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SERVICES FOR SCIENCE AND EDUCATION

Criteria For Evaluating Environmental Sustainability Performance of Building Projects: A Review

Sidik, M. A.
Department of Building Technology and Estate Management,
Dr Hilla Limann Technical University, Wa, U.W.R., Ghana

El Fathali, H. I.
Department of Civil Engineering, Faculty of Engineering,
College of Mechanical Engineering, Sabratha University, Libya

Ayarkwa, J.
Department of Construction Technology Management,
Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Acheampong, A.
Department of Construction Technology Management,
Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Osei-Tutu, S.
Built Environment Division,
Building and Road Research Institute, Kumasi, Ghana

Afful, A. E.
Department of Construction Technology Management,
Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

ABSTRACT

This study aimed at identifying the criteria for evaluating environmental sustainability performance (ESP) of building projects and examining the research developments and performance ('hot' themes, status quo, and research gaps) in the research domain. A literature search was conducted using the Scopus search engine, augmented by Google Scholar, to identify 59 relevant articles for analysis. A bibliometric analysis was undertaken with the use of VOSViewer to better understand the broad literature on ESP of building projects. Content analysis allowed for a systematic review of the selected articles to reveal the criteria for evaluating ESP of building projects in the literature. Among the criteria identified include energy, emissions, waste, materials, water, and land/site. These were grouped into Environmental Management, Resource Consumption and Protection, Design, Policies and Certification, and Preservation, for better appreciation and holistic understanding of building project evaluation criteria. The research "hot" themes were 'life-cycle assessment', 'sustainability in building projects', 'environmental assessment' and 'multi-criteria decision-making', and the research

status quo was 'life-cycle assessment', 'analytical hierarchy process ', 'key performance indicators', and 'building information modeling'. Research gaps identified from the study include 'Performance evaluation', 'Buildings', 'Key performance indicators. Grouping ESP evaluation criteria offers a holistic understanding of building project evaluation criteria, enhancing understanding and application in the industry.

Keywords: environmental sustainability, performance evaluation, criteria, building projects, bibliometric review, sustainable construction.

INTRODUCTION

The Construction Industry (CI) is crucial for sustainable development due to its resource consumption and environmental impact [1]. Although the CI drives global economic growth [2], as there is about $10 trillion in construction-related spending annually [3], it contributes 35% to global CO_2 emissions and 30% of greenhouse gases during the construction process, with 18% originating from materials transport and processing [4]. The CI also generates between 45% and 65% of the waste deposited in landfills [4].

Performance evaluation is a systematic process for project or organization decision-making, involving selecting indicators, collecting data, assessing against predefined criteria, reporting findings, and regularly reviewing and improving the evaluation process [5]. It is the process of quantifying the effectiveness and efficiency of previous actions, using identified criteria [6-7].

Tseng *et al*. [8] described ESP as the measurement of an organization's impact on the environment. ESP involves conserving resources, promoting environmental activities, ensuring employment, promoting health and safety, fostering community relations, involving stakeholders, and evaluating organizational economic impacts [9].

Construction projects exhibit poor sustainability performance, negating the call for green construction for a more sustainable environment [10]. Kiani Mavi et al. [11] therefore advocate for sustainability performance evaluation in construction projects from inception. There is a need for performance evaluation of building construction projects to demonstrate commitment to sustainability [12]. Presley and Meade [13] pointed out the need to evaluate and help improve performance toward sustainable construction and design. Researchers recognize the importance of performance evaluation to achieving continuous improvement and determining the effectiveness of organizations' actions [6].

Adabre and Chan [14] emphasize the importance of identifying criteria for evaluating the performance of building construction project to achieve sustainable development goals. It is therefore crucial to identify the criteria for evaluating ESP for building projects for accurate and comprehensive evaluation of their environmental performance. Congregating scattered criteria in the literature, can provide holistic appreciation for application to building project. Therefore, to efficiently evaluate the ESP of a building project, identifying and selecting appropriate criteria for the project's conditions must be ensured [15]. "The growing importance of

sustainability requires more standardized methods of assessing sustainability performance" [16, p 196].

Haapio [17] described criteria as the characteristics that are considered important and by which success or failure can be judged. Vega [18] described criteria as the characteristics of the specific aspects of the building system to be evaluated in order to determine their degree of sustainability. Evaluation criteria are the set of principles or standards through which judgment can be made [14]. This study therefore defines criteria as *the characteristics or conditions that must be met in order to comply with principles of environmental sustainability for building projects*. ESP evaluation criteria are used for benchmarking the performance levels of comparable projects [19], and need to be defined before evaluating the performance of building projects [14]. ESP evaluation of building construction projects remains critical to the industry's quest to become more sustainable [20]. Evaluation criteria play essential roles in projects by enabling policymakers and practitioners to determine the performance level of their projects. Furthermore, they guide construction practitioners and policymakers to appropriately plan resource allocation [14].

Considering the background presented, this study poses fundamental research questions:

1. What criteria for evaluating ESP of building projects are presented in the literature?
2. What are the research developments and performance ('hot' themes, status quo, and research gaps) in the research domain of criteria for evaluating ESP of building projects?

As suggested by Afful *et al.* [21], it is more beneficial to conduct systematic investigations rather than argue from a specific viewpoint to unearth what we do know, and thus, proceed to the broader spectrum of what we do not know to learn more. This bibliometric review would uncover the literature on various criteria for evaluating ESP introduced since the inception of the concept of sustainability and broaden the understanding of researchers and practitioners, and bringing to light what is known in the domain.

Through this review, this study will contribute to knowledge on ESP evaluation criteria by bringing to the fore, a percipience of ESP evaluation criteria identified in literature beyond the narrow scope of isolated criteria scattered in the literature. This study will also contribute to the global delivery of literature on the criteria for evaluation of ESP building construction projects by revealing research trends, hot themes, status quo, knowledge gaps, and future research direction in the domain.

REVIEW PROCESS

This section shows the processes followed by the study in selecting, screening, and analyzing publications for the achievement of the research objectives (Figure 1).

