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Unlocking the potentials of sustainable building designs and practices: A Systematic Review

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ABSTRACT

Sustainable building designs and practices are gaining traction as a blueprint for constructing eco-friendly and economically viable buildings that can enhance the quality of life for occupants. This study presents a comprehensive analysis of the characteristics, drivers and barriers of existing sustainable building designs and practices using the Systematic Literature Review (SLR) process.

Following the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) protocol, 40 characteristics, 63 drivers, and 48 barriers of sustainable building designs and practices were identified, categorised and analysed from peer-reviewed articles (n = 130) published in the Scopus database between 2013 and 2023. Accordingly, the categorised characteristics (i.e., energy efficiency, indoor environmental quality, sustainable sites, water efficiency, economic aspects, material and resources, waste management and social equity), drivers (i.e., financial and economic, environmental protection, policy and government-related, technological, educational awareness, health and socio-cultural, and organisational and marketing) and barriers (i.e., financial and economic, policy and government-related, technological, organisational and marketing, educational and awareness, and socio-cultural) were discussed, and recommendations provided.

This study's findings will serve as a crucial benchmark for relevant stakeholders, including governments, investors, building professionals, and researchers, to foster progress in the built environment field and encourage more sustainable approaches to building design and practices.

1. Introduction

Sustainable Building Designs and Practices (SBDPs) have gained increased attention in recent years, particularly in developed nations, to provide eco-friendly and economically viable building solutions that can enhance the quality of life for occupants [1,2]. To this end, the World Green Building Council (WGBC) plays a crucial role in monitoring and promoting sustainability in the built environment worldwide [3]. The WGBC's 'Advancing Net Zero' initiative is working towards ensuring all buildings operate with zero carbon emissions [4], thus advancing the concept of Net Zero Energy Buildings (NZEBs). NZEBs are those that have been purpose-built to attain a yearly equilibrium between the energy they generate and the energy they consume, generally accomplished by employing renewable energy sources [5]. Accordingly, the United Nations' Paris Agreement mandates developed countries like the United States to reduce their Greenhouse gas (GHG) emissions by 50 % below 2005 levels by 2030, ultimately achieving net-zero emissions by 2050 [6]. This focus can help countries to generate 90 % of their electricity from renewable sources by 2025 [7].

SBDPs are typically characterised by their focus on Energy Efficiency – EE [8], Water Efficiency – WE [9], Indoor Environmental Quality – IEQ [10], renewable energy system integration [11], improved health and well-being, and productivity [12]. These SBDP characteristics are currently gaining significant attention due to the United Nations' Sustainable Development Goals (SDGs) and the recent COVID-19 pandemic's impact on Indoor Air Quality – IAQ [13]. Accordingly, achieving the WGBC's net-zero energy target requires self-sufficiency in generating renewable resources and applying energy-efficient measures [14].

Some researchers have recently explored the core requirements for EE in buildings [11,15]. Meanwhile, SDG 7 aims to promote progress in EE to ensure everyone has access to cheap, dependable, sustainable, and modern energy to accomplish global climate objectives [16]. The targets of SDG 7 include increasing the amount of renewable energy in the

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energy mix and ensuring universal access to affordable, sustainable energy services. However, the observed improvement rate in EE requirements in buildings between 2010 and 2019 was only 1.9 %, indicating that more progress is required to meet the 2030 target [16]. Besides, Adeyeye [17] revealed WE as a crucial aspect of Sustainable Building Rating Systems (SBRS) such as the New Zealand Green Star, the Japanese Comprehensive Assessment System for Built Environment Efficiency (CASBEE), the United States Leadership in Energy and Environmental Design (LEED), and the United Kingdom's Building Research Establishment Environmental Assessment Method (BREEAM). The SDG relevant to WE is Goal 6, which focuses on 'ensuring the availability and sustainable management of water and sanitation for all' [16]. Hence, the target of SDG 6 for SBDPs is to enhance water quality, manage untreated wastewater, and improve water consumption efficiency using water recycling methods [16].

While IEQ refers to the quality of thermal, air, lighting, and acoustic elements of indoor surroundings [18], it is essential for ensuring good health and well-being, sustainable cities and communities, and climate action, as per the United Nations' SDGs 3, 11, and 13 [16]. These specific SDGs aim to promote healthy living for all ages, reduce mortality from non-communicable diseases, and decrease adverse environmental impacts from air quality and waste [16]. Moreover, the recent COVID-19 pandemic has further highlighted the importance of IEQ, as it is linked to the infection rates of many viruses [13]. Although improved ventilation is the most effective way to reduce indoor air pollution and pathogens, unfortunately, 99 % of the world's urban population is exposed to polluted air, and the World Health Organisation (WHO) recommends that Particulate Matter (PM) levels should be below 5 µg per cubic meter [16].

While SDG 11 aims to create resilient, secure, and sustainable cities and communities [16], communities worldwide have been striving for SBDPs due to their positive environmental impact, given that buildings account for 40 % of total energy consumption [19,20]. Accordingly, NZEBs and their characteristics have been analysed in different regions of the world [21,22]. SBDPs have been found to provide the most practical and efficient solutions to reduce GHG emissions [23], which includes the renovation of existing buildings into NZEBs [24,25]. Hence, various definitions of sustainable buildings or NZEBs have been proposed, indicating that these buildings are energy-efficient structures that generate most of their energy from renewable sources to achieve zero carbon emissions annually during the operation phase [26]. Nowadays, buildings are transitioning towards energy-efficient structures capable of consuming, producing, and storing energy [24].

2. Previous studies

Research into sustainable versus non-sustainable buildings highlights the importance of Post-Occupancy Evaluations (POE), IEQ [27], EE [28] and WE [9]. For example, Thatcher and Milner [27] indicated that moving into sustainable buildings significantly improved the physical well-being and productivity of tenants, highlighting the importance of the IEQ characteristics of sustainable buildings. Additionally, certified buildings have been found to exhibit higher post-certification EE and have proven to be more economically viable than buildings without certification, emphasising the importance of energy-efficient measures in building design and operation [28]. However, Luo, Scofield and Qiu [9] uncovered that LEED-certified buildings consume no less water consumption than non-certified ones, indicating that there are water performance gaps for LEED-certified buildings.

The connection between SBDPs and energy conservation, including building envelopes [29], high-performance glazing [30], and insulation [31] has been established in several studies. Accordingly, practical air barriers for new commercial buildings are critical for significant energy savings, which highlights the significance of a well-designed building envelope that minimises air leaking, leading to reduced energy demand from heating and cooling [29]. Also, photovoltaic-integrated glazing with large window-to-wall ratios and solar control glazing has been found to promote lower energy consumption compared to conventional ones [30]. This is due to advanced glazing technologies that optimise natural light while minimising heat gain, reducing the requirement for artificial lighting and HVAC systems [30]. Moreover, the life cycle operating energy is minimised when the maximum quantity of insulation with the highest thermal resistance coefficient is used, hence highlighting the effectiveness of insulation on the EE of the buildings [31].

Furthermore, Hafez, Sa'di, Safa-Gamal, Taufiq-Yap, Alrifaey, Seyedmahmoudian, Stojcevski, Horan and Mekhilef [8] identified the challenges, motivations, and the best energy-efficient strategies and their influences on the overall sustainability of the buildings. The findings revealed that EE could be improved by integrating renewable energy systems into buildings, installing energy-efficient systems, and selecting optimal materials and equipment to reduce GHG emissions [8]. The study recommended utilising software for energy modelling of the buildings, along with the implementation of policies, regulations, and energy-saving methods, which can contribute to EE improvement [8]. Regarding WE, Flores and Ghisi [32] examined the benchmarks for water conservation in buildings, demonstrating the ability of benchmarking as an effective tool for improving water-saving strategies in buildings. Moreover, Afful, Ayarkwa, Acquah and Osei-Asibey [33], along with a subsequent study by Afful, Ayarkwa, Acquah, Osei-Asibey and Osei Assibey [34], explored the factors enabling and obstructing the integration of IEQ principles into building designs. These studies classified the barriers into six distinct categories: economic, process-related, cultural, client-related, capacity, and steering, while the enablers were classified into seven categories: economic, environmental, occupant and end-user, process, corporate image, culture and vision, client-related, and external [33,34]. The researchers have examined three key aspects of SBDPs: EE, WE and IEQ. However, these studies are exclusively on EE, WE, and IEQ, offering a singular perspective on the subject.

Understanding the drivers of implementing SBDPs is crucial for promoting SBDPs and contributing to a more sustainable future [35]. Accordingly, various drivers that support the acceptance of SBDPs implementation across different regions such as in Africa [36], Asia [37, 38], North America [39,40], and Oceania [1,25] have been studied. These drivers have been categorised into stakeholder, technological, policy, design and construction, and organisational aspects [41]. Hence, government incentives and support [34,42] and mandatory codes and legislation [37,43] were identified as the most prominent drivers for adopting SBDPs.

On the other hand, several barriers are hindering the implementation of SBDPs [41,44]. It is essential to acknowledge these barriers to encourage the adoption of SBDPs [45]. These obstacles have been studied across different regions of the world [46], including Asia [44, 47], Europe [48], Africa [49,50], North America [40,51], and Oceania [1,52]. For instance, inadequate knowledge and guidelines, poor design techniques, and financial restrictions are the primary barriers to SBDPs [53]. The high initial costs of sustainable buildings are also a significant barrier [44,54], see APPENDIX A, C and D for sources and detailed information.

A thorough review of the literature was conducted to pinpoint areas with limited research or contradictory results. A notable deficiency was observed in the absence of comprehensive global studies that simultaneously investigate the characteristics, drivers, and barriers of SBDPs. It was found that the majority of existing studies were region-specific, offering a fragmented view rather than a comprehensive global perspective. Uniquely, no study to date has examined the characteristics, drivers, and barriers of SBDPs simultaneously in a global context. A significant limitation observed in many studies is the lack of a comprehensive global perspective regarding barriers and drivers and a comprehensive approach to examining the characteristics of SBDPs. Many studies provide valuable insights specific to individual countries, but these findings often have limited applicability to different socio-economic contexts. For instance, regarding drivers and barriers to adopting SBDPs, Ebekozien, Aigbavboa, Thwala, Amadi, Aigbedion and Ogbaini [41] focus exclusively on the African continent, and Wu, Jiang, Cai, Wang and Li [44] only examine the restricting the generalizability of their conclusions. Similarly, for SBDP characteristics, Luo, Scofield and Qiu [9] analysed water savings in LEED-certified buildings but neglected other critical aspects such as EE and IEQ. In the same manner, Thatcher and Milner [27] concentrated solely on IEQ, while Hafez, Sa'di, Safa-Gamal, Taufiq-Yap, Alrifaey, Seyedmahmoudian, Stojcevski, Horan and Mekhilef [8] focused only on EE in sustainable buildings. This highlights the need for more comprehensive evaluations that encompass multiple characteristics of SBDPs. The critical evaluation of these limitations reveals several research gaps, including the absence of comprehensive global studies and the necessity for a holistic approach to examining the characteristics, barriers, and drivers of SBDPs.

