the national context and its regulations, conduct to an ideal energy performance using the proper tools and methods, such as the interaction between LCA, BSA, and BIM
Jiménez-Roberto et al. (2017).	Colombia	Reinforced concrete, glass facades, metallic structure, concrete masonry	BIM methodology, Global Warming Potential (GWP). ArchiCAD 18, BEM, Google Earth, Eco designer STAR	Electrical energy, CO_2 emissions,	Office building nine floors and a basement in a total building area of 11 400 m2 and a lot of 1100 m2	Cradle-to-Use	The effects of cost, carbon footprint materials, and electrical energy consumption in building models can be determined with BIM
Porsani et al. (2021).	Spain	–	gbXML Design Builder, IFC CYPERTHERM HE. Autodesk REVIT 2020, BEM programs: Design Builder, Open Studio, CYPERTHERM HE	NZEB, W/m2K	Residential Building and industrial warehouse	Cradle-to-site	Performance of the data exchange using the BIM and BEM tools are crucial for energy savings and reducing costs
Carvalho et al. (2019)	Portugal	–	BSA methods, focusing on the SBToolPT-H. Green Building Studio CYPETHERM REH DesignBuilder; Vico Office; Geographic Information Systems (GIS) Google Maps; EASE CYPESOUND RRAE; DAYSIM; RADIANCE; SimaPro ATHENA Impact Estimator GABI; Revit	Sustainable score	Portuguese BSA method	Cradle-to-material	The integration of BIM context and BSA Methods delivers better and more sustainable buildings
Zhang and Jia (2021)	China	Material recycling	Literature survey and questionnaire survey. Questionnaire Survey	Reused, Recycled, taken to landfill, Sent to be burned	BIM model	Cradle-to-grave	One of the main solutions for environmental and economic problems is to manage the life cycle of

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Table 2 (*continued*)

Authors	Location	Selected Materials	Methods/Tools	Evaluation Indicators	Function Unit	LCA Phase	Significant Findings
							the project using BIM in material recycling
Priavolou (2020)	Epirus, Greece	Wood, mud, lime, straw, bricks (sun-baked), porcelain, iron, glass, and sand	Interviews. Revit	Potential energy savings	Museum	Cradle-to-gate	The adaptation of tacit knowledge as a vernacular design to technological development provides effective sustainable progress
Zhang et al. (2020)	China	–	(TPB); Questionnaire survey of 353 BIM users	Actual behavior, Behaviour intention, Behaviour attitude	Companies' behaviors	Cradle-to-use	Some results of the usefulness and efficiency of collaborative management of information depend on the BIM behavior intention and attitude
Kovacic and Honic (2021)	Vienna, Austria	–	Integrated Data Assessment and Modelling (IDAM) method based on digital scanning and modeling technologies, BIM, and ground penetrating radar (GPR). Laserscan, PointCab, Archicad, MS Excel	MP-suitable BIM-model	Single-story building	Cradle-to-use	The material identification with scanning technologies increases the recycling potential of the building
Liu and Wang (2022)	Northern China	Concrete frame, brick wall, granite, stone-like paint, insulation material	Based on the Green BIM framework, using BIM architecture to analyze building performance, and the Assessment Standard for Green Building (GB/T 50378–2019) standard to establish benchmark values for evaluation, and project objectives. BIM, CFD simulation	National energy efficiency, heating load, and cooling load	Library building	Cradle-to-use	A standardized framework for the decision-making process should be provided to improve the green performance of the building
Zhan et al. (2022).	Xiamen, China	–	Literature review; experts' interviews; G1 Method and Entropy Weight Methods. BIM, MATLAB, Ecotect, Dynamo	Indoor comfort, environment, resource utilization	Hospital building	Cradle-to-use	Using simulation, cyclic optimization, and ambiguous quantification to build a performance pre-evaluation model can help to effectively direct the design and construction of a green hospital.
Naneva et al. (2020).	Switzerland	Prefabricated elements	LCA parameter creation, Calculation, and check. Revit, mapping of eBKP-H codes, Excel	GHG emissions, UBO	Mixed-use timber building	Cradle-to-use	To optimize the evaluation employed in buildings in a straightforward manner, LCA performance should be ongoing throughout the entire construction phase.
Lasarte et al. (2021)	Spain	–	The online questionnaire, interviews, workshops. AutoCAD ADT, Revit, Navisworks All plan, Tekla, Solibri, MicroStation, Bentley, Synchro	KPI	Living labs (LL)	Cradle-to-grave	BIM is a useful tool for improvements in the renovation process of the building
Cheng et al. (2022)	Anhui, China	Timber, Concrete, Lime-sand brick, Concrete block, Steel, PVC, Glass	BIM with LCA. Autodesk Revit	24 environmental impact factors (EIFs)	–	Cradle-to-grave	Integration of BIM with LCA is useful to evaluate the environmental impact of the buildings.
Hasanain and Nawari (2022)	Saudi Arabia	–	Quantitative and qualitative methodology. Surveys, collection of data. Autodesk Revit and Dynamo	KSA 203,0 Vision, Dynamo Water Reduction plug-in.	1 bedroom home	Cradle-to-use	The BIM-Based application model can improve sustainability in the KSA by reducing water use and converting that into points towards the Mostadam Green building grading system,