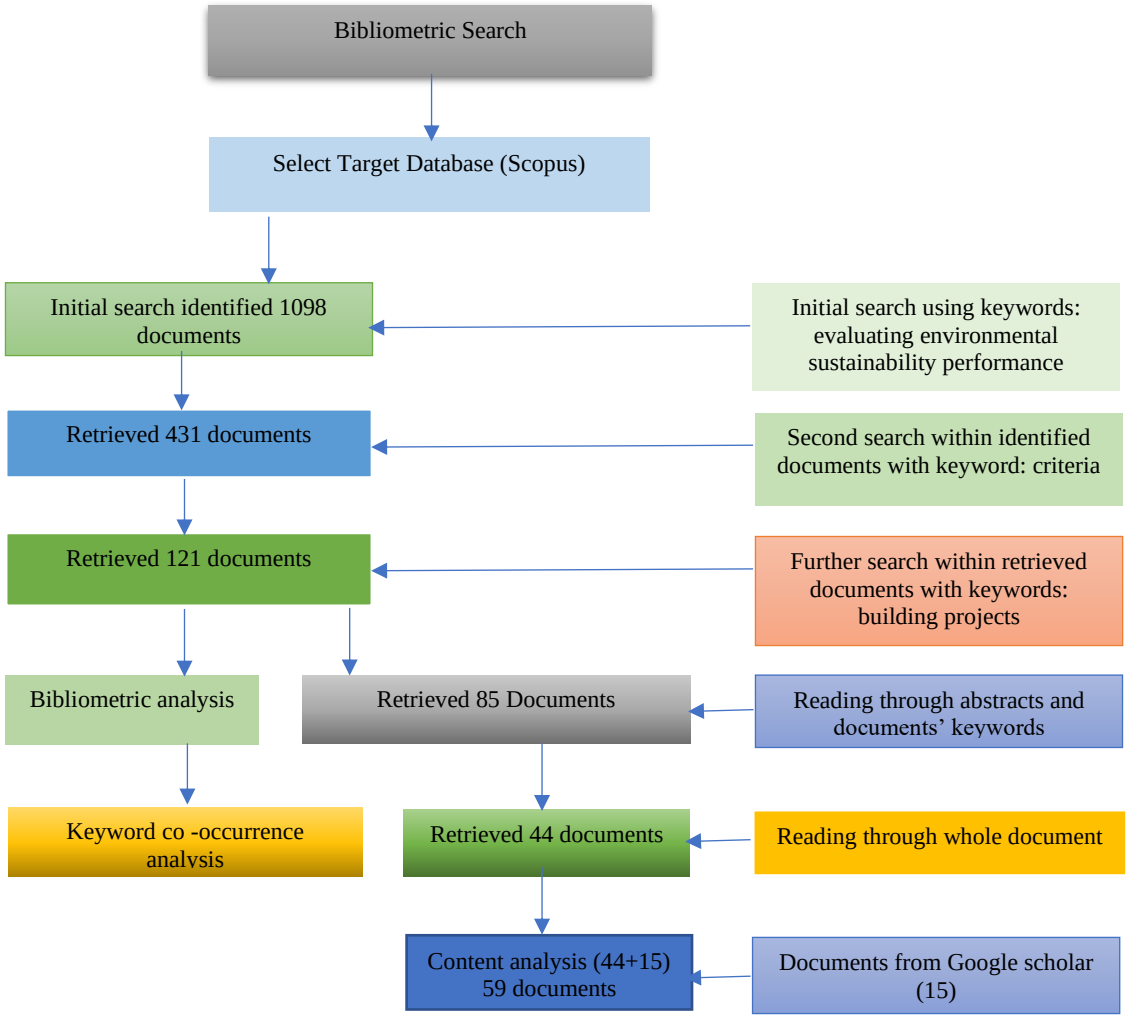


Figure 1: Review process
Source: Author(s) Construct, 2023

Database Selection

Scopus database was used to undertake this study because of its extensive coverage of academic literature in construction and engineering-related fields [22], and Scopus has a much broader database [23]. Archambault et al. [24] found high correlation between Scopus and WoS, indicating no significant difference in bibliometric analyses of the two databases. Additional documents were, however, obtained from Google Scholar to broaden the scope of documents reviewed.

Article Search and Screening

The article search was carried out on the 31st of March 2023. The search query used was intended to be exhaustive to allow for publications on ESP evaluation criteria for building projects to be retrieved. This search string was: TITLE-ABS-KEY ("Evaluating environmental sustainability performance"). The query obtained 1098 documents. Screening within the 1098 documents with the keywords "criteria" and "evaluating environmental sustainability performance" gave 431 documents. The next screening was done to restrict documents to

"building projects" as contextually scoped for this study. One hundred and twenty-one (121) documents passed this screening. This number was used for the bibliometric analysis. Further screening was done by reading the abstracts and keywords of the 121 documents to know their focus. Eighty-five (85) documents were obtained. A final level screening was done by reading the contents of the 85 documents to identify the criteria used for evaluating the ESP of building projects. Forty-four (44) documents contained criteria for evaluating ESP of building projects. Fifteen (15) additional documents were obtained from Google Scholar search, and added to broaden the scope of documents used for the content analysis. A total of 59 documents were used for identifying the criteria for evaluating ESP of building projects. The search was not limited by years in order not to miss any relevant documents. Table 1 shows the list of the 59 publications in order of year of publication.

Software Selection

Various science mapping tools exist for the analysis and visualization of dynamic trends and patterns in knowledge domains. Some widely accepted science mapping tools include VOSViewer, Leydesdorff's Software, Sci2Tool, Bibexcel, Cite Space, and CoPalRed [22]. This study, however, employed the VOSViewer software to undertake the bibliometric review due to its unique ability to visualize, explore and produce bibliographic maps from data exported from Scopus as well as its better performance in mapping knowledge domains through the visualization of bibliographic data [25].

RESULTS AND DISCUSSION

Table 1: List of publications reviewed for the criteria for evaluating ESP of building projects

Code	Authors
R1	Ugwu and Haupt [67]
R2	Erol *et al.* [68]
R3	Chen *et al*. [69]
R4	Krídlová-Burdová and Vilčeková [70]
R5	Tseng and Chiu [38]
R6	Padgett and Tapia [71]
R7	Collier *et al.* [72]
R8	Biswas *et al.* [66]
R9	Kucukvar *et al.* [73]
R10	Chou and Ongkowijoyo [74]
R11	Supino *et al.* [57]
R12	Vega [18]
R13	Wibowo and Deng [75]
R14	Afful-Dadzie *et al.* [76]
R15	Li *et al.* [77]
R16	Ding *et al.* [78]
R17	Govindan *et al.* [79]
R18	Zhao *et al.* [80]
R19	Hojjati *et al.* [81]
R20	Tupenaite *et al.* (2017) [56]

R21	Jafari and Valentin (2018) [82]
R22	Jovanović *et al.* (2018) [83]
R23	Yang and Jiang (2018) [84]
R24	Bertagni et al. (2018) [61]
R25	Kraus and Senitkova (2019) [31]
R26	BuHamdan *et al.* (2019) [85]
R27	Su *et al.* (2019) [86]
R28	Cheng and Li (2019) [87]
R29	Reddy *et al.* (2019) [88]
R30	Artelt and Lukas (2020) [89]
R31	Kokkinos and Karayannis (2020) [90]
R32	Wang *et al.* (2020) [91]
R33	Najini *et al.* (2020) [63]
R34	Artino *et al.* (2020) [92]
R35	Hendiani *et al.* (2020) [93]
R36	Chen and Zhang (2020) [94]
R37	Reddy *et al.* (2021) [88]
R38	Nara *et al.* (2021) [95]
R39	Nabeeh *et al.* (2021) [58]
R40	Khan *et al.* (2021) [96]
R41	Sahlol *et al.* (2021) [59]
R42	El Hawary and Marzouk (2021) [46]
R43	Lim *et al.* (2021) [55]
R44	Aktaş and Demirel (2021) [97]
R45	Marzouk *et al.* (2021) [54]
R46	Hong *et al.* (2021) [98]
R47	Asgari and Noorzai (2021) [47]
R48	Ghosh *et al.* (2021) [99]
R49	Erdogan and Tosun (2021) [100]
R50	Lin *et al.* (2022) [49]
R51	Rajabi *et al.* (2022) [40]
R52	McGinley *et al.* (2022) [51]
R53	Andersen *et al.* (2022) [101]
R54	Sanchez-Garrido *et al.* (2022) [102]
R55	Khokhar *et al.* (2022) [103]
R56	Zhang and Xu (2022) [104]
R57	Di Maria *et al.* (2022) [105]
R58	Navarro *et al.* (2022) [37]
R59	Ramakrishnan *et al.* (2023) [106]