This oversight is significant given the urgency of achieving the SDGs in less than ten years. Therefore, adopting SBDPs is an expedited way to achieve SDGs as the construction industry plays an essential role in achieving the goals by reducing energy consumption, water consumption, and GHG emissions, as well as improving IEQ. Recognising the various characteristics, drivers, and barriers to their adoption can encourage its widespread adoption towards building a more sustainable future. This study, therefore, aims to provide insights into existing SBDPs within the built environment using the SLR technique. Accordingly, three questions will be followed.

RQ1: What are the characteristics of existing SBDPs?
RQ2: How do the drivers and barriers of adopting SBDPs influence stakeholders' perceptions?
RQ3: What recommendations can be provided to relevant stakeholders in SBDPs to promote sustainable building designs and operations?

The results of this research will act as a significant point of reference for relevant stakeholders, such as governments, investors, building experts, and scholars, to advance the field of built environment and promote more sustainable methods of building design and operations.

3. Material and methods

This study employed a mixed-methods approach to fulfil the research objectives by combining the Systematic Literature Review (SLR) and meta-analysis techniques to explore the characteristics of SBDPs as well as the factors that facilitate or hinder their adoption. SLR provides a structured and replicable framework for identifying, selecting, and evaluating relevant research literature and factors. The SLR technique also ensures that the literature review is systematic, transparent, and replicable, covering a wide range of studies to gather a broad understanding of the topic [55,56]. Meta-analysis is a statistical technique that, in conjunction, synthesises quantitative data from multiple studies to identify patterns and reduce research biases [55]. Employing statistical methods to consolidate effect sizes from studies of similar scope

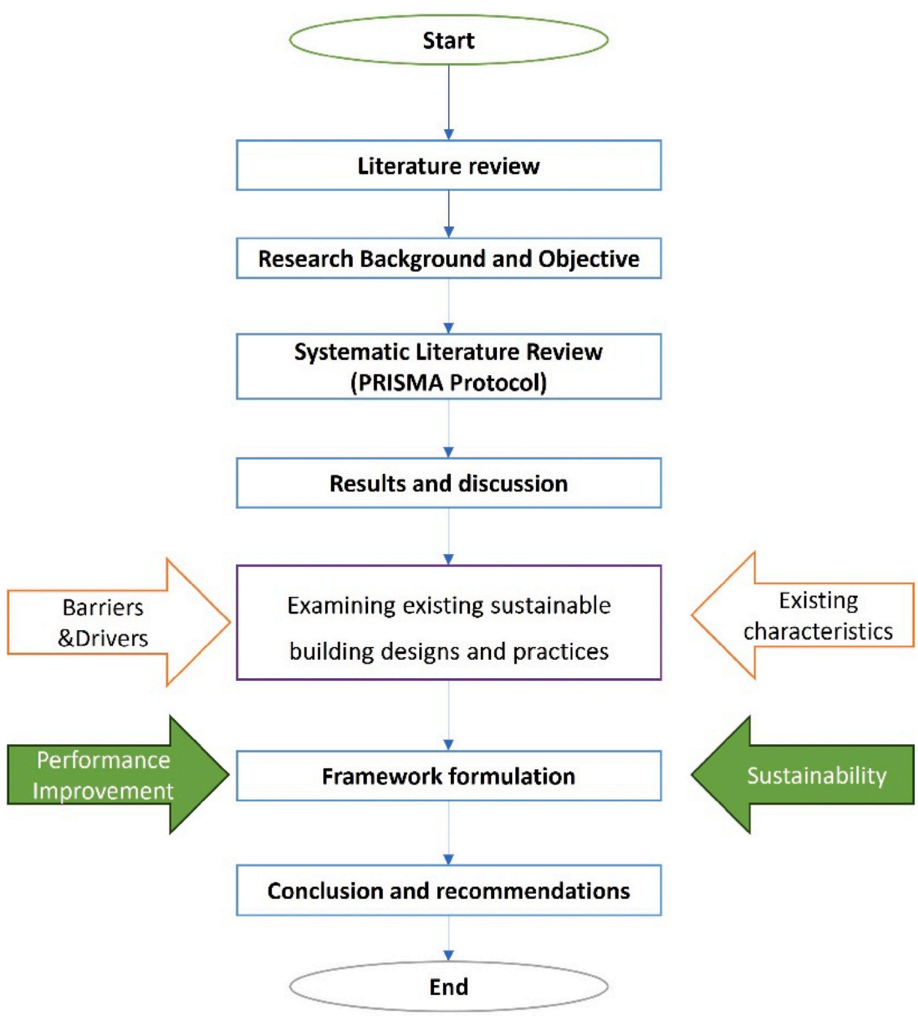

Fig. 1. Schematic flow chart of the study process.

provides a detailed examination of prevailing patterns, thus enriching the research topic's understanding [56]. Consequently, meta-analysis was chosen as the preferred data analysis method for this study, aiming to examine current trends and insights into SBDPs (see Fig. 1).

3.1. SLR using the PRISMA protocol

This study's SLR followed the PRISMA 2020 protocol [57] to analyse SBDP characteristics and adoption factors. The initial phase involves collecting all available studies related to the research questions and evaluating all possible studies' results on a given topic and design [55], which is followed by the screening and elimination process, beginning with the title and abstract screening of each identified paper to prevent the retrieval of irrelevant documents [57]. Eliminating duplicates is crucial since the meta-analysis results would be impacted if duplicate samples were present [58]. After refining the collection of the studies through the exclusion of duplicates and irrelevant papers, a full-text assessment of the remaining studies is conducted to ensure their eligibility for inclusion in the review [55]. Finally, the final selection of studies, having undergone a comprehensive evaluation process, is then subjected to meta-analysis, allowing the synthesis of data extracted from the included papers and the derivation of comprehensive results and insights [55].

3.2. Data search process and strategy

The data search process comprises four significant steps (see Fig. 2), including (i) Paper identification, (ii) Paper screening and elimination, (iii) Eligibility check and quality appraisal, and (iv) paper included in the study.

3.3. Paper identification

This study initiated an automated literature search in August 2023, utilising the Scopus database [59] to search for relevant articles [57]. The Scopus database was selected over Google Scholar due to its superior clarity, reliability, and transdisciplinary coverage, alongside its comprehensive geographic coverage [60,61]. This preference is further justified by Scopus's notable indexing capabilities in construction management publications despite the extensive content available on

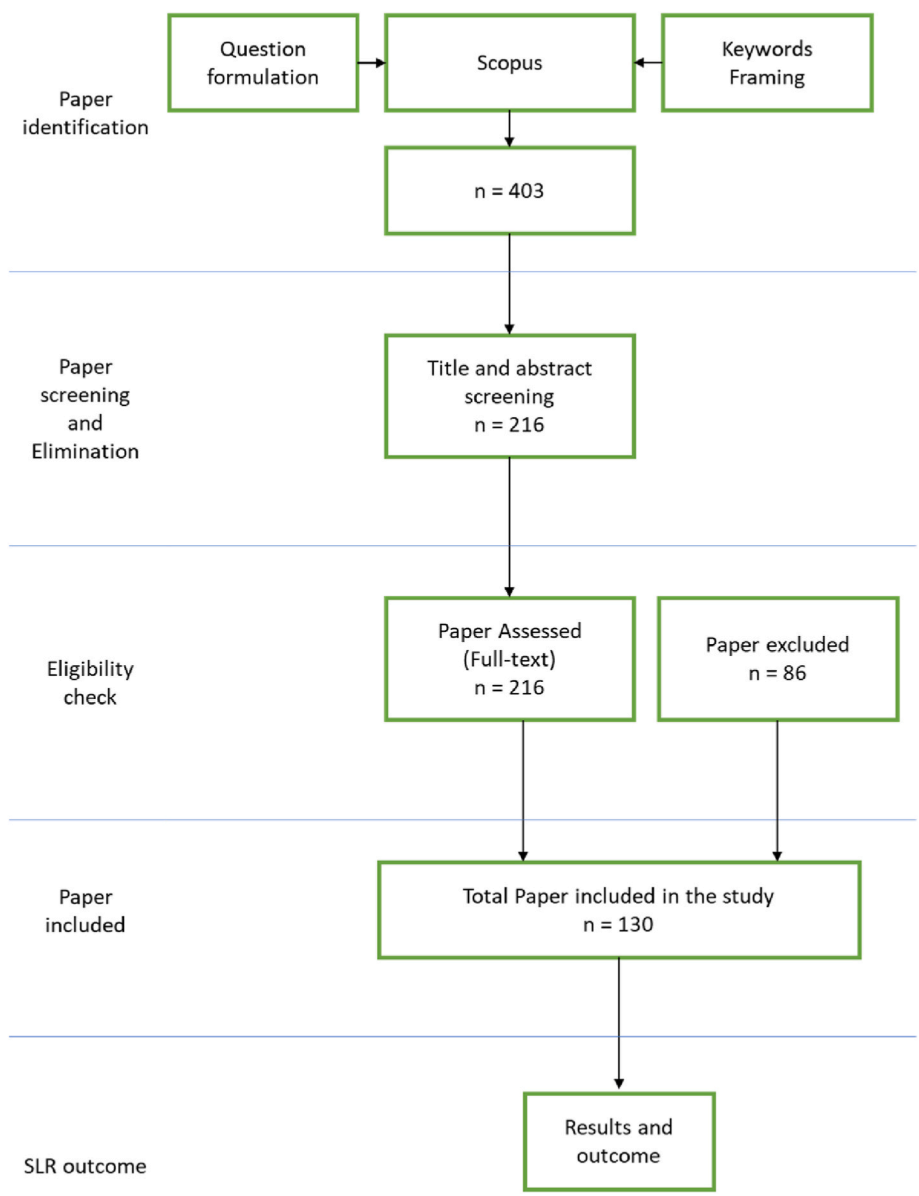

Fig. 2. PRISMA Protocol Guidelines in the systematic literature review process.