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Table 2 (*continued*)

Authors	Location	Selected Materials	Methods/Tools	Evaluation Indicators	Function Unit	LCA Phase	Significant Findings
							which supports and is in line with the KSA vision of 2030.
Zhao et al. (2022)	–	Single and double glazing clear, translucent wall panel.	BIM model, parametric design, performance simulation, Multi objective optimization, pareto frontier analysis. Revit, Dynamo, Optimo, Green building studio	EFit = AEUMin, DFit = DLSMax	Educational Building	Cradle-to-use	Building design optimization using just one objective has shown to be quite successful when using optimization methods.
Skrzypczak et al. (2022)	Poland	Reinforced concrete technology, steel frame technology, laminated wall panels	(TLS), (UAV), Measurements, ReCap Pro 2019, Revit 2019, geodetic tachymeter	–	utility/laboratory building, sports facility, sports hall	Cradle-to-use	Data collection takes less time and costs less money when scanners are used.
Filho et al. (2022)	Brazil	Cast-in-place concrete, precast concrete, and structural masonry, ceramic and fiber cement tiles.	BIMLCSA-FAHP-based model.	kgSO2eq, kgNeq, kgCO2eq, CFC-11qe, kgO3eq, MJ, Kg	Single-family residence	Cradle-to-grave	The scenarios with the greatest environmental effect findings stood out negatively and were adopted in structural masonry systems. Contrarily, precast concrete construction has the lowest environmental effects.
Naderi and Shojaei (2022)	–	–	Database identification, Data acquisition, Data pre-processing, Data processing metrics	Infrastructure Digital twins	–	Cradle-to-use	Recognized journals ought to designate special issues on sustainability that examine the social, organisational, and financial implications of using digital twins in infrastructure projects.
Rajabi et al. (2022b)	Iran	–	Exploratory Factor Analysis (EFA), Kaiser-Meyer-Olkin (KMO), Principal Axis Factoring (PAF)	BIM Capability Requirement (BIMCR), positively affects organizational capabilities (OCA). Organizational Culture (OCU)	–	–	BIMCR positively affects OCA
Omer et al. (2022)	–	–	Qualitative data collection, interviews, thematic analysis.	AutoCAD, Navisworks, and Tekla. Revit MEP.	–	–	Every important decision in the construction business must be made by individuals to ensure the safety of a structure being built.
Rajabi et al. (2022a)	Malaysia and Iran	–	Questionnaire surveys, systematic literature review (SLR),	Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA), Mann–Whitney *U* Test, rank agreement factor (RAF)	–	–	The best method for evaluating organisational BIM capabilities for the regional industry can be developed by researchers and industry practitioners.

Modeling (BIM) in improving construction material reusing must be based on the whole life cycle disposal of construction materials. If this recycling process is considered from the Building Information Modeling (BIM)-based dynamic (Zhang and Jia, 2021), having all the required data, such as information on the characteristics of each material, demolition planning and where to dispose of the resources at the end of life of the construction, the ecological and economic challenges that the construction industry face today would begin to show positive results. The significance of the recycling material process is not only an economical approach, moreover, is the capacity for awareness that those of us who work in this sector (Najjar et al., 2017). Knowing how buildings can be recycled, without pretending that the only option for urban growth is to demolish and create new buildings where CO_2 is increased and continues to contribute negatively to climate change (Tam and Tam, 2006).