Source: Author(s) Construct, 2023

Trend Analysis

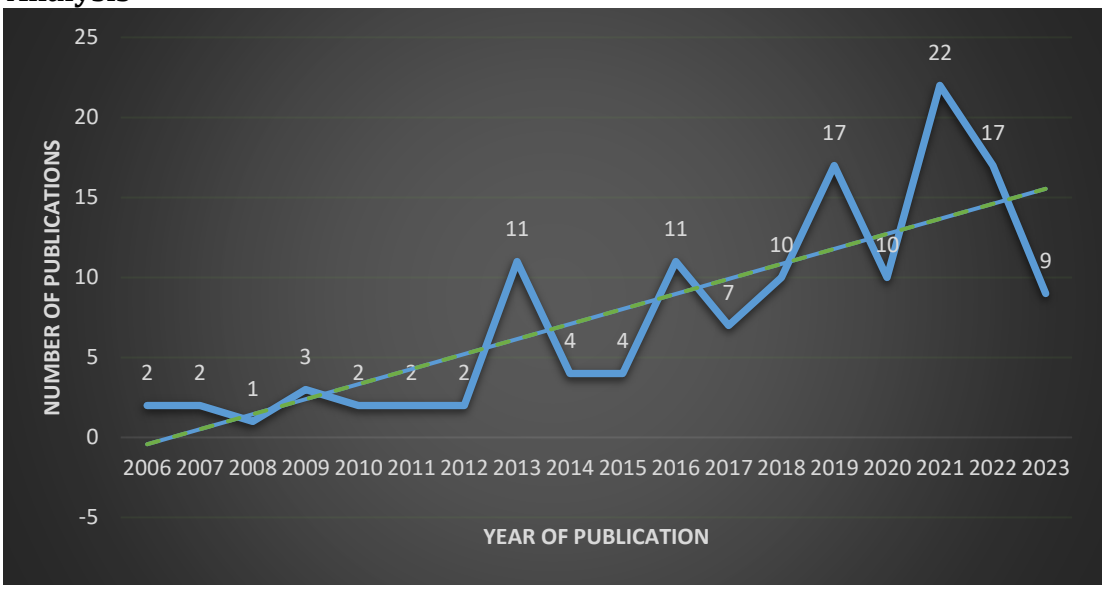


Figure 2: Trend of Publications
Source: Author(s) Construct, 2023

Figure 2 presents a trend graph of the publications for this study. The graph reveals a slow rise in the number of publications for the first 7 years and a sharp increase from 2013. For the first 7 years (2006–2012), the average number of publications on the subject area per year was 2.0, followed by a sharp increase of 7.8 over the next six years (2013–2018). The remaining five years showed an average of 15.0 publications per year. It is worth mentioning that the total number of 9 publications in 2023 is up to March when the literature searches were conducted. The number will most likely grow before the end of the year, looking at the trend of average annual publications. Similar trends were observed by Afful et al. [26] in their study to identify the capacity needs of building professionals to deliver environmentally sustainable buildings. The study shows a continuous increase in the number of publications in the knowledge domain from 2006 to 2023.

The increasing trend in publications could be attributed to the following reasons: 1) the adoption of technology (BIM, Big Data, Internet of Things, etc.) into construction processes, accounting for the growth of environmentally sustainable buildings and, thus, the need to train consultants and BE professionals in the use and application of such technologies [27], 2) increase in competencies of building professionals for both traditional and green buildings in the wake of highly competitive construction job markets [26], 3) the pressure on the construction industry to design and build sustainable buildings to meet green evaluation systems.

Knowledge Domain Analysis

Knowledge domain is a broad-based understanding of a particular body of knowledge [23]. For this study, the knowledge domain is the criteria for evaluating ESP of building projects. The science mapping method, which aid in analyzing and visualizing trends and patterns in bibliographic data [28], was adopted in the domain analysis. Science mapping methods employ

either a bibliometric or scientometric analysis for knowledge domain analysis. This study adopted the bibliometric analysis which presents objective quantitative findings, interpretation, and replicability [29].

Bibliometric Analysis

This study employed the use of co-word analysis to identify the hot themes, status quo, and research gaps on criteria for evaluating ESP of building projects from the bibliographic data. Co-word analysis is vastly adopted in bibliometric reviews on various knowledge domains [22]. "Such methods introduce a measure of objectivity into the evaluation of scientific literature and hold the potential to increase rigor and mitigate researcher bias in reviews of scientific literature by aggregating the opinions of multiple scholars working in the field" [30, p 429].

Co-word Analysis:

The co-word analysis presents the co-occurrences of keywords in clusters.

Co-occurrence of Keywords:

The minimum occurrence of keywords to be included in the analysis of documents in the VOSviewer software was set to two (2), to allow for the visualization of more relevant keywords. Out of 511 keywords, 54 met the threshold.

Figure 3 shows the network visualization of keyword co-occurrence in four clusters. Different colours represent different clusters. The colours are red, green, blue, and yellow, ranging from the highest number of links to the lowest [25].