Google Scholar [62]; this study analysed bibliographic data collected from Scopus rather than those from other databases, such as the Web of Science and Google Scholar. In addition, the rationale behind this is that compared to the other databases, Scopus has a wider range of scientific publication coverage compared to Google Scholar [23]. Also, Scopus has a relatively faster indexing process, increasing the likelihood of retrieving more recent publications [63].

Accordingly, keywords were selected by the researchers based on an unsystematic search regarding the characteristics of sustainable buildings and their measurement or evaluation, such as EE, WE, and IEQ [64]. To provide an answer to the first and the second research objectives, the representative words used as inputs to search engines were "Green building", "Sustainable building", "Energy Efficiency", "Water Efficiency", "Indoor Environmental Quality", "Characteristics", "Features", "Barriers", "Motivations" "Obstacles" "Stakeholders" and "Clients." The search string used was (TITLE-ABS-KEY ("Sustainable Building design" OR "Green Building") AND TITLE-ABS-KEY ("Barriers" OR "Obstacles" OR "Motivations" OR "Incentives" OR "Drivers") AND TITLE-ABS-KEY ("Stakeholders" OR "Clients"))) OR ((TITLE-ABS-KEY ("Green Building" OR "Sustainable Building") AND TITLE-ABS-KEY ("Measurement" OR "Assessment" OR "Rating" OR "Evaluation") AND TITLE-ABS-KEY ("Energy Efficiency" OR "Water Efficiency" OR "Indoor Environmental Quality") AND TITLE-ABS-KEY ("Characteristics" OR "Features"))). After the retrieval of articles, the researchers verified the relevance of search algorithms by examining sample search results to ensure comprehensive coverage of relevant literature.

3.4. Paper screening and elimination

The Scopus search engine initially retrieved 403 academic publications. The titles and abstracts of these articles were screened to eliminate irrelevant documents. The identified papers were subsequently screened to eliminate irrelevant articles that did not correspond with the study's topic and objectives. The researchers carefully reviewed the titles and abstracts of the articles to remove any irrelevant documents, making sure that the papers matched the study's topic and objectives. This step was essential to avoid retrieving irrelevant documents. After this screening process, the number of documents was reduced to 216 academic papers.

3.5. Eligibility check and quality assessment

The 216 screened academic papers were further subjected to a detailed full-text assessment by researchers to ensure their eligibility for inclusion in the review. This evaluation led to the exclusion of 86 papers, ensuring the final review included only the most pertinent and high-quality studies. The inclusion criteria for this study targeted articles that contribute significantly to understanding SBDPs, favouring English-language, peer-reviewed works for their global reach and research credibility [58,65,66]. Additionally, articles published between 2013 and 2023 were selected to align with sustainability research norms, allowing for the study of emerging trends and developments in sustainability [67,68]. Moreover, the exclusions included grey literature and non-peer-reviewed materials to maintain rigour [41].

3.6. Papers included in the study

The final selection of 130 high-quality, peer-reviewed academic papers involved comprehensive evaluation and meta-analysis by researchers. This allowed for the synthesis of data extracted from the included papers and the derivation of comprehensive results and insights (see Fig. 2). These papers specifically addressed the characteristics of SBDPs, the drivers for implementing SBDPs, and the barriers that hinder their adoption. Details of the retrieved papers were systematically inputted into a Microsoft Excel spreadsheet to facilitate the meta-analysis, allowing for a more organised and efficient review of the literature applicable to the study's objectives.

4. Results and discussion

The analysis of carefully chosen publications offers valuable insights into SBDPs, with a particular focus on the leading countries in this field and the trends observed over time. Throughout this section, three critical aspects of SBDPs are presented, including the countries that contribute to studies, the annual publication trend that highlights the increasing interest and focus within the research community, and the research methods utilised. In the following sections, the characteristics of existing SBDPs, along with the drivers and barriers that influence their adoption and implementation, are also presented and discussed. Accordingly, these findings will deepen the current understanding of SBDPs, revealing how they are conceptualised, applied, and evolved over time for the benefit of all.

4.1. Meta-analysis of selected publication

4.1.1. Countries of origin of published studies on sustainable building design

The reviewed papers were categorised based on the study area, focusing on the research countries involved. Out of 48 countries represented, China and the United States of America (USA) had the highest number of papers (20 and 14 papers, respectively) among the countries contributing to research on sustainable building characteristics, barriers, and drivers. This indicates a significant focus on these nations within the dataset. Other notable contributors, with four to nine studies each, include Ghana, Australia, South Africa, Malaysia, Singapore, the United Kingdom, Hong Kong, and India. However, despite the studies conducted in various regions worldwide, many were limited to specific geographic contexts rather than providing a comprehensive global perspective, which can be observed from the countries with only a single study each (see Fig. 3). While studies in specific regions provide valuable insights into the dynamics of SBDPs within specific contexts, there remains a need for more comprehensive and globally representative research to gain a better and more comprehensive understanding of SBDPs and their implications.

4.1.2. Annual publication trend

The analysis reveals an upward trajectory in the volume of publications focused on the characteristics, drivers, and barriers related to SBDPs spanning the years 2013–2023 (see Fig. 4). Notably, the peak publication years of 2017 and 2022 accounted for 16 publications, signalling an increasing interest in and recognition of SBDPs within the academic and professional communities. Additionally, the lack of papers addressing these topics between 2013 and 2016 indicates that the topic is relatively new and has gained significant attention in recent years. This pattern indicates the increasing urgency and significance of integrating SBDPs into the construction sector (see Fig. 5).

4.1.3. Research methods of identified studies

The identified methodologies range from quantitative and qualitative approaches to mixed-methods and other specialised techniques. Among these, the mixed-methods approach emerges as the most common, constituting 49 % of the studies. The mixed methods often combine case studies [22,69] with quantitative and qualitative methods [70,71], indicating a comprehensive strategy for investigating SBDPs. Significantly, the combination of literature reviews, questionnaires, and interviews is highlighted as the most common methodological approach utilised in 49 % of the selected studies, indicating a strong preference for these methods. The category labelled "others" encompasses a variety of specialised research methods, including energy modelling and simulation [30], evolutionary game theory [72], life cycle failure mode effect and analysis [51], and analytical hierarchy process [73].

The methods identified in the study demonstrate the interdisciplinary nature of SBDP research, utilising sophisticated analytical tools

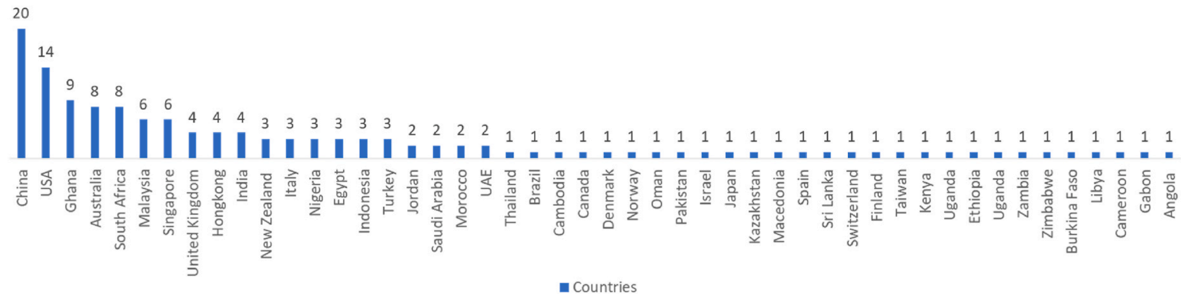

Fig. 3. Distribution of countries included in the study.

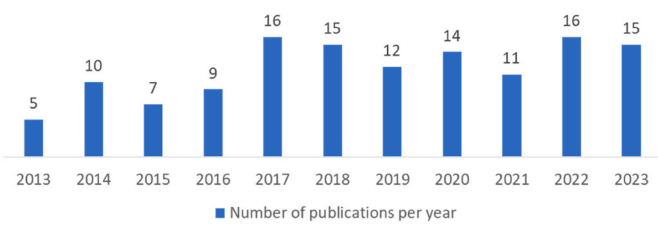

Fig. 4. Distribution of annual publications trend.

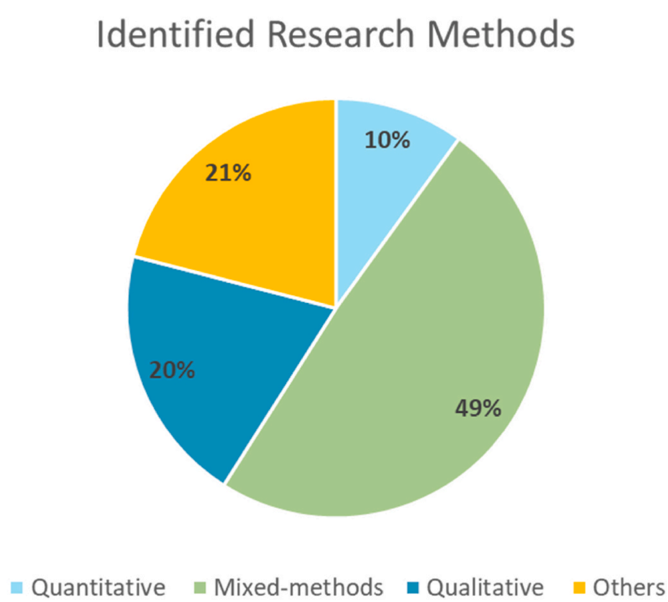

Fig. 5. Research methodologies utilised in the selected studies.

to evaluate sustainability in building designs. Additionally, the frequency of reported characteristics, drivers, and barriers in the literature serves as a basis for ranking these elements based on their importance across the literature. This quantification not only emphasises the crucial components of SBDPs but also provides insights into the evolving priorities and challenges within the field of SBDPs.

4.2. Characteristics of existing SBDPs

Forty (40) distinct characteristics were grouped under eight main themes, including EE, WE, IEQ, Sustainable Sites (SS), Economic Characteristics (EC), Materials and Resources (MR), and Social Equity (SE), highlighting the multidimensional nature of SBDPs and diverse aspects that contribute to SBDPs. The characteristics were referenced 1460 times throughout the literature, with EE accounting for 41 % of mentions, highlighting the importance of energy conservation and EE in the building sector. Codes were used to systematically categorise and illustrate the frequency and proportion of each characteristic (see Appendix A and B for sources). The analysis quantifies the prevalence of each characteristic and contextualises their significance, providing a detailed exploration of how these elements are integrated and applied in SBDPs, enhancing the overall comprehension of SBDPs (see Fig. 6). The subsequent sections provide a detailed explanation of each characteristic, providing a more comprehensive understanding of how these elements are integrated and applied within SBDPs.