4.2.2. *Policymakers in the implementation of green building practices*

The construction industry is facing the same environmental challenges for a long time ago, as is shown in the studies included in this review, for several years this industry is named one of the most contaminants on the planet (World Business Council for Sustainable Development, 2022). The importance of placing the necessary environmental measures from the governments to the construction sector is vital to solving the problems such as lack of building recycling and continuous poor management of waste (Qin and Ofori, 2000). As is proven in the different reviewed case studies, Building Information Modeling (BIM) is a powerful tool that improves green building practices, for instance, more investment is needed in the application, furthermore, in learning materials for professionals, such as designers, architects, engineers, and others. This information and learning tools must be accessible to everyone who wants to contribute to sustainable practice in the construction industry.

Table 3
An overview of the recent studies related to Sustainability and BIM.

Author	Publication Year	Citation	Research areas	Future Prospects
Röck et al. (2018)	2018	29	Science & Technology; Engineering	Improve embodied impact assessment and communication within future design practices by making LCA more accessible.
Soust-Verdaguer et al., 2020	2020	18	Science & Technology; Engineering; Environmental Sciences & Ecology	–
Bueno and Fabricio (2018)	2018	52	Construction & Building Technology; Engineering	During the early stages of the design process, implement a decision-making process based on the environment.
Yang et al. (2018)	2018	83	Science & Technology; Engineering; Environmental Sciences & Ecology	To make BIM-enabled LCA more effective for low-carbon transitions in the AEC sector, more attention needs to be given to data-capturing technology and interoperability.
Schwartz et al. (2016)	2016	17	Construction & Building Technology; Engineering	There are currently some data loss issues associated with importing IFC models into BIM with the ifcXML - BIM integration.
Lee et al. (2015)	2015	68	Science & Technology; Environmental Sciences & Ecology	For the green template to be more useful and reliable, steel as a major building material will have to be considered in future studies.
Mésároš et al. (2021b)	2021	6	Science & Technology; Environmental Sciences & Ecology	Depending on the project's factors, such as size, building design, kind of building, etc., compare different project sizes or identify which project the approach has a track record.
Carvalho et al. (2021b)	2021	5	Science & Technology; Environmental Sciences & Ecology	Integrating a comparative approach should be the main goal of future studies. A few simulations should be able to be saved by the program, and the results should be categorized and organized for user interpretation.
Onososen and Musonda (2022)	2022	7	Construction & Building Technology; Engineering	To confirm the ISM hierarchical structure developed using the experts surveyed, subsequent research could make use of additional analytical tools.
Maskil-Leitan et al. (2020)	2022	11	Construction & Building Technology; Engineering	–
Carvalho et al. (2021a)	2021	14	Construction & Building Technology; Engineering	Before running the energy simulation, the generation of renewable energy must be evaluated using outside tools.
Lim et al. (2019)	2019	2	Construction & Building Technology; Materials Science	OTTV and construction cost are the only objective functions included in the recently proposed computational BIM-based optimization model, but by employing a similar technique, it can be further developed into a robust integrated BIM tool.
Manzoor et al. (2021)	2021	6	Chemistry; Engineering; Materials Science; Physics	To effectively accomplish sustainability, there is a need to apply and produce a more thorough comprehensive study in many countries with various cultural backgrounds.
Carvalho et al. (2020)	2020	2	Construction & Building Technology	Certain databases would also let the automatic assignment of material identification to determine the potential environmental implications.
Jiménez-Roberto et al. (2017)	2017	3	Engineering	Studies on such parameters for the building material used in Colombia must be done to increase the precision of the carbon and energy values incorporated for the projects in the nation.
Porsani et al. (2021)	2021	22	Chemistry; Engineering; Materials Science; Physics	One of the major barriers between digitization and the construction industry is the absence of BIM-BEM interoperability.
Carvalho et al. (2019)	2019	70	Construction & Building Technology; Engineering	It is crucial to develop strategies for integrating and automating Building Sustainability Assessment (BSA) approaches within the BIM framework given the desire for more efficient and environmentally friendly buildings.
Zhang and Jia (2021)	2021	2	Science & Technology	The use of BIM, waste reduction, and recycling should all receive more funding and resources.
Priavolou (2020)	2020	2	Environmental Sciences & Ecology	It is important to look into incorporating smart features and environmental considerations into BIM technology.
Zhang et al. (2020)	2019	5	Environmental Sciences & Ecology; Science & Technology	–
Kovacic and Honic (2021)	2021	1	Engineering	One of the main barriers to fully realizing the potential of BIM is the limited automated data transfer from one step in the process to the next, as well as the insufficient data structuring that would enable a fluent data transfer.
Liu and Wang (2022)	2022	4	Science & Technology; Energy & fuels	Not only can an effective plan-view arrangement that is tailored to functions increase a building's energy use efficiency, but it can also maximize how well a building meets its needs for noise, illumination, and heat while consuming less energy.
Zhan et al. (2022)	2022	57	Science & Technology; Environmental Sciences & Ecology	Future updates to the indicators should incorporate additional information regarding smart medical.
Naneva et al. (2020)	2020	24	Science & Technology; Environmental Sciences & Ecology	According to LOD, information about various scenarios can be produced, and a procedure is given for implementing such use cases in BIM models.
Lasarte et al. (2021)	2021	3	Science & Technology; Environmental Sciences & Ecology	Create research projects involving a user ecosystem. The creation and dynamism of user-based communities that produce both cultural and social capital is a requirement for user-based research.
Zhong et al. (2021)	2020	5	Thermodynamics; Energy & Fuels	Future research into the use of theory and intelligent systems should be considered.
Liu et al. (2021)	2020	23	Construction & Building Technology; Energy & Fuels; Engineering	Additional variables, including daily occupancy rates and patterns in overtime work, are needed for the classification trees.
Yazdani et al. (2021)	2020	127	Science & Technology - Other Topics; Engineering; Environmental Sciences & Ecology	Future studies may find it remarkable to extend the simulation-optimization framework by incorporating more metaheuristic techniques.
Mustaffa et al. (2021)	2021	11	Construction & Building Technology; Engineering	Future research should consider more stakeholders and more building kinds, as well as involve policymakers in the adoption of green building methods.
(L. Y. Chen et al., 2022)	2021	11	Construction & Building Technology; Engineering	Pay close attention to studying the connection between these CSFs.