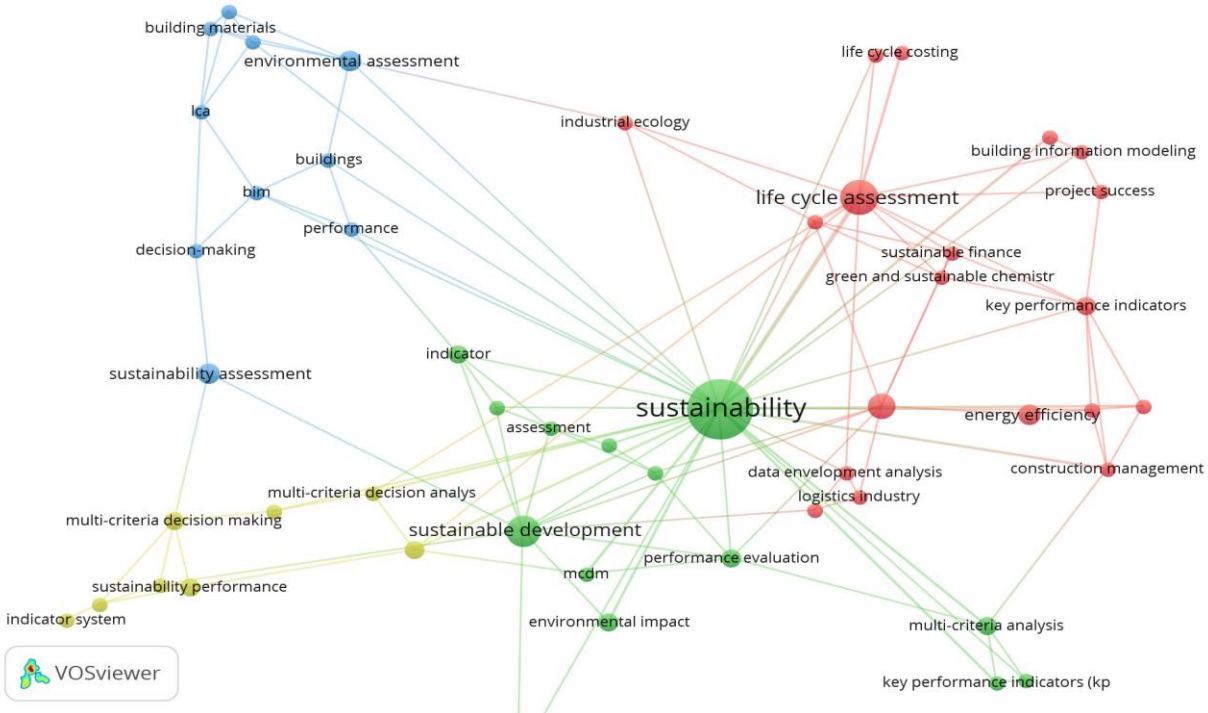


Figure 3: Network Visualization of Keywords

Source: Author(s) Construct, 2023

In Figure 3, the size of the circles represents the occurrences of keywords. Larger circles represent more co-cited keywords in the selected publications. The keywords "sustainability", "life-cycle assessment" and "sustainable development" occurred the most as depicted by the sizes of the circles. The distance between items shows how strong the keywords are correlated. Thus, the smaller the distance, the stronger the keyword correlation [4]. This distance between keywords reveals relative strength and topic similarity. Also, circles in the same colour cluster suggest similar topics among the publications. Example the keywords 'multi-criteria decision making', multi-criteria decision analysis', relates with 'sustainability performance' in the yellow cluster in Figure 3.

HOT THEMES

The highly ranked keywords in each cluster reveal the "hot" themes in each research domain as shown in Table 2. These include Life-Cycle Assessment, Sustainability in Building Projects, Environmental Assessment, and Multi-criteria Decision Making

Table 2: Hot Themes

Cluster No.	No. of Keywords	Colour	Keywords	Hot Themes
Cluster 1	19	Red	Analytic hierarchy process, building information modelling, circular economy, construction management, data envelopment analysis, energy efficiency, environmental sustainability, green and sustainable chemistry, industrial ecology, key performance indicators, KPIs, life cycle assessment, life cycle costing, logistics industry, multiple criteria decision-making, OECD countries, project success, sustainable finance, system dynamics	Life-cycle Assessment
Cluster 2	15	Green	Ahp, assessment, environmental impact, evaluation, indicator, indicators, key performance indicators (KPIs), MCDM, multi-criteria analysis, performance evaluation, performance measurement, stakeholders, sustainability, sustainability indicators, sustainable development	Sustainability in Building Projects
Cluster 3	10	Blue	BIM, building materials, buildings, decision-making, environmental assessment, ICA, performance, Slovakia, sustainability assessment, sustainable buildings	Environmental Assessment
Cluster 4	8	Yellow	Case study, corporate sustainability, indicator system, multi-criteria decision analysis**,** multi-criteria decision making, TOPSIS, triple bottom line	Multi-criteria Decision Making

Source: Author(s) Construct, 2023

Life-cycle Assessment (LCA)

LCA is a method used to assess the environmental impact of materials, products, or buildings across their entire life cycle. A building's life cycle begins from planning through design, construction, operation, maintenance, renovation, and demolition [31]. LCA is among the

approaches used in evaluating the ESP of building projects using defined criteria. For instance, in a study to select the most sustainable foundation system based on LCA and ESP, Kraus and Senitkova [31] indicated that the recommended criteria for evaluating sustainable building materials are low embodied energy, recyclability, use of renewable resources, locally or regionally produced, energy efficiency, low environmental impact, durability, and minimization of waste. Sameer and Bringezu [32] proposed an LCA methodology of material resource use in buildings, taking into consideration the applicability of material input indicators, raw material input, and total material requirements.

Sustainability in Building Projects

Sustainability in building projects involves sustainable design and construction practices, preserving energy, water, and natural resources through reuse, recycling, creative design, and waste reduction to meet present and future generations' needs [4]. These principles aim to reduce the amount of energy used and waste generated by the construction industry [33]. The criteria for evaluating ESP of building projects are the conditions to comply with, to make the projects environmentally sustainable. This study shows that researchers are studying building project sustainability and the criteria to attain it. Sustainable buildings focus on reducing resource consumption, reusing materials, using recyclable materials, protecting nature, and removing harmful materials [34] This embodies environmental management and protection [33].

Environmental Assessment

Environmental assessment of building projects is the objective and systematic evaluation of a building's performance consistently, harmonized with pre-established criteria [35]. This has captured the attention of building professionals worldwide [33]. According to Tam et al. [36], green evaluation systems assess construction operations by measuring environmental performance, analyzing trends, and providing a consistent foundation for eco-labeling and benchmarking across sites. Kamali et al. [15] indicated that, to efficiently evaluate the ESP of building projects, a set of appropriate ESP evaluation criteria that suit the conditions of the project should be identified and selected.

Multi-criteria Decision-Making (MCDM)

MCDM is a performance evaluation approach such as AHP, ANP, ELECTRE, TOPSIS, VIKOR, DEMATEL, etc., where decision-makers determine the relevance of criteria, based on their knowledge and overview of the problem to be evaluated [37]. MCDM analysis assists the decision-makers in selecting the most appropriate alternatives from a set of alternatives [38]. Researchers such as Mushtaha et al. [39] and Rajabi et al. [40] have evaluated the ESP of building projects using MCDM approach.

KNOWLEDGE GAP AND FUTURE RESEARCH

Figure 4 shows the areas in criteria for evaluating ESP of building projects where knowledge gaps exist as obtained from the bibliometric analysis data imported into VOSViewer. The background colours of the keywords in the density visualization, range from Blue to Green to Yellow, and keywords in yellow background such as “sustainability’ and “life cycle assessment” show areas that are more researched [25].