4.2.1. Energy efficiency (EE)

Sixteen (16) key characteristics were found to influence EE in sustainable buildings. The top five critical characteristics include “renewable energy generation (52 %)”, “energy-efficient equipment (48 %)”, “higher EE compared to conventional buildings (45 %)”, “window design and glazing, and thermal insulation through materials and design (42 %)”. Other essential factors include “building facade and shading design (25 %)”, “demand response control (2 %)”, “occupancy and daylight sensor (15 %)”, “building envelope design (34 %)”, “passive design (39 %)”, “natural and mechanical ventilation (41 %)”, and “energy performance and monitoring (22 %)”, see Fig. 6. Particularly, *EE1* has the highest proportion, underscoring its crucial role in integrating sustainable energy solutions in buildings. This finding is supported by Refs. [8,47], highlighting the potential for improved EE through *EE1*.

However, challenges such as the high initial costs of photovoltaics, noise from wind turbines, and the impact of urban structures on wind turbine efficiency pose obstacles to implementation [74,75]. Despite the challenges, 45 % of the studies affirm that *EE3* provides a significant boost in EE through SBDPs. This finding is supported by several studies [8,76], since improving the EE of new and existing structures is an expedited method of mitigating the adverse consequences associated with the construction industries [70,77]. However, Mustaffa, Mat Isa and Che Ibrahim [78] argued that sustainable buildings have comparable performance to conventional ones. Additionally, implementing *EE2*, such as LED lighting [78] and Heating, Ventilation, and Air Conditioning systems – HVAC [69] in building designs is essential for increasing overall EE, which is supported by Simpeh, Pillay, Ndihokubwayo and Nalumu [79]. Furthermore, *EE4* including window-to-wall ratio [80] and low emissivity window glazing [8], are effective strategies leading to reduced cooling and heating loads [81], together with the design and calculation of internal heat loads [82] also play an important role in achieving optimal EE [31].

Integrating *EE1* into buildings, such as photovoltaic panel installation, is the most common strategy to enhance EE in sustainable buildings [83,84], followed by wind and geothermal power [77,82], which is supported by Refs. [67,78] as a method to reduce energy use and limit GHG emissions, thereby protecting the ecosystem. *EE1* in SBDPs reduce environmental impact, grid dependence, and life cycle costs [85,86]. SBDPs frequently prioritise EE using *EE1*, *EE2*, and EE5, consistent with [8,22]. The overall implications of EE characteristics include energy saving, occupant comfort, and reduced environmental impacts [79]. In summary, integrating *EE1*, *EE2,* and *EE5* within SBDPs is crucial for

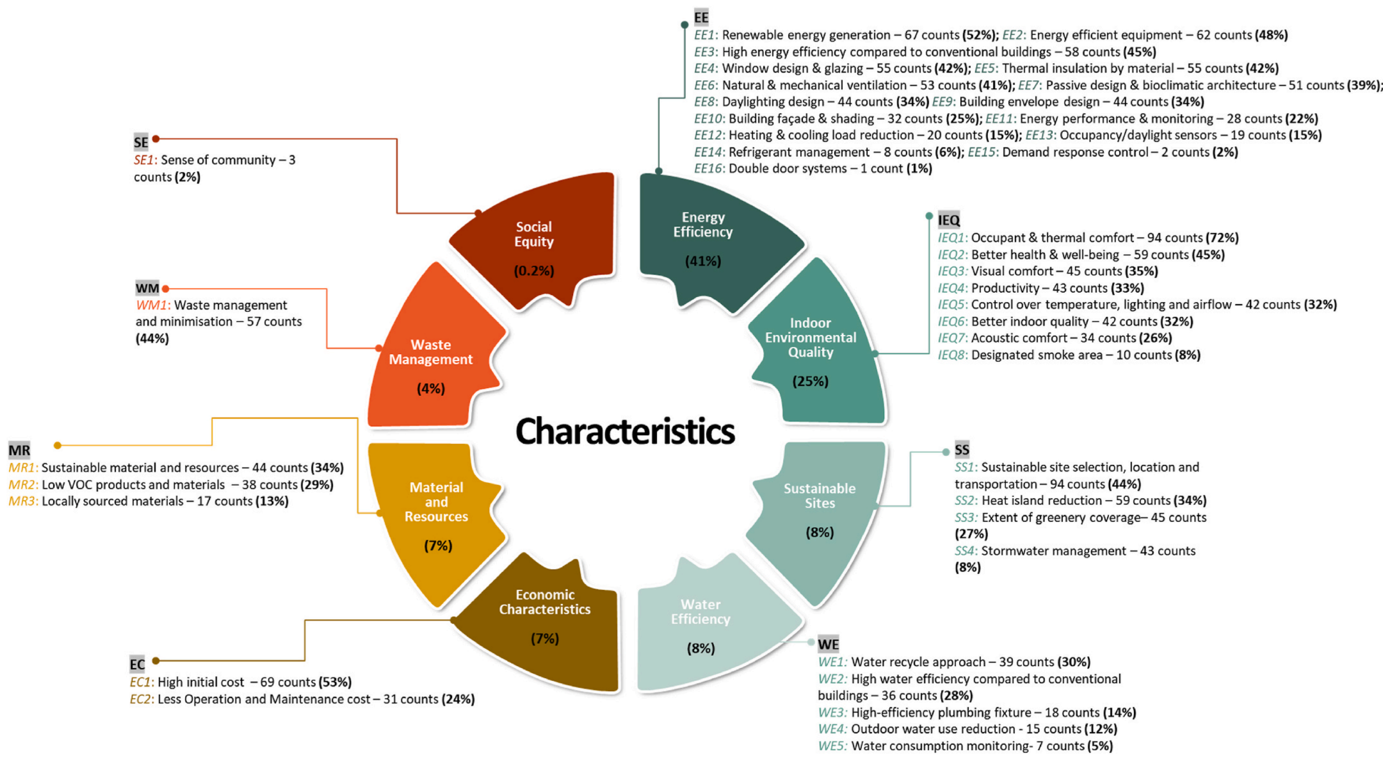

Fig. 6. Characteristics of existing sustainable building design and practices.

addressing environmental challenges while also providing economic, societal, and technological benefits.

4.2.2. Water efficiency (WE)

Five (5) characteristics were identified under this category. The top three critical characteristics are "water recycling (30 %)", "higher WE of sustainable buildings (28 %)", and "the installation of water-efficient fixtures and appliances (14 %)". In addition to these, "monitoring water consumption (5 %)" and "implementing outdoor water use reduction strategies (12 %)" are also crucial in improving the overall WE of buildings, see Fig. 6. *WE1* and *WE2* are ranked as the most prominent characteristics, which are supported by Refs. [87,88] because sustainability criteria frequently incorporate water management and efficiency. So, incorporating sustainability criteria into SBRS can significantly enhance a building's WE, which encompasses several aspects of water usage. Several studies claimed that the WE of sustainable buildings is typically higher than that of conventional buildings ***(WE3)***, including those conducted by Refs. [41,54]. However, Luo, Scofield and Qiu [9] argued that a water performance gap exists for LEED buildings since they contend that LEED-certified structures do not consume any less water than non-LEED buildings in some circumstances. To address this issue, wastewater treatment systems and rainwater harvesting have proven to be highly effective water recycling strategies [77,89]. In addition, installing low-flow faucets, showerheads, and toilets is a critical measure for conserving water within sustainable buildings [22,90]. These interventions collectively contribute to significant water conservation, economic savings, and reduced energy consumption associated with water heating and treatment, demonstrating the comprehensive benefits of integrating WE features into SBDPs [91].

4.2.3. Indoor environmental quality (IEQ)

In this category, eight (8) distinct characteristics were recognised, out of which the top four include "occupant and thermal comfort (72 %)", "improved health and well-being (45 %)", "visual comfort (35 %)", and "productivity (33 %)". The remaining characteristics are control over temperature, lighting, airflow [92], better IAQ [93], acoustic comfort [78], and designated smoke areas [94], where control over temperature, lighting, airflow and better IAQ have an equal proportion of 32 % (see Fig. 6).

IEQ1 emerges as the most significant characteristic for raising occupant satisfaction and comfort levels in the indoor environment [95,96]. Similarly, *IEQ3* plays a crucial role in enhancing occupant satisfaction, productivity, and overall well-being, significantly impacting overall IEQ dynamics [97]. Improvements in IEQ have been linked to a decrease in symptoms related to sick-building syndrome, highlighting its positive effects on health and well-being [2]. In addition, this finding is supported by research from Refs. [27,98], which demonstrated that superior IEQ can improve tenant productivity and satisfaction. Additionally, the introduction of features such as dimmable lighting and operable windows, as highlighted in *IEQ5*, contributes to occupant comfort and promotes energy conservation efforts in buildings [97], as mentioned by Candido, Marzban, Haddad, Mackey and Loder [99] as a critical factor for occupant satisfaction.

The implications of emphasising IEQ in sustainable buildings include health and well-being, productivity, and comfort [100]. Strategies for improving IEQ include increasing ventilation and reducing VOCs [92] and improving visual comfort by using natural light, installing appropriate artificial lighting, providing task-specific lighting, and installing glare controls [94]. Moreover, acoustic comfort is vital for maximising productivity and performance in various environments, such as businesses [101], schools [102], and healthcare facilities [103], employees are more focused on their work if they are not frequently interrupted by noise. This comprehensive view of IEQ within sustainable buildings represents its pivotal role in promoting environments that support occupant health, comfort, and productivity. By addressing a broad spectrum of IEQ characteristics, relevant stakeholders can improve tenants' overall quality of life and enhance the relationship between SBDPs and occupant well-being.

4.2.4. Waste management (WM)

From Figs. 6 and 44 % of the studies surveyed emphasise the significance of waste minimisation and management in sustainable building and development. This is supported by the recommendations of [22,82,104], advocating for the adoption of recycling and construction waste reduction strategies to promote resource conservation, cost efficiency, energy savings, and environmental impact reduction. Incorporating these practices into building projects can enhance the overall sustainability profile of building projects as well as reduce the negative environmental impacts of construction activities [105]. The comprehensive benefits of *WM1* encompass resource conservation, cost reduction, energy savings, and environmental impact mitigation. This comprehensive approach to WM in SBDPs not only emphasises the integral role of efficient waste practices in sustainability efforts but also showcases the several advantages, from economic to environmental, that these practices bring to the construction and operation of buildings [106], underscoring the importance of integrating WM and minimisation principles in the criteria for SBRS. Therefore, by prioritising WM within SBRS, the construction industry can transition towards resilient, efficient, and environmentally friendly building practices that align with global sustainability goals.