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Table 3 (*continued*)

Author	Publication Year	Citation	Research areas	Future Prospects
Ferrari et al. (2022)	2021	6	Science & Technology - Other Topics; Energy & Fuels	Future analysis of human-centered qualities could provide a comprehensive, sustainable strategy.
Li et al. (2021)	2021	32	Thermodynamics; Energy & Fuels	The findings of this research should only be applied to structures with the same architectural style and intended use. Other efficiency studies should be carried out depending on whether the building is residential or commercial.
Wu et al. (2019)	2019	36	Construction & Building Technology; Engineering	To be more realistic regarding results, future research should be based on already completed decoration projects.
Zhang et al. (2017)	2016	122	Science & Technology - Other Topics; Energy & Fuels	The establishment of standards and norms for green buildings requires considering the unique characteristics of each nation.
Ansah et al. (2019)	2019	53	Construction & Building Technology; Science & Technology - Other Topics; Energy & Fuels	BREEAM, BEAM Plus, API, and models created by IES and One Click Lifecycle will be the subject of future study.
Chi et al. (2020)	2020	53	Science & Technology - Other Topics; Engineering; Environmental Sciences & Ecology	Building performance should be examined under the headings of energy usage, waste management, and indoor climate to identify variances in diverse circumstances.
Castro-Lacouture et al. (2009)	2008	166	Construction & Building Technology; Engineering	It is essential to conduct further research on the properties of materials if we are to keep challenging LEED-based systems.
Cavalliere et al. (2019)	2018	69	Science & Technology - Other Topics; Engineering; Environmental Sciences & Ecology	Add more case studies from various country contexts.
Hossain (2018)	2017	17	Science & Technology - Other Topics; Energy & Fuels	–
Wong and Zhou (2015)	2015	291	Construction & Building Technology; Engineering	It is necessary to incorporate optimization algorithms to aid decision-makers.
Maglad et al. (2023)	2022	0	Construction & Building Technology; Engineering; Materials Science	According to the ARCHITECTURE 2030 challenge, using virtual technologies early in the design process might significantly reduce energy consumption and assist establish optimal energy flows.
Hasanain and Nawari (2022)	2022	0	Construction & Building Technology; Engineering	Concerns regarding environmentally friendly building methods and materials must be considered in the Saudi construction sector.
Zhao et al. (2022)	2022	0	Science & Technology - Other Topics; Environmental Sciences & Ecology	–
Skrzypczak et al. (2022)	2022	8	Construction & Building Technology	–
Filho et al. (2022)	2022	8	Construction & Building Technology; Engineering	The increase of social indicators
Naderi and Shojaei (2022)	2022	2	Computer Science, Engineering, Telecommunications	It is necessary to perform interdisciplinary research across several knowledge disciplines.
Rajabi et al. (2022b)	2022	4	Computer Science, Engineering, Telecommunications	To use BIM successfully and ensure its claimed benefits, it is crucial to create a plan.
Omer et al. (2022)	2022	3	Construction & Building Technology; Engineering	Increasing the target population from various project participants in the AEC business will help the target population improvement.
Rajabi et al. (2022a)	2022	9	Construction & Building Technology; Engineering	Comparing the results to those of other countries with varying income levels would aid in determining the impact of a country's income level on the criteria for assessing organisational BIM capabilities.