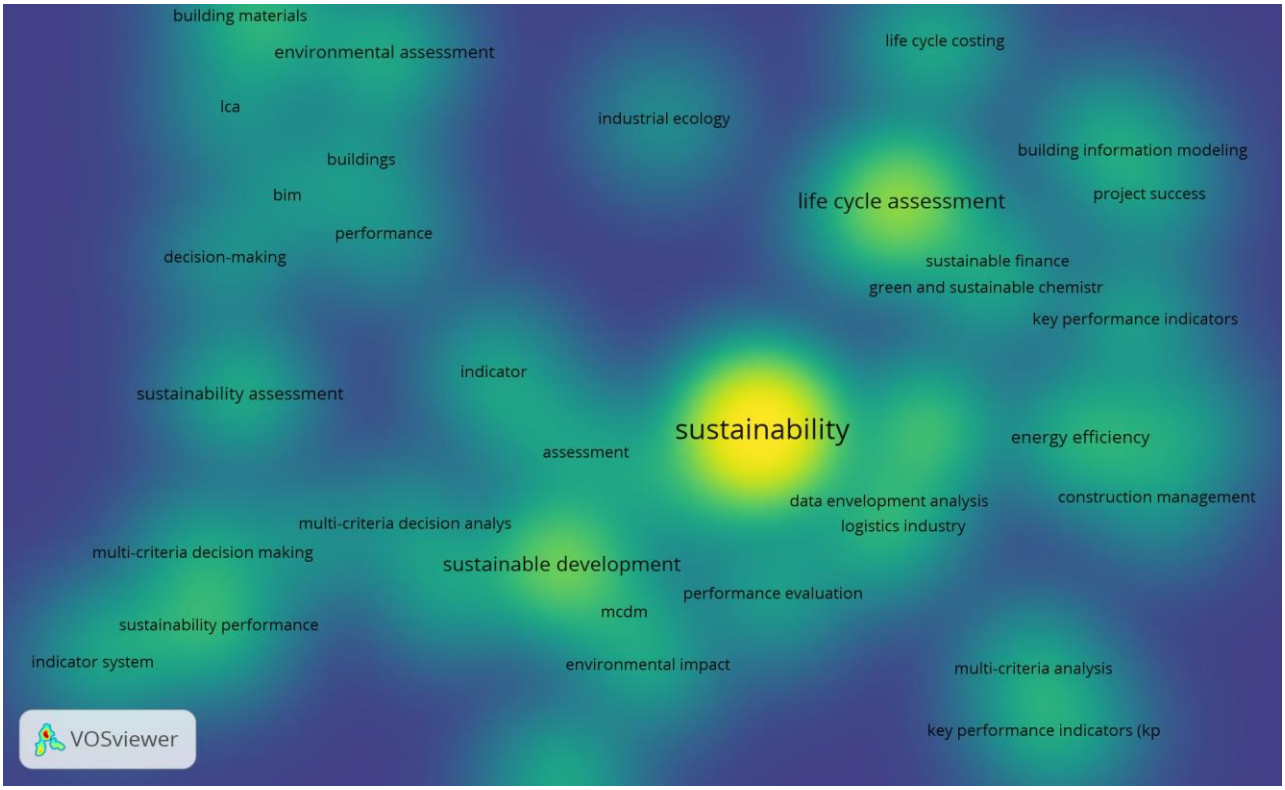


Figure 4: Keywords Density Visualization
Source: Author(s) Construct, 2023

Some of the less researched areas, with blue/green background, identified in Figure 4 are areas requiring attention, and include 'Performance evaluation', 'Buildings', 'Key performance indicators', etc. These areas (greenish in colour) indicate the knowledge gaps in criteria for evaluating ESP of building projects and identify the direction for future research as discussed below:

Performance Evaluation

Performance evaluation is a systematic procedure that assists in making decisions on the performance of a project or an organization. From Figure 4, the colour of the keyword "performance evaluation" indicates that there is little research linking it to the ESP of building projects. For instance, Owusu-Manu et al. [41] indicated that there is paucity of studies focused on the linkage between green building projects and ESP evaluation, while Sanmi and Ayodeji [1] indicated that some ESP evaluation techniques for building projects neglect to incorporate the needed sustainable performance criteria. ESP encompasses performance with respect to the management of resources and preservation [9].

Buildings

The colour of the keyword "buildings" in Figure 4 suggests that there are few studies that link building projects to the criteria for evaluating ESP. More studies that will reveal the impact of buildings on the environment and the criteria for evaluating ESP of building projects are therefore required. Climate mitigation strategies of how to reduce energy consumption have

become an important driving force in the design and delivery of modern buildings [42]. According to Ng et al. [43], the increasing importance of building construction has led to the employment of building environmental assessment tools to evaluate the ESP of buildings which are done through various environmental performance criteria such as site management, energy efficiency, materials, water efficiency, indoor environmental quality, waste generation as well as ecology.

Key Performance Indicators (KPIs)

KPIs are metrics that are used to evaluate relevant characteristics of processes, products, and systems [44]. Sustainability KPIs can play an essential role in advancing the practice of sustainable construction [40]. Maslesa et al. [45] found research gaps in indoor environmental quality and reuse potential of building components and materials, indicating a need for more comprehensive studies. There is therefore the need to extend research on sustainability KPIs to advance the practice of sustainable construction.

STATUS QUO (CURRENT RESEARCH THEMES)

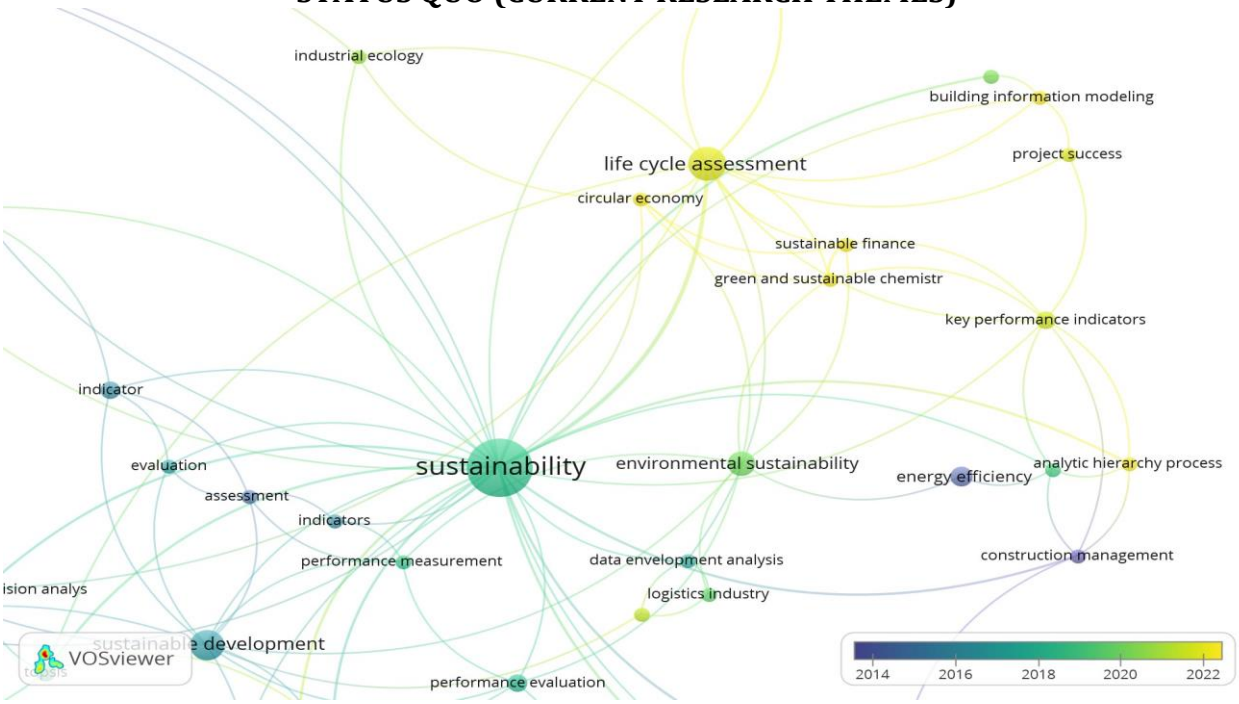


Figure 5 Overlay Visualization of Keywords Showing Status Quo

Source: Author(s) Construct, 2023

Figure 5 presents a visualization of the years of publication of the documents in which the keywords appeared. This overlay map reveals the status quo of research on criteria for evaluating ESP of building projects. The colour of the keywords shows the year trend of the keywords. The keywords appearing in yellow are the most current ones ranging from 2021 to 2023. The keywords in purple are the older keywords before and up till 2016. Among the current keywords from Figure 5 are “life-cycle assessment”, “key performance indicators”, “Analytical Hierarchy Process” and “building information modeling”.