4.2.5. Sustainable sites (SS)

Four (4) key characteristics were identified under this category, including SS selection, “location and transportation (38 %)”, “greenery coverage extent (21 %)”, “heat island effect reduction (26 %)”, and “stormwater management (6 %)”, see Fig. 6. The prioritisation of SS selection is emphasised as the most crucial element, supported by several studies that highlight the significance of access to public transportation and the preservation of sensitive ecological land features in site selection decisions [42,73].

The efforts to minimise car usage through improved public transportation access and services further demonstrate the holistic approach to sustainable site development [107]. This strategy, along with green roofs and the creation of open green spaces, addresses *SS2* and *SS4* objectives and contributes significantly to EE and WE, as demonstrated by Refs. [108,109]. *SS2* is essential for reducing cooling energy demands, enhancing tenant health, and minimising environmental impacts, as noted by Wang, Wang, Kaloush and Shacat [109]. However, some researchers, such as [110,111], pointed out situations where strategies aimed at reducing heat through *SS2* may be ineffective. Conversely, enhancing thermal performance through *SS3* is affirmed by Aboelata and Sodoudi [112]. It is crucial to note that SS4 plays a vital role in development and mitigating impacts, especially in decreasing erosion and flooding, which has been highlighted by Refs. [113,114], as a method for reducing the impact of heavy rainfall due to climate change using nature-based solutions.

In essence, integrating SS characteristics into SBDPs offers a comprehensive approach to enhancing the sustainability of building projects. By prioritising site selection, greenery coverage, heat island effect mitigation, and stormwater management, stakeholders can ensure that buildings contribute positively to their environmental, social, and economic contexts. These SS characteristics, through their impacts on EE and WE, underscore the importance of careful consideration of the planning and design of sustainable buildings.

4.2.6. Material and resources (MR)

Within this category, three (3) characteristics were identified: “sustainable MR (34 %)”, “low VOC products and materials (29 %)”, and “locally sourced materials (13 %)”, see Fig. 6. Among these, the employment of *MR1* is highlighted as the most crucial characteristic, aligning with the findings of Rodriguez-Nikl, Kelley, Xiao, Hammer and Tilt [39], emphasising the pivotal role of material use in building sustainability. Furthermore, *MR2* is the second most critical characteristic, reinforced by multiple studies for its importance in improving the IEQ and its crucial aspect for the SBRS [94,115]. It is because the utilisation of low-VOC products is crucial because they are the main pollutants in the indoor environment [116]. Also, it was suggested by Omer and Noguchi [117] that *MR3* is also essential because it helps reduce the carbon footprint from transportation and is minimally processed.

The strategies associated with MR contribute to resource conservation, improve IEQ, and reduce carbon emissions [39]. Notable *MR1* strategies encompass utilising certified products [54], renewable materials [90] and recycled materials [50]. Collectively, these initiatives contribute to reducing embodied energy, carbon footprint, and energy required for transportation [118]. Additionally, they play a crucial role in elevating IEQ [119], further justifying the emphasis on sustainable material selection within SBDPs. By prioritising these material choices, SBDPs contribute to a future characterised by enhanced sustainability and resource efficiency, underlining the essential value of integrating these characteristics into the core of SBDPs.

4.2.7. Economic Characteristics (EC)

Two (2) distinct characteristics were identified under this category: “high initial costs” and “lower Operation and Maintenance costs (O&M)”, see Fig. 6. A significant body of research, with 53 % of studies reviewed, indicates that sustainable buildings incur higher initial costs compared to conventional buildings, a finding supported by Refs. [88,120], which suggested that sustainable building initial costs are approximately 10–20 % higher than the conventional ones. The elevation in initial costs, or *EC1,* can be attributed to several factors, including upfront costs [42,121], costs from new green technologies and materials [22,70] and the green certification process [40,122], and higher design costs [33]. Despite *EC1*, sustainable buildings offer compensatory lower O&M, referred to as *EC2*, which accounts for 31 % of the selected studies. Reduced O&M cost is primarily due to their water and energy-saving features [22,47], consistent with [8,123].

These findings underscore the importance of viewing the higher initial costs of sustainable buildings not merely as expenses but as investments that yield long-term savings and environmental benefits. Stakeholders are encouraged to weigh these upfront costs against the potential for significant reductions in operational expenses, promoting a balance between additional expenditure and long-term financial and environmental gains. By prioritising SBDPs and adopting cost-effective measures, the financial viability and sustainability of sustainable buildings can be enhanced, contributing positively to both economic outcomes and environmental conservation.

4.2.8. Social equity (SE)

Among the evaluated characteristics, a singular focus emerges on fostering “a sense of community (2 %)”, a critical aspect particularly in densely populated urban settings (see Fig. 6). In such environments, social inequalities can pose significant challenges to social sustainability because SE necessitates an equitable distribution of public resources, benefits, and opportunities [124]. Also, sustainable buildings have the potential to strongly support place attachment [125]. The perspective aligns with Mustaffa, Mat Isa and Che Ibrahim [78], who similarly emphasise that an *SE1* is essential to sustainable buildings and cities, as well as Li, Li, Jia, Yan, Wang and Liu [126], who claimed that a sense of community is the most important factor for residents’ satisfaction. Strategies to enhance SE, such as urban agriculture and community gardens [126], can foster a sense of community inclusion and connectedness [127]. By prioritising SE within SBDPs, stakeholders can create communities that consider all individuals’ well-being and equitable treatment, thereby contributing to the goals of SDGs [16].

4.3. Drivers to adopting SBDPs

The meta-analysis highlights three (3) primary factors: “reduced O&M costs (53 %)”, “providing education on sustainable buildings to stakeholders (47 %)”, and “government legislation and incentives (46 %)”. This ranking of factors offers valuable direction for policymakers, stakeholders, and advocates in prioritising strategies to encourage SBDPs. The analysis further organised these factors into seven categories: financial and economic, environmental protection, policy and government-related, technological, educational and awareness, health and socio-cultural, and organisational and marketing. 63 factors were coded and categorised; see Fig. 7, which provides a detailed look at their representation and frequency within the literature. For detailed sources, refer to Appendix A and C. This methodical approach highlights the complex and varied drivers of SBDP adoption and their interconnectivity, presenting a strategic framework for effectively promoting SBDPs.

4.3.1. Financial and economics

Under this category, 17 factors were identified. The three most significant factors were: "a reduction in O&M costs (53 %)", "government legislation and incentives (46 %)", and "higher Return On Investments (ROI) and a short payback period (35 %)". The remaining factors include further market-based incentives and funding from private organisations [35], reducing liability and risks [128,129], an increase in demand for sustainable construction [1,130], an improved method of estimating costs [50], reducing depreciation in rent and price [128], avoiding legal costs due to opposition [131], higher rental income and occupancy rate [43], increase property value [132], lower project capital cost [133], lower total ownership cost [131], local competition [134], reduction in life cycle cost [78], reduction in incremental cost [135], and overseas competition and influence [136], see Fig. 7.

D1 is the most influential factor, with studies by Refs. [47,133] pointing to energy and water savings as critical factors. These features enhance ROI and are also a primary reason for investing in sustainable buildings [128,137]. *D2* is the second most significant factor, representing the impact of policy and financial incentives, which is supported by Darko and Chan [138] as one of Ghana's top strategies to promote sustainable building adoption through various means such as tax incentives, cash incentives, fee reductions, grants, loan funding [139] and relevant government policies [140]. *D3* is the third critical factor as it motivates stakeholders to participate in SBDPs since project owners can recover all investments within a shorter time frame, corresponding with Agyekum, Goodier and Oppon [132] as a critical factor for sustainable building project financing in Ghana and other parts of the African continent [41]. In contrast, Akomea-Frimpong, Kukah, Jin, Osei-Kyei and Pariafsai [141] claimed that favourable ROI was the most significant factor due to reduced O&M costs. This analysis underlines the importance of recognising the different perceived importance of these factors across different contexts and studies, illustrating the multi-layered nature of economic and financial factors in promoting the adoption of SBDPs.

4.3.2. Environmental protection

Within this category, four (4) factors were identified, with "reducing the environmental impacts of the building (21 %)" and "conserving natural resources (10 %)" as the most significant factors. The remaining factors include increased carbon neutrality, reduced carbon offset cost [25], and waste reduction and minimisation [35], each having an identical proportion of 5 %, see Fig. 7. *D18* emerges as the most significant factor, representing stakeholders' commitment to reducing the building's environmental effects using SBDPs, supported by findings from Bertone, Stewart, Sahin, Alam, Zou, Buntine and Marshall [25]. In contrast, Masia, Kajimo-Shakantu and Opawole [92] present a contrasting view, indicating that SBDPs have had minimal impact on mitigating climate change effects, thus showcasing the different perspectives within the field.

D19 is the second most significant in adopting sustainable construction, aligning with Al Harazi, Zhang, Shah, Al Asbahi, Al Harazi and Alwan [142] as a major factor in the United States, as construction activities consume many resources [143]. Adopting sustainable and highly recycled materials as a countermeasure to environmental degradation demonstrates the sector's transition towards more sustainable practices [78]. Furthermore, *D20* highlights the importance of reducing carbon emissions, mentioning that sustainable buildings emit less carbon than conventional constructions, supported by Refs. [144,145] as an approach to achieving carbon neutrality. In addition to promoting environmental protection, *D21* also contributes to a comprehensive environmental sustainability framework. For instance, the selection of