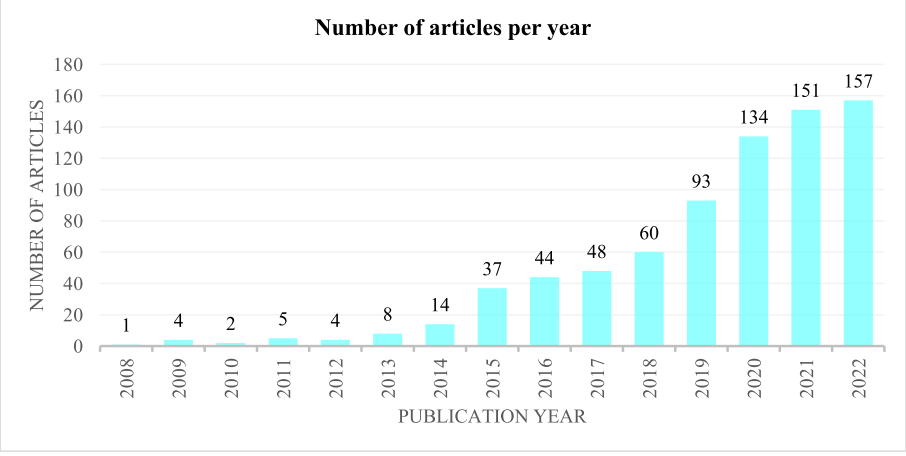

Fig. 2. The number of articles per year (WOS).

4.2.3. Holistic sustainable approach

The interaction between human and building regarding health and comfort (Day et al., 2020), have been highly considered in every of the sustainable certification systems, such as BREEAM, LEED, DGNB, CASBEE and WELL. Where is highly important the human-oriented effects impacted by building construction (Ferrari et al., 2022). A significant finding in this study is the lack of information about the importance of the relationship of the human being with each of the functionalities of the building (Almeida et al., 2020) and that this interaction should be taken as a premise when advancing a sustainable design, including a