Life Cycle Assessment (LCA)

Researchers are currently evaluating ESP of building projects based on their entire life-cycle. For example, El Hawary and Marzouk [46] studied the interactions between ESP evaluation criteria throughout a building's life-cycle.

Asgari and Noorzai [47] performed a life-cycle assessment to determine the impact of energy, land use, and global warming potential on performance of building projects. LCA provides a holistic overview of a building's environmental performance by taking into account the entire building's life-cycle and all relevant environmental impact criteria [48]. This avoids overlooking important life-cycle processes and environmental impact criteria. This helps informed decision-making and avoids unintentional decisions to reduce impacts in one environmental criterion may lead to even bigger impacts in other impact criteria [48].

Analytical Hierarchy Process (AHP)

The AHP is an MCDM approach used to find the best results in complex scenarios, including various criteria, conflicting goals, and standards [49]. According to Lin et al. [49], the AHP is often utilized to evaluate sustainable buildings, smart buildings, and the thermal comfort and post-use evaluation of building users. For example, Reddy et al. [50] developed a Sustainable Material Performance Index (SMPI) for building materials using the AHP, and Rajabi et al. [40] evaluated the importance of each criterion by applying the AHP. Mushtaha et al. [39] evaluated buildings with respect to defined criteria for evaluating ESP using the AHP. AHP is simple to apply in pairwise comparison and is used to prioritize criteria based on their relative importance [39].

Key Performance Indicators (KPIs)

KPIs are used to evaluate the performance of critical project objectives and are useful for dealing with complex contexts such as the ESP of building projects [51]. KPIs are also among recent approaches in evaluating ESP of building projects. In their studies, Rajabi et al. [40] identified and assessed KPIs for monitoring and evaluating the sustainability performance of building projects, whiles McGinley et al. [51] proposed an integrated framework for evaluating retrofits using a set of KPIs. KPIs play an essential role in advancing the practice of providing environmentally sustainable buildings [40] through the selection of KPIs [52] and the evaluation of a building [53] to help determine a its environmental sustainability performance [52].

Building Information Modelling (BIM

BIM involves generating and managing information for building projects throughout their life cycle, utilizing defined processes and technology to work effectively and efficiently [54]. It is an existing technology that is currently applied in the evaluation of ESP of building projects. For instance, Lim et al. [55] investigated the recent development of BIM for evaluating existing buildings' sustainability performance and green retrofitting, and [54] proposed a framework that aims at improving building system energy performance using BIM during building design.

CO-AUTHORSHIP ANALYSIS OF COUNTRIES

Table 3: List of Countries in the research domain of evaluating ESP of building projects

No	Country	Documents	Citations	Total link strength
1	United Kingdom	13	129	20
2	Spain	11	165	18
3	Italy	13	138	16
4	France	5	22	14
5	China	15	218	12
6	Sweden	4	128	11
7	Belgium	4	31	10
8	Australia	10	145	9
9	Netherlands	2	14	9
10	Germany	2	24	8
11	Poland	2	14	8
12	Canada	9	77	6
13	India	12	150	5
14	United States	13	369	5
15	Egypt	6	90	4
16	Turkey	5	104	4
17	Hong Kong	3	73	3
18	United Arab Emirates	4	9	3
19	Iran	5	46	2
20	Malaysia	3	21	2
21	Saudi Arabia	3	19	2
22	Brazil	5	55	1
23	Czech Republic	2	5	1
24	Taiwan	2	11	1
25	Greece	3	35	0
26	Slovakia	4	7	0
27	Switzerland	2	38	0

Source: Author(s) Construct, 2023

To show the academic research collaboration among countries in the research domain of evaluating ESP of building projects, a country co-authorship analysis of the document was conducted. A threshold of a minimum number of documents for a country to be included was set as 2, and of the 48 countries, 27 met the threshold. Table 3 captures the total link strength of the countries in terms of co-authorship. From Table 3, China, United Kingdom, Italy and United States are the leading countries in terms of documents with 15 and 13 documents each. However, United Kingdom has the highest total link strength of 20, followed by Spain, Italy, France, and China with total link strengths of 18, 16, 14 and 12 respectively. This shows that The United Kingdom is currently the leading research country collaborating with other countries on criteria for evaluating ESP of building projects. Collaboration in a research domain helps in partnership and sharing of knowledge and experiences to deepen global research.

CONTENT ANALYSIS

This part analyzes literature on ESP evaluation criteria in building projects using content analysis, and identifies evaluation criteria mentioned in the literature. The content analysis involved reading the 59 publications and extracting 22 relevant criteria from them. Table 4 shows the 22 criteria identified, and their categorization into six groups. Categorization was based on global environmental concerns, including management, resource consumption, design, policies, preservation, technology, and innovations. This categorization enhances understanding of the subject area and contributes to existing knowledge. It facilitates discussion of findings, develops relationships among individual criteria, and provides implications and solutions for stakeholders and practitioners. This will show them the environmental impact categories to concentrate on in the performance evaluation of building projects.

Table 4: Categorization of Criteria for Evaluation of ESP of Building Projects

Criteria Group	Sub-Group	Criteria	Occurrence	Author(S)
Environmental Management	Emissions/Pollution	Air/Emissions/Pollution	38	R1, R2, R3, R4, R6, R8, R9, R10, R11, R12, R14, R15, R17, R18, R19, R20, R25, R26, R29, R30, R31, R32, R34, R35, R36, R39, R41, R43, R44, R45, R46, R48, R49, R51, R52, R56, R57, R59
		Transportation emissions	4	R2, R8, R37, R49
	Process Management	Waste	30	R1, R2, R3, R7, R9, R11, R12, R14, R15, R17, R18, R19, R20, R23, R29, R31, R32, R34, R35, R36, R37, R38, R39, R41, R44, R48, R49, R50, R51, R59
		EMS	4	R5, R32, R49, R55
		Environmental risk	2	R12, R37
		Environmental reporting system	1	R2
	Materials Management	Materials	25	R3, R4, R8, R12, R17, R19, R20, R24, R25, R28, R29, R30, R34, R35, R38, R39, R41, R42, R47, R48, R49, R51, R54, R55, R58
		Green packaging and labeling	4	R2, R4, R17, R49