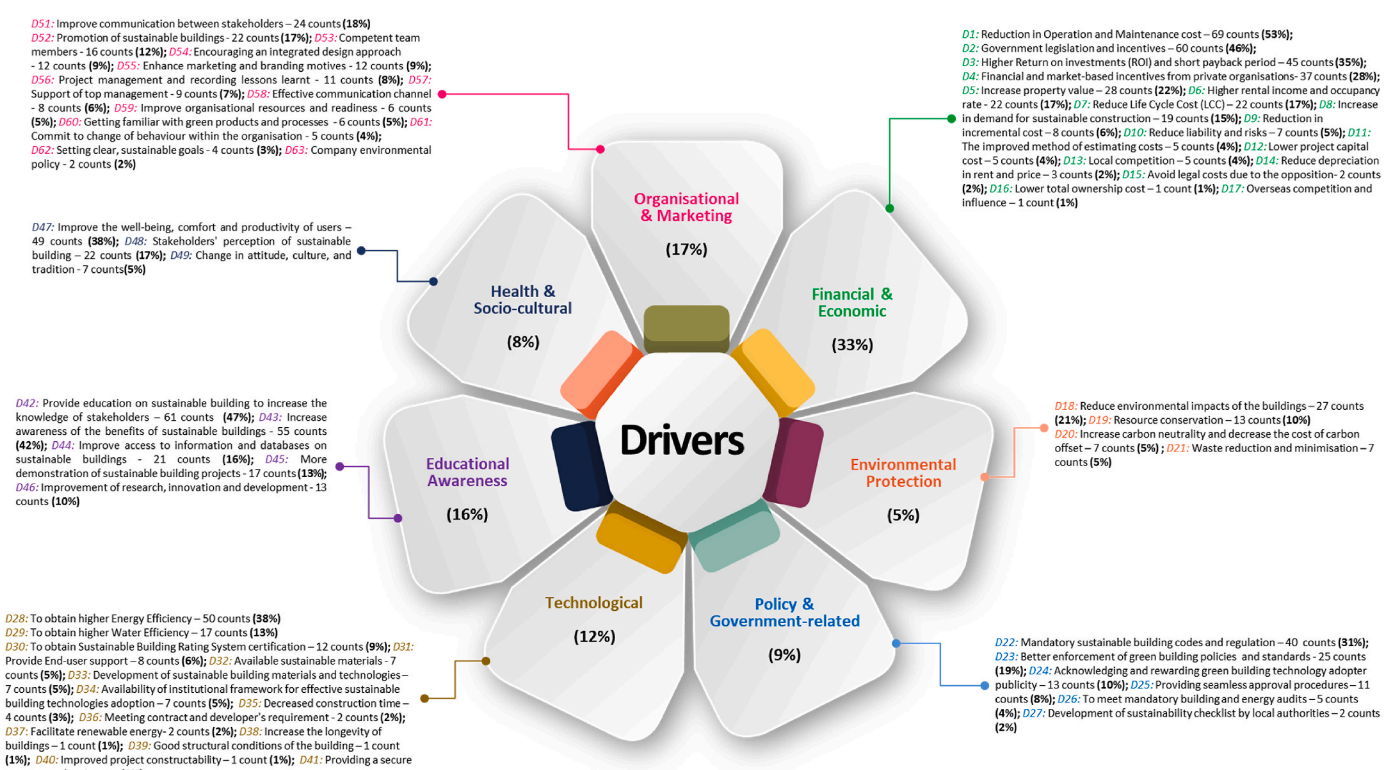

Fig. 7. Drivers to adoption of sustainable building design and practices.

sustainable construction materials significantly impacts SBDPs [146]. Therefore, employing strategies like utilising durable, natural, and locally sourced materials while minimising waste is critical in reducing the environmental impact of buildings [147].

The emphasis on these environmental protection factors underscores the pivotal role of sustainability considerations in redefining construction practices. It highlights the integral connection between adopting SBDPs and their effects on reducing construction's environmental impact, advocating for a continued focus on sustainability within the sector [35]. The identified factors represent a significant shift towards more sustainable practices in the construction industry, illustrating the sector's role in promoting sustainability and mitigating climate change. While the construction industry significantly impacts the environment, SBDPs aim to mitigate this impact by incorporating sustainable practices and materials. Overall, these factors indicate a meaningful transition towards sustainability, demonstrating the construction industry's commitment to reducing its environmental footprint and addressing the challenges of climate change.

4.3.3. Policy and government-related

Six (6) key policy factors were identified under this category, including "meeting mandatory sustainable building codes and regulations (31 %)", "better enforcing green building policies (19 %)", "acknowledging and rewarding green building technology adopters' publicity (10 %)", leading the charge. The remaining factors include providing seamless approval procedures [137], meeting mandatory building and energy audits [25], and developing a sustainability checklist by local authorities [133]; see Fig. 7.

D22, emphasising the importance of adhering to mandatory sustainable building codes and regulations, emerges as the most significant factor under this category, resonating with findings from Refs. [148, 149] in Pakistan and China. Additionally, Darko, Chan, Yang, Shan, He and Gou [150] suggested that if the government imposed mandatory green construction policies and regulations, stakeholders would be obliged to use SBDPs to avoid fines and penalties, increasing the adoption of SBDPs [43]. Also, the second most reported factor is *D23*. This is corroborated by Darko and Chan [138] and involves the enforcement of existing standards, including robust government interventions [42], as well as the rigorous implementation of various government award and penalty mechanisms [72]. Furthermore, *D24*, which focuses on acknowledging and incentivising green technology adoption, is identified as a pivotal strategy to motivate stakeholders towards SBDPs [108, 151]. The importance of policy and government-related factors represents the significant responsibility of governmental involvement in driving the construction industry towards sustainable practices. By instituting and enforcing regulations and policies that promote SBDPs, governments can significantly influence the construction sector's transition to sustainability.

4.3.4. Technological

Within this category, 14 factors were identified, with "increasing the building's EE (38 %) and WE (13 %)" and "obtaining a SBRS (9 %)" as the most prominent factors. The remaining factors include facilitating renewable energy [131], increasing the longevity of buildings [129], providing good structural conditions for existing building projects [133], decreasing construction time [135], meeting contract and developer's requirements [138], providing end-user support [139], availability of sustainable materials [140], developing sustainable building materials and technologies [152], availability of institutional framework for effective green building technologies adoption [36], improving project constructability [133], and providing a secure energy supply for buildings [131], see Fig. 7.

D28 and *D29*, which focus on enhancing EE and WE, are identified as the most significant factors for adopting SBDPs. This finding is consistent with the research by Refs. [78,153], which attributes the significance to the reduced O&M costs resulting from lower energy and water bills. Additionally, *D30,* which emphasises the value of SBRS certification, motivates the stakeholders to adopt SBDPs since sustainable buildings with SBRS attract premium clients [133], high rental returns and increased property value, as mentioned by Refs. [35,154]. However, challenges such as delays and higher initial costs associated with green certification processes are acknowledged, as Deng, Yang, Tang and Tang [42] claimed, underscoring the requirement for balanced approaches in leveraging technology to promote SBDPs.

4.3.5. Educational and awareness

Five (5) factors were identified in this category, with "offering education on sustainable buildings to raise stakeholders' knowledge (47 %)" and "increasing awareness of sustainable building benefits (42 %)" as the most significant factors. The remaining factors include improved access to information and databases on sustainable buildings [58], more demonstration of sustainable building projects [49,129], and research improvement, innovation, and development [82], see Fig. 7.

D42, which focuses on offering education on sustainable buildings, is ranked as the most significant factor under this category, which can be achieved by educating owners and tenants [52] and offering training programs [134], as also reported by Refs. [41,148] since they have a considerable influence on the knowledge and awareness levels of clients and the general public. *D43* was also reported as a top factor by Anzagira, Duah, Badu, Simpeh and Marful [155], underlining the importance of providing stakeholders with workshops, seminars, and conferences [148] and awareness-raising programs [25] to further disseminate knowledge about the benefits of SBDPs. D44 highlights the significance of improved access to information, advocating for the utilisation of online platforms to enhance stakeholders' awareness and knowledge of SBDPs, as suggested by Refs. [42,148]. Similarly, *D45* emphasises the importance of promoting SBDPs through the presentation of successful case studies, as these case studies serve as benchmarks for new design and construction standards [36,148]. Lastly, the advancement of research and development, facilitated by increased funding and strengthened research programs, is vital for driving innovation and progress within the sustainable building sector. This is supported by the findings of [58,138]. Such advancements can be achieved through the funding of research projects in partnership, as suggested by Assadiki, Merlin, Boileau, Buhé and Belmir [70].

4.3.6. Health and socio-cultural

Within this domain, three (3) key factors were identified: "enhancing users' well-being, comfort, and productivity (38 %)", "the perception of stakeholders towards sustainable buildings (17 %)", and the change of attitudes, culture, and tradition (5 %), see Fig. 7. *D47* emerges as the most influential factor, as highlighted by Darko, Chan et al. (2017), indicating that IEQ leads to less absenteeism and higher productivity of tenants, a finding supported by Wadu Mesthrige and Chan [89]. *D48* ranks as the second most significant factor, reflecting that stakeholders believe that adopting SBDPs is the right thing to do, as mentioned by Refs. [35,138]. This factor is further reinforced by Agyekum, Goodier and Oppon [132], who emphasise that stakeholders consider the promotion of ethical investment to be a critical factor for sustainable building project financing. *D49* also contributes to adopting SBDPs, consistent with [41,70] due to the evident advantages of SBDPs regarding tenants' health, well-being, and productivity [43]. Thus, the attitudes and traditions should be changed to facilitate the adoption of SBDPs [31]. In summary, integrating health and socio-cultural considerations into SBDPs not only enhances the physical and psychological conditions of building occupants but also aligns with evolving societal values towards sustainability, ethics, and well-being.

4.3.7. Organisational and marketing

Within this category, 14 factors were identified, with four emerging as particularly significant: "improving Corporate Social Responsibility (CSR) and organisational image (28 %)", "improving stakeholder communication (18 %)", "promoting sustainable buildings (17 %)", and "having competent team members (12 %)". The remaining factors include encouraging an integrated design approach [41], enhancing marketing and branding [54], project management and recording lessons learnt [68], support from top management [137], effective communication channels [49], improving organisational resources and readiness [43], getting familiar with green products and processes [41], committing to change of behaviour within the organisation [83], setting clear, sustainable goals [25], and company environmental policies [133], see Fig. 7.

The first-ranked factor is *D50*, which was also supported by Darko, Zhang and Chan [133], as investing in sustainable buildings can demonstrate a company's CSR and boost image; for example, environmental awareness can be part of CSR [35] and contribute to a better public image of the company [39]. Following closely, *D51* is also vital as it leads to successful project delivery, which can be achieved through the early involvement of stakeholders [58] and frequent stakeholder meetings [136]. Similarly, *D52*, promoting sustainable buildings, is identified as a crucial factor for clients to adopt environmentally conscious products [155]. Strategies include using various media platforms to increase awareness and adoption rates, for example, in Pakistan [148], Ghana [150], and India [156]. *D53,* highlighting the necessity of competent team members, is aligned with a perspective that skilled labourers [83], project managers [157] and consultants with green expertise are essential for successful project delivery [139]. Accordingly, retention and attraction of competent staff [133] are essential and can be achieved by reducing turnover rates and attracting quality employees [138]. These findings represent the nature of organisational and marketing strategies in fostering sustainability within the construction industry. By leveraging these drivers, stakeholders can effectively promote and implement SBDPs, leading to enhanced company reputations, improved stakeholder relationships, and the successful delivery of sustainable building projects.