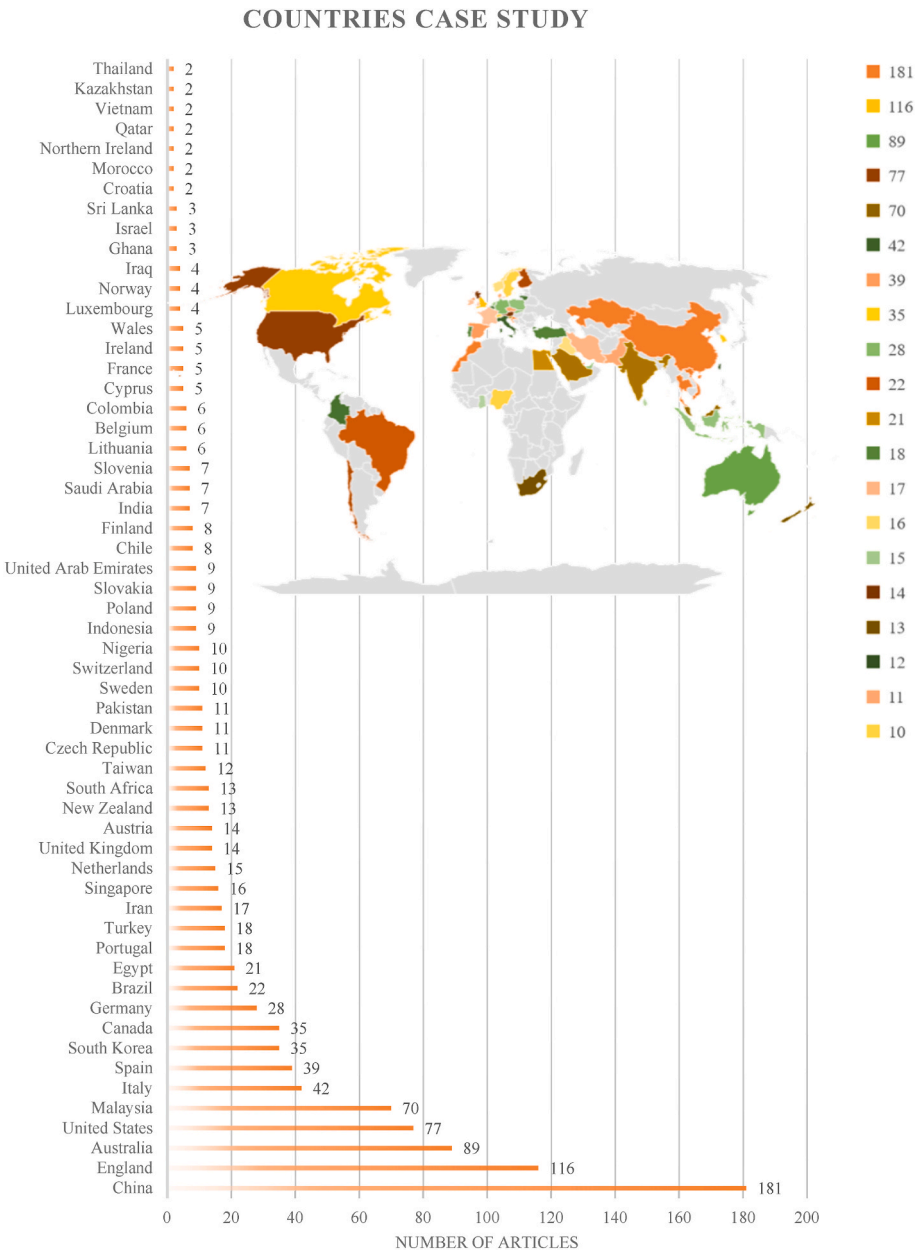

Fig. 3. Countries case study.

human approach in the Building Information Modeling (BIM) application.

4.2.4. *Green performance of the building based on the decision-making process*

The concept of Green Building Information Modeling (BIM) introduced by Krygiel and Nies in 2018 (Krygiel and Nies, 2008) was defined as "the process to generate and manage the full-lifecycle data information of building based on the building information model, improving the building performance and promoting and accomplishing the expected sustainable goal". Through this analysis is concluded that the green building design process could be quick decision-making using the Building Information Modeling (BIM) application (Liu and Wang, 2022). These decisions must be based on the characteristics of the built environment of each country or region and the functionalities of the building type, since the functions depending on the use are simple or complicated and the energy-saving consumption in the buildings must be based on improving indoor comfort and thermal performance.

4.2.5. *Building Information Modeling (BIM) and sustainability perspectives*

Life cycle assessment (LCA) of buildings integrated into Building information modelling (BIM) facilitates data acquisition and decreases labour-intensive processes (Teng et al., 2022). LCA is a tool to research environmental problems of a construction process or building, considering the whole life cycle, from cradle to grave (ISO 14040, 2009). In this consideration is taken into account, the natural environment, human health, and resource weakening to avoid complications between different life cycle stages, between localities, and between environmental challenges (Buyle et al., 2013). Through a case study of an institutional building in Egypt, Alothman, Ashour, and Krishnaraj (Alothman et al., 2021) prove the effective contribution of Building Information Modeling (BIM) to support sustainable decision-making in buildings. A BIM-based life cycle framework was developed to fix the energy performance gap and also achieved sustainable goals in the building such as reviewing designs, monitoring energy quality, exchanging data, and "real-time operation and maintenance management" (Tahmasebinia et al., 2022). Also, Chen (2019) through the

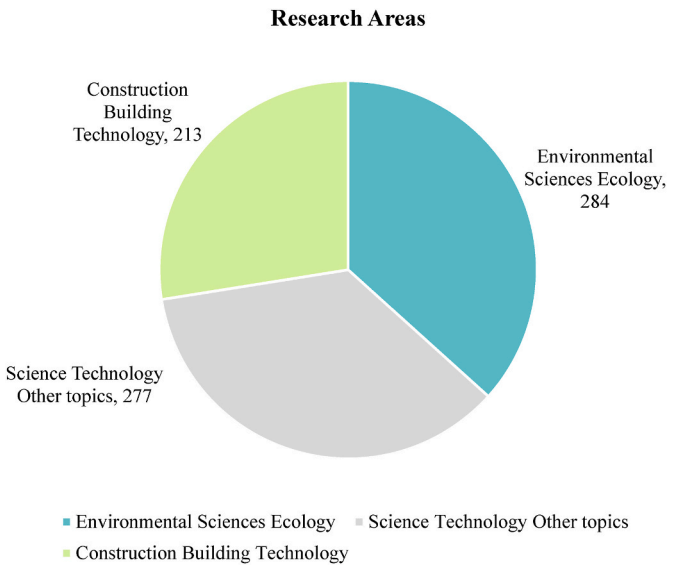

Fig. 4. Articles research areas.