Environmental Resource Consumption and Protection	Resource	Energy	40	R2, R3, R4, R6, R7, R8, R9, R11, R12, R14, R15, R16, R17, R18, R19, R20, R21, R22, R23, R24, R26, R30, R32, R33, R34, R36, R37, R38, R39, R40, R41, R42, R43, R44, R45, R46, R50, R51, R52, R59
		Water	24	R1, R2, R3, R7, R8, R9, R10, R12, R14, R15, R18, R19, R20, R23, R24, R30, R33, R37, R38, R42, R47, R50, R51, R59
		Fuel	2	R30, R44
Environmental Design	Humane Design	IEQ	10	R8, R12, R16, R20, R24, R37, R43, R50, R54, R58
	Green Innovation design	Recyclability and reusability	10	R3, R4, R12, R14, R17, R25, R29, R38, R41, R44
	Sustainable Design	Eco/Green design	5	R5, R17, R32, R48, R55
Environmental Policies and Certification	Environmental protection policies	Conformation to Laws/Regulations/Policies	5	R13, R17, R28, R32, R48
		Certifications	5	R2, R5, R17, R41, R52
Environmental Preservation	Ecological preservation	Land/Site	17	R1, R2, R3, R8, R10, R13, R19, R20, R24, R31, R35, R36, R37, R39, R47, R51, R57
		Biodiversity preservation	9	R1, R8, R28, R31, R35, R48, R51, R54, R58
		Erosion	1	R35
Environmental Technology and Innovations		Innovations	5	R8, R12, R20, R24, R41
		Green technologies	5	R5, R17, R43, R48, R49

Source: Author(s) Construct, 2023

Discussion of Criteria Categories

Environmental Management:

The most occurring criteria identified under the Environmental Management group were air emissions/pollution, waste, and materials, with 38, 30, and 25 occurrences respectively. Rajabi et al. [40] identified pollution criteria, including air, water, and noise pollution, while Tupenaite et al. [56] also identified greenhouse gas emissions from NO_2 and CO. Building materials like

clinker emit a lot of CO_2. This has led to the application of solutions like co-processing alternative raw materials and fuels to improve environmental performance, reduce emissions, improve waste management, and reduce natural resource and fossil fuel extraction [57].

The waste criteria involve monitoring, managing, recycling and reuse of construction waste, as well as waste generated during material transport to sites [58]. Materials criteria prioritize sustainable management of responsibly sourced and low-embodied materials, monitoring consumption, recycling, and reuse, ensuring responsible sourcing and low embodied impact throughout their life span [40]. Minimizing materials resource consumption (particularly non-renewable ones) and its appropriate use is crucial for reducing environmental impact of buildings [59]. Reddy et al. [50] asserts that, sustainable material performance is assessed using specific criteria during extraction, transportation, manufacturing, maintenance, and demolition stages, requiring energy, water, and land inputs, and producing outputs (emissions and waste).

Environmental Resource Consumption and Protection

Under this group, energy and water were seen as the highest occurring criteria with 40 and 24 occurrences respectively. Resource consumption and protection emphasize efficient utilization and natural resource safeguarding during construction, minimizing energy and water consumption [60]. Researchers has emphasized various aspects of the energy criteria. For instance, Tupenaite et al. [56] studied building energy efficiency and renewable energy use, while Nabeeh et al. [58] focused on reducing carbon dioxide emissions and energy consumption in buildings. Rajabi et al. [40] examined energy consumption from construction plants, equipment, and temporary site setups, focusing on renewable energy usage. Energy efficiency is crucial for evaluating green buildings, as it reduces greenhouse gas emissions [56]. Similarly, various researchers have emphasized various aspects of the water criteria. Nabeeh et al. [58] described water efficiency as the minimum amount of water consumed for a specific task. Rajabi et al. [40] emphasized reducing water consumption and using recycled water resources. Tupenaite et al. [56] emphasized potable water quality, alternative water sources, and water conservation. The water criteria monitor and record potable water consumption data [40]. Water efficiency promotes smarter water use, preservation, and metering for indoor, outdoor, and specialized uses [61]. Environmental resource consumption and protection is therefore a vital criterion for evaluating ESP of building projects.

Environmental Design

The highest occurring environmental design criteria include Indoor Environmental Quality (IEQ) and recyclability and reusability with 10 occurrences each. Environmental design optimizes building projects' environmental performance through thoughtful design choices, incorporating sustainable principles [33]. IEQ includes indoor air quality, thermal comfort, visual comfort, acoustic comfort [51], lighting comfort, and aural comfort [56]. IEQ aims to achieve high standards of indoor air quality and thermal comfort for occupants [21]. Recyclability and reusability involve promoting circular production and consumption patterns, reducing raw material use by reusing or recycling processed waste and promoting sustainable consumption [62]. It is therefore vital to consider environmental design as a criterion for evaluating ESP of building projects.

Environmental Policies and Certification

This group is made up of laws/regulations/policies and certifications, with 5 occurrences each. Environmental policies and certification frameworks provide guidelines and standards for sustainable practices in building projects. There is a need for green building laws and regulations for the successful achievement of environmental sustainability in the building sector. As a result, building permits in some countries require conformance to green building regulations to promote sustainable living environments [63]. Implementing sustainable material consumption laws will reduce energy consumption, prevent waste, and reduce greenhouse gas emissions (Reddy et al., 2019). Energy efficiency standards need to be promulgated within green building regulations [63]. Site-related energy and water impacts are monitored and reported to ensure compliance and improve awareness and understanding of sustainability objectives [40]. Certification tools assist governments in developing policies to achieve national environmental targets in the building sector [51]. Conditions are necessary during design and development for building certification to ensure compliance with evaluation requirements [61].

Environmental Preservation

The most occurring criteria for this group were land/site and biodiversity, with 17 and 9 occurrences respectively. Environmental preservation prioritizes protecting ecosystems and biodiversity, and minimizing building projects' impact on the environment. The land/site and biodiversity criteria focus on reusing brownfield sites, enhancing ecology, protecting habitats, and improving long-term biodiversity in project sites and surrounding land [40]. This includes proper site selection, utilizing damaged lands, landscape design, ecosystem preservation, and outdoor environment quality [56]. Sustainable sites include strategies that allow for the regeneration of damaged areas [61]. Site selection, site design, and land use are important criteria in the ratings of green buildings [56].

Environmental Technology and Innovations

This group is made up of innovations and green technologies criteria with 5 occurrences each. Environmental technology and innovations involve the adoption of advanced technologies and techniques to reduce environmental impact. Innovations involves the application of smart and intelligent building concepts to improve building performance and reduce environmental impacts [45]. Environmentally friendly design involves innovation transitioning from traditional to smarter approaches and smart methods like smart grids, smart cities, and BIM [58]. This rewards design solution that have innovation and high environmental performance [61]. Green technologies utilize thermochemical and biochemical methods to convert waste into fuels for electricity and heat production, transforming waste into valuable resources [64].