4.4. Barriers to adopting SBDPs

From Fig. 8, the barriers to adopting SBDPs were broadly classified into six categories: financial and economic, policy and government-related, technological, educational and awareness, socio-cultural, and organisational and marketing. Notably, Environmental Protection is not included as a barrier in the adoption of SBDPs. This exclusion is due to the fact that protecting the environment is a core value and fundamental objective of SBDPs. As such, environmental protection efforts are integral to the design and implementation of SBDPs rather than being perceived as an impediment [35,158]. Accordingly, 48 distinct factors for adopting SBDPs were identified (see Appendix A and D). Out of these, four significant factors are particularly noteworthy: "the high initial costs of sustainable buildings (52 %)", "lack of professional expertise and green training (49 %)", "absence of mandatory green building codes, regulations, and policies (35 %)", and "stakeholder perception and resistance to change (34 %)". Addressing these requires financial incentives, regulatory reforms, professional training, and awareness campaigns for a sustainable construction industry. The subsequent sections offer a detailed explanation of these factors, encompassing financial, policy, technological, educational, socio-cultural, and organisational categories. It underscores the multifaceted nature of the obstacles faced in the adoption of SBDPs.

To ensure the study's findings' wide applicability, barriers were categorised based on different regions worldwide. In Asia, significant financial and economic barriers like high initial costs [89,122] and a lack of government incentives are prevalent [129,148], as well as policy-related obstacles such as the absence of mandatory green building codes [35,159]. Moreover, substantial technological barriers, including the absence of green building technology databases and project complexity, must be addressed along with notable socio-cultural resistance to change. In Africa, similar financial challenges exist, coupled with policy-related issues, including insufficient SBRS programs

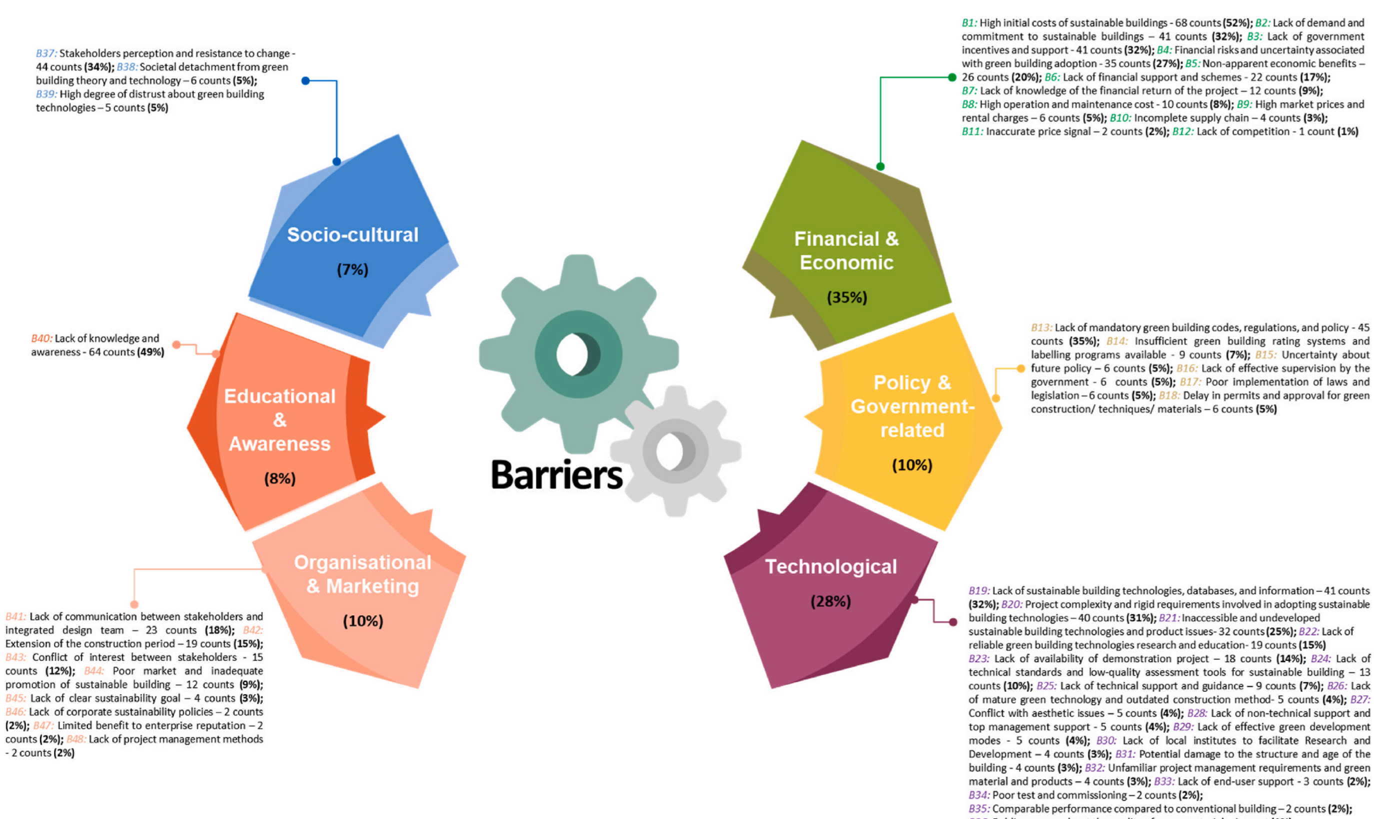

Fig. 8. Barriers to adoption of sustainable building design and practices.

and inadequate government supervision [41,49]. North America contends with high market prices and financial risks, coupled with policy uncertainties and technological challenges related to demonstration projects [40,51]. In Europe, non-apparent economic benefits and high initial costs [48,160] are significant barriers, alongside with lack of demand and commitment to adopting SDBPs [158]. Oceania, particularly Australia, faces a lack of government support and technological accessibility [25,52], with socio-cultural resistance remaining a significant challenge [1,161]. This regional classification of barriers is designed to assist stakeholders in addressing specific challenges more effectively.

4.4.1. Financial and economic

Under this category, 12 factors were identified (see Fig. 8). Among these factors, the most significant factor is the high initial cost of sustainable buildings, which was mentioned in 52 % of the selected studies, followed by a lack of demand and commitment to sustainable buildings and a lack of government incentives and support, with an identical proportion of 32 %. Additional barriers include financial risks and uncertainty [50], non-apparent economic benefits [52], lack of financial support and schemes [121], lack of knowledge of the financial return of the project [92], high O&M costs [47], high market prices, rental charges [134], incomplete supply chain [42], the inaccurate price signal [89], and lack of competition [52].

The results revealed that *B1* is the most significant factor, corresponding with Mollaoglu, Chergia, Ergen and Syal [140] as an essential barrier in India and Turkey. These additional costs often come from the incremental cost, which comprises upfront cost [42], certification application [40], sustainable materials and technologies [70], green features [128] and extended construction time [162]. Secondly, *B2* from sustainable building stakeholders [130] is ranked as the second most significant factor. For instance, Lambourne [128] highlighted this as a major issue in the United Arab Emirates. *B2* is also related to a lack of motivation [42], a lack of institutional interest [121], a lack of interest expressed by customers and market demand [70], a lack of government commitment, client demand [1], and stakeholder support [162]. Hence, the best method to enhance demand is to develop stakeholder awareness of SBDPs [42,44]. The third significant factor (*B3*) relates to the absence of incentives, resonating with Darko and Chan [163] because the lack of governmental fiscal incentives has had an adverse impact on the adoption of SBDPs in numerous nations [41,89]; furthermore, insufficient awareness regarding the enduring advantages may have exacerbated the challenge associated with providing incentives and technical support [132,159].

In contrast, Darko, Chan, Yang, Shan, He and Gou [150] argued that the *B3* is the most significant factor and should be addressed since it leads to a lack of client demand. To mitigate these factors, stakeholders must acknowledge the significant impact of high initial costs and develop comprehensive strategies that encompass financial incentives, enhanced awareness programs, and supportive policies. Such measures are essential for overcoming the financial factors associated with sustainable building projects and fostering a more encouraging environment for their adoption.

4.4.2. Policy and government-related

Within this category, six (6) factors were identified, with the lack of mandatory green building codes, regulations, and policies being the most dominant factor, as reported by 35 % of the selected articles. This barrier is particularly notable in countries such as Turkey [140], Pakistan [148], and China [44], reflecting the global challenges of promoting SBDPs. The remaining barriers include insufficient SBRS and labelling programs available [50], uncertainty about future policy [52], lack of effective supervision by the government [49], poor implementation of laws and legislation [25], and delays in permits and approvals for green construction, techniques, and materials [122] which have the same proportion of 5 %, see Fig. 8. Additionally, the prominence of *B13* as the most reported factor underscores a critical gap in the codes and regulations supporting sustainable construction, leading to reduced adoption of SBDPs. Challenges have been noted in countries such as Turkey [140], Pakistan [148], China [44], the United States [164], and across the African continent [41], demonstrating the widespread nature of this issue globally. This highlights the urgency of addressing these policy deficiencies. To effectively overcome these barriers, there is a clear need for the adjustment and flexibility of codes and regulations to better align with local contexts, as suggested by Refs. [35,164], thereby supporting the transition towards more sustainable building practices.

4.4.3. Technological

Within this category, 18 factors were identified. The three (3) most significant factors are “a lack of green building technology, databases, and information (32 %)”, “project complexity and rigid requirements involved in adopting sustainable buildings (31 %)”, “inaccessible and undeveloped green building technologies and product issues (25 %)”. Additional factors include a lack of reliable green building technology, research, and education [42], availability of demonstration projects [50], technical standards and low-quality assessment tools [49] and technical support and guidance [54]. Other noted factors include a lack of mature green technology and construction processes [50], non-technical support from top management [68], effective green development modes, and aesthetic issues [38], having an identical proportion of 5 %. The remaining factors include the lack of local institutes to facilitate research and development [38], potential damage to the structure and age of the buildings [52], unfamiliar project management requirements, and green materials and products [38] having an identical proportion of 4 % followed by poor test and commissioning, public concern about the quality of green material [138], and comparable performance compared to the conventional building [78], see Fig. 8.

Among other barriers, *B19* emerges as the mos.t prominent barrier, aligning with Chan, Darko, Olanipekun and Ameyaw [151], reporting it as a significant factor in adopting SBDPs in Ghana. *B19* includes a lack of reliable market data [128], a lack of professional design information [34] and missing guidelines and documentation [84]. These highlight the role of education and research efforts in overcoming this challenge [39] as well as the development of online databases [42]. *B20* is the second most reported factor, as identified by Darko, Chan, Owusu-Manu and Ameyaw [153], and it includes strict legal codes and more significant construction requirements [47]. For example, technical difficulties during the construction period [35], unfamiliar materials and technology [162], and the complexity of green rating tools [1]. *B21* is the third most reported factor, as mentioned by Refs. [84,148], as a significant factor in Egypt and Pakistan. These factors can be eliminated by promoting SBDPs and providing a comprehensive national database, including public prompt, accurate, and updated sustainable building information [36]. Addressing these factors through promoting SBDPs, investing in research and development, and providing robust support and guidance is essential for advancing the adoption of SBDPs.