integration of Building Information Modeling (BIM) and Building Performance Analysis (BPA) software demonstrates the procedural steps in the application of green Building Information Modeling (BIM) to encourage the design of zero-energy buildings (NZEBs). Building Performance Analysis (BPA) also known as Building Performance Simulation (BPS), involves software to predict building performance and Building Information Modeling (BIM) to reduce data transmission faults and also decrease operational management cost and risk (Chen, 2019).

4.2.6. Building Information Modeling (BIM) for improvements in the renovation process of the building

The renovation process is related to time-saving and cost-saving, nowadays stakeholders are conscious of environmental concerns (Schwartz et al., 2016), but also have useful tools to quickly get indicators that show results during the compliance of the building sustainability requirements. Lasarte et al. (2021) proposed KPIs, to assess the savings in time and cost that were accomplished thanks to the application of Building Information Modeling (BIM) (Singh and Sadhu, 2019). These results help to improve the collaboration between stakeholders and architects in terms of architectural design and are aligned with the improvement of CO2 emissions and environmental targets.

5. Research gap and future directions

The systematic literature review was conducted to propose new research as a prolongation of developing studies in the explored areas. These continuations should be developed based on the analysis and exploration of the studies and the respective future prospective, identifying research gaps, which are explained below (shown in Fig. 5 below).

5.1. Informational issues

Data exchange and collaboration are considered by most researchers one of the most difficult tasks which is still a challenge for data transmission, even if there is the existence and management of the IFC standard *ISO 16739-1:2018: Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries* (16739–1:2018, 2018) the interoperability of Building Information Modeling (BIM) models is not a guarantee. The found limitations are based on the data exchange in different software (Panagiotidou et al., 2022), and this is affecting the pace with which these methodologies can be adopted in the construction industry. Furthermore, the Building Information Modeling (BIM) platform should develop specific features for ecosystem professionals who pretend to work together and add new values to the project (Aksenova et al., 2019).

5.2. Operational issues

Setting and defining Building Information Modeling (BIM) strategies and achievements is one of the most difficult steps in the managing process the targets are based on project performance and in this performance is simple to identify BIM-specific uses in the project (Alireza et al., 2017). The use of Building Information Modeling (BIM) models can be specific to any of the phases through its life cycle, however, there are variations in analysis and descriptions (Panagiotidou et al., 2022). The functionality of Building Information Modelling (BIM) is based on Building Information Modeling (BIM) capability and process interoperability reaching requirements and completing the activities in the expected time. Furthermore, future research should focus on the implementation of the Building Execution Plan (BEP) (Panagiotidou et al., 2022) to support and define the strategies and internal standards for the development of a BIM-based project to involve coherent and coordinated work.

5.3. Integration of BIM and BEM

Integration of Building Information Modeling (BIM) and Integration of Building Energy Modeling (BEM) allows us to understand the environmental impacts based on the quantity of buildings' energy performance (Mohajer and Aksamija, 2019), this methodology is very helpful to decision-makers based on environmental consciousness these two methodologies are mostly implemented individually in the design phase and is proven by one of the cases studies explored (Tahmasebinia et al., 2022) that the energy performance could be successfully improved using

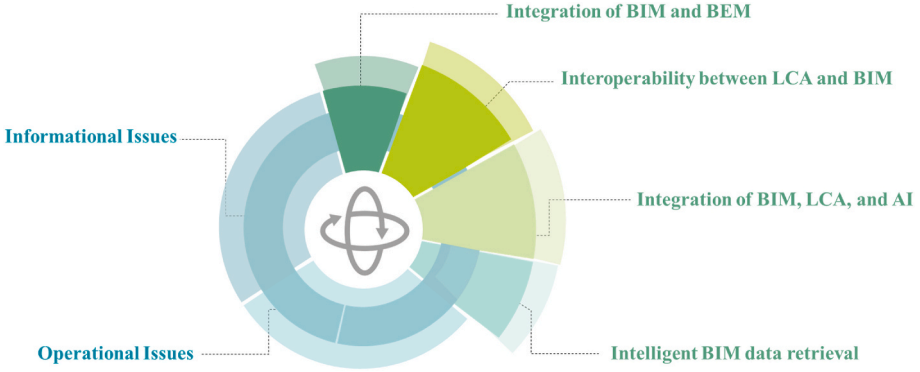

Fig. 5. Future research challenges.

these two methodologies in one environment utilising REVIT for the physical model and Green Building Studio for the energy model as tools.