INTERRELATIONSHIPS AMONG CRITERIA GROUPS

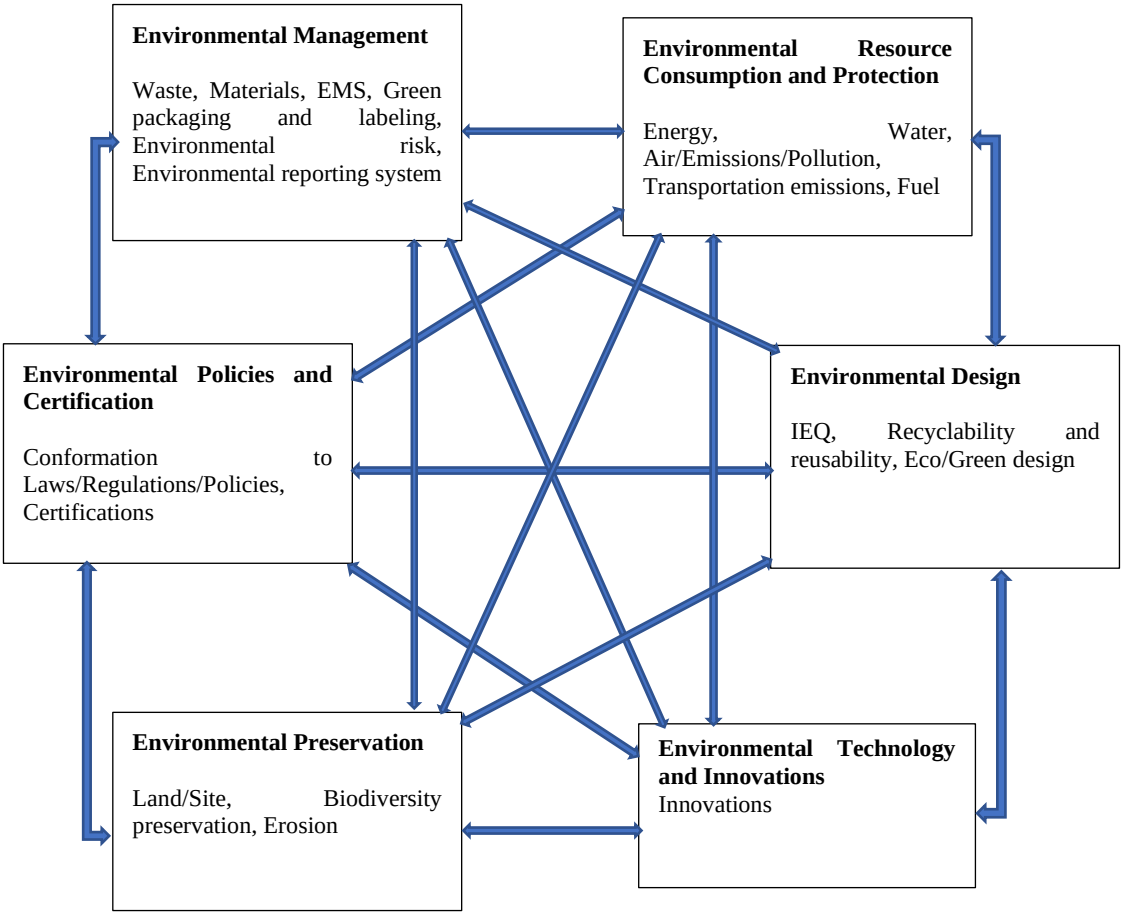


Figure 6: Interrelationship among various criteria for environmental sustainability performance evaluation

Source: Author(s) Construct, 2023

Interrelationships among the criteria are presented in Figure 6. The groups are interconnected and interrelated to achieve the ESP of building projects [45]. Environmental laws and regulations require an environmental management system to develop policies and practices in environmental design to reduce energy and other resource consumption leading to environmental preservation. This could be achieved through incorporating environmental technology and innovation. Effective environmental management integrates policies, resource consumption, design, preservation, technology, and innovations for sustainable development. The criteria for evaluating ESP of building projects are interconnected and influence one another [65]. Lowering a building's carbon footprint involves energy efficiency measures. Similarly, sustainable material choices may reduce resource depletion and waste.

Research on the relationships among ESP evaluation criteria in building projects is growing. Awuzie et al. [20] highlight the influence of management of energy, natural resources, and waste on sustainability performance. McGinley et al. [51] highlight the connection between energy efficiency, improved IEQ and occupant's health, including sick building syndrome. Eco/green designs prioritize environmental sustainability, reducing resource depletion and preventing degradation, making them increasingly desirable for reducing energy, water, and

raw material use [66]. Design plays a crucial role in selecting low-impact materials during project conception, considering materials' impact at the early stage [59]. This minimizes the impacts of extraction, processing, maintenance, and disposal of materials as well as the embodied energy [61]. Building materials production is energy-intensive, requiring various solutions to enhance environmental performance in their production. Co-processing of alternative raw materials reduces emissions, resource extraction, and improves waste management operations [57]. Energy recovered from waste is one of the sources that has been considered environmentally friendly and renewable [64]. Green building projects utilize limited natural resources like land/site, which relates with other criteria for evaluation [56]. Natural resources extraction for production of construction materials and dumping of construction and demolishing waste affects biodiversity. Regulated extraction of raw materials, recycling, and reusing of waste from building projects will minimize the negative effect on land. Environmental performance of buildings depends on design, selection of materials, location, and choice of energy source [45].

CONCLUSION

The study reviewed literature on criteria for evaluating ESP of building projects, identifying and categorizing existing criteria, examining their relationships, and analyzing current trends. It also identified "hot" themes and current research focus (status quo), highlighted knowledge gaps, and proposed future research directions. A review of 59 peer-reviewed articles identified 22 criteria for evaluating ESP in building projects. The highest identified criteria include energy, air/emissions/pollution, waste, water, and recyclability/reusability. All the criteria were categorized into six groups including 'environmental management', 'resource consumption and protection', 'design', 'policies and certification', 'preservation', and 'technology and innovations**.** The study developed a framework highlighting interconnections and relationships among the criteria groups and the identified criteria, revealing where they interact. A change in materials used may affect energy and other resource use. The framework will also aid in proposing solutions for environmental sustainability performance evaluation of buildings. A bibliometric review revealed the research trends: "hot" themes, status quo, research gaps, and future research directions in ESP evaluation criteria. The "hot" themes include 'LCA', 'sustainability in building projects', 'environmental assessment', and 'MCDM', while the status quo include 'LCA', 'AHP', 'KPIs, and BIM. China leads in publications whiles the UK leads in research collaboration on ESP evaluation criteria for building projects. Research gaps include 'performance evaluation', 'buildings', and 'KPIs' for evaluating ESP of building projects. Future research should focus on performance evaluation of building projects, criteria and indicators for evaluating ESP of building projects, and studies that reveal the impact of buildings on the environment. This study identifies appropriate criteria for evaluating ESP in building projects, providing guidance for decision-makers and helping to implement environmental strategies, enhance knowledge, and expand existing literature on evaluation criteria. It also highlights research developments and performance, highlighting areas requiring further research.

IMPLICATIONS

Grouping ESP evaluation criteria offers a holistic understanding of building project evaluation criteria, enhancing understanding and application in the industry. This will enable policymakers and practitioners to determine the performance level of their projects and guide

them to appropriately plan resource allocation. This study contributes to knowledge on ESP evaluation criteria by bringing to the fore, a percipience of ESP evaluation criteria identified in literature beyond the narrow scope of isolated criteria scattered in the literature. It also contributes to the global delivery of literature on the criteria for evaluation of ESP of building construction projects by revealing research trends, hot themes, status quo, knowledge gaps, and future research direction in the domain.

Limitations

The use of different terminologies by researchers could have resulted in some documents missing in the document search process. The VOSViewer software used for the bibliometric analysis only allowed the use of one database.

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