4.4.4. Socio-cultural

Three factors were identified under this category: “stakeholders’ perception and resistance to change (33 %)”, “societal detachment from green building theory and technology (5 %)”, and “a high degree of distrust about green building technology (4 %)”, see Fig. 8. *B37* is the most reported factor, which was also reported by Bijivemula, Sai and Chepuri [152] as a significant factor in India, including a perception of high costs [49] and unfavourable attitudes about adopting SBDPs [54]. *B37* arises from the reluctance to transition from conventional construction practices to sustainable ones [51,165]. Also, in delivering sustainable building projects, the general fear of high initial costs is common among stakeholders [49], which should be tackled by changing mindsets about the high initial cost of sustainable buildings [1]. In this case, awareness-raising programs and training can address the relevant stakeholders' perceptions and resistance to change [166]. Addressing this psychological resistance requires targeted interventions to change stakeholder perceptions and foster a more favourable attitude towards sustainable construction, thereby facilitating the broader adoption of sustainable building practices and technologies.

4.4.5. Educational and awareness

Only one (1) factor was identified under this category, with a notable lack of knowledge and awareness identified as a significant factor. *B40* was highlighted in 69 articles, accounting for 49 % of the selected studies (see Fig. 8). The findings show that this issue is significant globally, for example, as the most significant factor in the African continent [41], Pakistan [148] and Ghana [134]. The deficiency in expertise and green training exacerbates the challenges, including a lack of qualified staff [148] and a shortage of professionals with green building expertise [128]. Addressing the lack of knowledge and awareness in several world regions as a significant concern is important since SBDPs are associated with improving EE, WE, IEQ, productivity, health and well-being [155]. Moreover, they play a pivotal role in contributing to the achievement of the SDGs [16], emphasising the broader implications of the adoption of SBDPs in the construction sector. By enhancing understanding and expertise in SBDPs, relevant stakeholders across various regions can unlock the full potential of sustainable buildings, contributing to a more sustainable and resilient built environment.

4.4.6. Organisational and marketing

Eight (8) factors were identified. Three significant factors include "a lack of communication between stakeholders and the integrated design team (18 %)", "an extension of the construction period (15 %)", and "a conflict of interest between stakeholders (12 %)". The remaining factors are poor market and inadequate promotion of sustainable buildings [78], lack of clear sustainable goals [51], corporate sustainable policies [121], limited benefit to enterprise reputation [138], and lack of project management methods [38], see Fig. 8.

The most reported factor is *B41*, highlighting the crucial role of communication between stakeholders, resonating with Ebbini and Al-Assaf [54] because new sustainability frameworks and integrated design processes cannot be introduced without effective communication. Hao, Du, Huang, Shao and Yan [167] also claimed that establishing a robust communication infrastructure will facilitate information exchange and diminish communication barriers. In addition, *B42* emerges as a significant factor that has been observed by Refs. [42,152] in countries such as China and India. Delay, change, wasteful rework.

This factor is usually exacerbated by technical challenges and complexity associated with sustainable building methods and design, leading to delays in the design and construction period, increased initial costs and also possible wasteful rework [151,162]. *B43* is ranked the third most crucial factor, consistent with Rock, Hosseini, Nikmehr, Martek, Abrishami and Durdyev [52], as a solid factor in adopting green office design in Australia, as well as Ebekozien, Aigbavboa, Thwala, Amadi, Aigbedion and Ogbaini [41] who mentioned B43 as a critical barrier to the adoption of SBDPs in Africa. Such conflict may arise from different perspectives regarding the method and rationale behind the retrofitting of a structure, leading to a conflict of interest [131,138]. Overcoming these factors requires approaches that emphasise the importance of clear communication, project management, and commitment to sustainability objectives. These strategies must also ensure that organisational and marketing strategies support the adoption of SBDPs.

5. Implications of research findings

These findings have substantial implications for the built environment engineering field, sustainability and construction industry. By identifying the essential characteristics of SBDPs, this study provides a strategic framework for stakeholders to promote and implement SBDPs. For policymakers, the data underscores the importance of transitioning from voluntary to mandatory sustainable building and energy certifications, facilitating stakeholder investment and advancing SBDPs. For building professionals, the study highlights the importance of effective stakeholder communication, recommending early involvement and continuous engagement to overcome common barriers. This study makes an essential novel contribution by thoroughly identifying and categorising the characteristics, drivers, and barriers of SBDP, offering valuable insights for stakeholders. For example, renewable energy generation was frequently cited as a critical factor, with specific instances such as the installation of photovoltaic panels showing significant potential in lowering environmental impact and operational costs. Likewise, the importance of water recycling approaches was highlighted for enhancing water efficiency, backed by examples of successful wastewater treatment and rainwater harvesting systems.

Moreover, the investigation into drivers influencing stakeholders' perceptions revealed that government legislation and incentives, enhanced organisational image, and CSR are critical in fostering the broader acceptance of SBDPs. Specific examples include the impact of mandatory codes and regulations in driving SBDP adoption and the role of enhanced organisational image in increasing company competitiveness and revenue. Conversely, significant barriers such as substantial initial investments, resistance to change, and a lack of governmental support were identified. These barriers are particularly impactful in regions with limited awareness and knowledge about SBDPs, contributing to stakeholder hesitancy. The study provides targeted recommendations to address these barriers, such as financial incentives, regulatory reforms, professional training, and awareness campaigns, thereby fostering a more encouraging environment for the adoption of SBDPs.

Based on the SLR findings, four recommendations are proposed to enhance the adoption of SBDPs. Firstly, building professionals should emphasise water recycling approaches and renewable energy generation as paramount methods for improving WE and EE, respectively, while also focusing on improving IEQ through enhanced thermal comfort, health, and well-being of occupants. Secondly, policy regulators should address the limited understanding of SBDPs among stakeholders in certain regions by providing education, access to comprehensive databases, showcasing demonstration projects, and leveraging media to promote sustainability. Next, the national government should promote the transition from voluntary to mandatory sustainable buildings and energy certifications to facilitate stakeholder investment in sustainable building initiatives, thereby enabling governments to play a pivotal role in advancing SBDPs. Lastly, building professionals should highlight the importance of effective stakeholder communication, recommending early involvement and continuous engagement throughout the project lifecycle to overcome common barriers. Implementing these recommendations can help stakeholders make significant progress towards integrating SBDPs into construction projects. This can contribute to the attainment of global sustainability objectives and enhance buildings' overall performance regarding EE, WE, and IEQ.

6. Conclusion

This study reviewed extant literature on SBDP adoption on a global scale. Through the SLR, 40 characteristics, 63 drivers, and 48 barriers relevant to the adoption of SBDPs were identified. The integration of renewable energy generation and the use of energy-efficient equipment, despite the challenge of higher initial costs, were among the most reported characteristics of SBDPs. Likewise, the investigation into drivers that influence stakeholders' perceptions explained how drivers and barriers affect the adoption of SBDPs. Accordingly, stakeholders' involvement in the adoption of SBDPs was found to be typically influenced by mandatory codes and regulations, the ethical imperative of investment, and the urgent need to combat climate change. Additionally, the enhancement of organisational image and CSR are identified as critical factors in strengthening company competitiveness, increasing revenue, and fostering the broader acceptance of SBDPs.

Conversely, the study highlighted significant barriers, including substantial initial investments, resistance to change, and a lack of governmental support, which collectively hinder the stakeholder uptake of SBDPs. These barriers, particularly the daunting initial costs and general resistance to change, are intensified by a lack of awareness and knowledge about SBDPs, contributing to stakeholder hesitancy and negative attitudes towards SBDPs. Despite the growing global attention towards SBDPs, it is evident that understanding and implementation of SBDPs are still in their infancy in some parts of the world. By identifying the essential characteristics of SBDPs and critical drivers and barriers, this study offers fundamental guidelines for promoting the adoption of sustainable buildings worldwide. Strategic insights and recommendations were also provided to enhance stakeholders' understanding and address the main barriers to the adoption of SBDPs, ultimately facilitating its widespread acceptance and implementation.

This research significantly contributes to the field by critically identifying the characteristics of SBDPs and highlighting the significant role of communication, regulatory frameworks, and stakeholder education in overcoming the challenges to sustainable building adoption. As such, the study serves as a valuable resource for relevant stakeholders of SBDPs, helping them achieve sustainability in the built environment and contributing to the success of achieving the SDGs. A limitation of this study's findings is the use of only secondary data collection through the SLR. To gain a more thorough understanding of stakeholders' perceptions of SBDPs, future studies should consider including primary data collection methods, such as interviews and questionnaires. Direct engagement with key stakeholders will facilitate effective communication and yield valuable insights into the factors that influence, drive, and hinder sustainable practices in the industry. Incorporating this multifaceted strategy into the field of sustainability and the built environment will result in a more comprehensive understanding of SBDPs.

CRediT authorship contribution statement

Tharaya Poorisat: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Itohan Esther Aigwi:** Writing – review & editing, Supervision. **Dat Tien Doan:** Writing – review & editing, Supervision. **Ali GhaffarianHoseini:** Supervision.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.buildenv.2024.112069.

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Abbreviation list

BREEAM: Building Research Establishment Environmental Assessment Method
CASBEE: Comprehensive Assessment System for Built Environment Efficiency
CSR: Corporate Social Responsibility
EC: Economic Characteristics
EE: Energy Efficiency
GHG: Greenhouse Gas
HVAC: Heating, Ventilation, and Air Conditioning
IAQ: Indoor Air Quality
IEQ: Indoor Environmental Quality
LEED: Leadership in Energy and Environmental Design
MR: Materials and Resources
NZEBs: Net Zero Energy Buildings
NZGBC: New Zealand Green Building Council
O&M: Operation and Maintenance
PM: Particulate Matter
PRISMA: Preferred Reporting Items for Systematic Review and Meta-Analysis
SBRS: Sustainable Building Rating Systems
SBDPs: Sustainable Building Designs and Practices
SDGs: Sustainable Development Goals
SE: Social Equity
SS: Sustainable Sites
SLR: Systematic Literature Review
WE: Water Efficiency
WM: Waste Management
WGBC: World Green Building Council
WHO: World Health Organisation