5.4. Interoperability between LCA and BIM

The lack of all integrated Building Information Modeling (BIM) Tools for 'cradle to grave' management of a building's environmental sustainability, which should include the analysis of the energy required and materials through the whole life cycle is impeding the improvement of the environmental analysis of the building based on the Life Cycle Assessment (LCA) and the consideration of indicators regarding the carbon emissions and carbon footprint of buildings (Wu et al., 2014).

5.5. Integration of BIM, LCA, and AI

The Artificial Intelligence (AI) voice assistant interface and the mediation environment used to translate spoken requests and obtain information into CSV files all have a high degree of compatibility. The developed system will be expanded through further study to retrieve and access data from a Building Information Modeling (BIM) cloud model. To allow multiple users to engage with the Building Information Modeling (BIM) model without connecting the device to the Artificial intelligence (AI) voice assistant skill, link a BIM model in the cloud, such as BIM 360, and an artificial intelligence voice skill (Elghaish et al., 2022). For intelligent Building Information Modeling (BIM) data retrieval and representation based on the needs of nonexperts, there is a pressing need and a solid foundation. The usefulness of cloud Building Information Modeling (BIM) based on flexible retrieval and workable representation must be further promoted given the significant volume of Building Information Modeling (BIM) data gathered from various Building Information Modeling (BIM) applications (Lin et al., 2016).

6. Conclusions

Due to the results of this review, it can be assumed that Building Information Modeling (BIM) is a powerful tool with capabilities that improve the environmental and sustainable approaches in the design and construction phases of green buildings. Building Information Modeling (BIM) provides several advantages such as sustainable knowledge between stakeholders, policymakers, and project managers that could lead to successful and quality green buildings; Building Information Modeling (BIM) is a methodology and a tool that could help the construction industry to achieve environmental goals and allows the performance of Life Cycle Assessment (LCA) through each stage of the project.

Building Information Modeling (BIM) is utilized in most countries and every stage of the project, the design (Quiñones et al., 2022), the construction, the renovation, and the recycling process. The interoperability of Life Cycle Assessment (LCA) with Building Information Modeling (BIM) is vital to achieving successful sustainable approaches in construction projects. In addition, establishing environmental goals from the initial stage of the project would allow having indices for a clear understanding of the sustainability of the project. This article demonstrates the importance of conducting research in recent studies to provide the latest information for future studies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Abbreviations

BIM	Building Information Modeling
BEM	Building Energy Modeling
LCA	Life Cycle Assessment
CO_2	Carbon Dioxide
BoQ	Bill Of Quantities
LCI	Life Cycle Inventory
GWP	Global Warming Potential
ADP	Abiotic Depletion Potential
EP	Eutrophication Potential
ODP	Ozone Depletion Potential
PP	Polypropylene
POCP	Photochemical Oxidant Creation Potential
ENR	Excess Noise Ratio
SSIM	Structural Similarity Index Measure
IPD	Integrated Project Delivery
SNA	Social Network Analysis
OTTV	Overall Thermal Transfer Value
REH	Portuguese Thermal Regulation
FFDP	Fossil Fuel Depletion Potential
GHG	Greenhouse Gas
UBO	Ultimate Beneficial Owner
WoS	Web Of Science
BREEAM	Building Research Establishment Environmental Assessment Method
LEED	Leadership In Energy And Environmental Design
DGNB	Deutsche Gesellschaft Für Nachhaltiges Bauen (German Sustainable Building Council)
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
WELL	Performance-Based System to Measure And Monitor The Building Environment
NZEBs	Zero-Energy Buildings
BPA	Building Performance Analysis
BPS	Building Performance Simulation
KPI	Key Performance Indicator
ISO	International Organization for Standardization
IFC	International Foundation Class
AI	Artificial Intelligence
CSV	Comma-Separated Values
AP	Acidification Potential
EFA	Exploratory Factor Analysis
OCA	Organizational Capabilities
BIMCR	BIM Capability Requirement
OCU	Organizational Culture
KMO	Kaiser-Meyer-Olkin
SLR	Systematic Literature Review
RAF	Rank Agreement Factor
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses

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