Review Article

*International Journal of Advanced Technology and Engineering Exploration, Vol 11(110)*
*ISSN (Print): 2394-5443 ISSN (Online): 2394-7454*
*http://dx.doi.org/10.19101/IJATEE.2023.10102084*

# Structural design and construction using energy analytical modelling for sustainability: a review

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Received: 07-August-2023; Revised: 18-January-2024; Accepted: 20-January-2024

## Abstract

***In recent years, there has been a significant increase in research focused on designing sustainable structures (SS). Strategies for sustainable design aim to minimize the environmental, economic, and social impacts of structural components by considering their lifecycle, which includes the materials used, energy consumed, and waste generated during construction, operation, and disposal. The building sector alone accounts for about 37% of annual primary energy consumption (EC) in India. Recognizing the critical nature of this crisis, there is an urgent need to embrace and implement the practice of designing and constructing sustainable structures (DCSS). This approach is vital for reducing energy demand and intensity, thereby optimizing the overall building energy performance (BEP) and reducing greenhouse gas (GHG) emissions. Several approaches based on construction technologies have been proposed, advocating for the inclusion of sustainability right from the project's inception. A systematic literature review has been conducted, analyzing various considerations and approaches such as optimizing building orientation, maximizing daylight and ventilation, and employing energy-efficient (EE) systems, in conjunction with building information modeling (BIM) and energy analytical modeling (EAM), based on the country's existing regulations and standards. The purpose of this paper is to highlight the importance of implementing design strategies and parameters for DCSS in green building rating systems (GBRS). The study presented in this paper aims to promote sustainable development (SD) by increasing awareness of the importance of sustainable and green building (GB) practices, and by encouraging individuals and organizations to incorporate environmental considerations into their building projects.***

## Keywords

***Energy efficiency, Design and construction, Green building, Greenhouse gases, Structure, Sustainability, Buildings.***

## 1.Introduction

### 1.1Background

Sustainability is an essential concept that recognizes the entail to estimate economic, social, and environmental determinants to elevate long-term well-being and prosperity for all. It requires us to think long-term and consider the impacts of our actions on the planet and society as a whole [1]. Ultimately, the goal of sustainability is to create a world that is liveable and prosperous for everyone, now and in the future. This requires conserving natural resources, minimizing waste and pollution, and creating a more equitable and just society. Sustainability improves the resilience of the system which has ability to absorb and recover from disturbances or shocks, whether they are natural disasters, economic crises, or other unexpected events [2, 3]. By building resilience into our systems, we can help to ensure that they withstand and recover from shocks and disturbances and continue to provide the goods and services that we rely on for our well-being. This is an important aspect of sustainability, as it can help to ensure that our systems are able to function long term, even uncertainty and change [4]. The triple bottom line (TBL) framework consists of three components or "bottom lines": social, environmental, and economic [5]. TBL framework is often used in sustainability reporting and decision-making processes to help organizations evaluate their performance and identify areas for improvement. By considering all three bottom lines, organizations can better understand the complete effect of their actions and make more informed decisions about how to operate in a sustainable and responsible manner [6].

Sustainable buildings (SB) or green building (GB) are designed and constructed with emphasis on

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reducing their impact on the environment throughout their entire lifecycle, from construction to operation and eventual demolition [7]. Energy efficiency is key feature for SB, designed to use less energy than conventional buildings by incorporation of features like high-performance cushioning, energy-saving lighting and appliances, and renewable resource systems like solar panels or wind turbines [8]. Water efficiency is another important aspect of SB. They use low-flow fixtures and technologies such as rainwater harvesting systems to reduce water consumption and minimize wastewater production [9]. Materials selection in SB significantly contributes in terms of their environmental impact and durability. These buildings often use recycled or sustainably sourced materials, and construction methods that minimize waste and maximize recycling and reuse of materials [10]. SB also prioritize the well-being of occupants. It incorporates features and techniques to enhance natural lighting, improved air quality, low-toxicity materials to promote occupant health and comfort [11]. SB design and construction can be instrumental in elevating the economic benefits by scaling down the operating costs and upgrading the property value time ahead. Leadership in energy and environmental design (LEED), building research establishment environmental assessment method (BREEAM), green rating for integrated habitat assessment (GRIHA) and other notable SB standards plays crucial roles in the promotion of sustainable development (SD), as they provide guidelines and standards for creation of sustainable, efficient, and environmental beneficial built environment [10]. Technological advancement and software like building information modelling (BIM) tools (Revit, EQUEST, etc.,) simulation in design of buildings contributes to enhance the sustainability as compared to the conventional design practices [12].

The aspiration for sustainability is notable, researchers experience multi-directional challenges that can retard progress and successful implementation of sustainable principles. The major challenges faced by the researchers are listed as below: -

a) Interdisciplinary complexity- Sustainable construction (SC) and design of sustainable structures (SS) involves a complex interaction of various disciplines, including architecture, engineering, materials science, and environmental science, etc. The collaboration among area and topic specific focused research is found missing.
b) Holistic approach research lacking- Researchers experience challenge in accumulating comprehensive data on the long-term performance of SC materials, techniques, and practices. Issues raised by researchers are not holistically analyzed including diversified areas of research. Standardizing assessment methodologies and data collection is essential to ensure comparability across studies.
c) Technological advancements- It is observed that majority of research articles using technologies to limited extent. Latest technologies should be applied and studied in deep and details to explore extensively.

## 1.2Current challenges

On the basis of the above discussion and literature review conducted for this study, the implementation of the sustainable design and practices observes the below mentioned challenges: -

(a)Modelling complexities- Energy analytical modelling (EAM) comprises complex simulations considering several factors which depends on building materials, climate, occupants’ behaviour, etc. [8,11]
(b)Skill gap and technological advancement- Continuous speedy technological advancements in energy modelling tools, demands upgradation of professionals and construction sector by planning and imparting training periodically [12].
(c)Standardization and regulatory compliance- Development of building codes, provisions, standards, regulations, certifications, and compliance for different regions is complex and time consuming [9].
(d)Data accuracy and availability- Procuring accurate and comprehensive data as input into EAM, especially for existing buildings or in regions with limited data availability is challenging [3].
(e)Occupant awareness- Occupant awareness and behaviour significantly impact energy consumption (EC) [11].
(f)Construction sector acceptance- Lack of training and understanding about the effectiveness and benefits of sustainable design at contractor’s end is stimulating [6].
(g)Resilience to changing climate conditions- Climate change uncertainties affect the accuracy of EAM [2, 3].
(h)Initial investment and long-term benefits- Initial investment is higher in implementing sustainable design, simulation and construction, results to challenging task in convincing construction sector to invest in long-term benefits [8].

(i) Renewable energy sources incorporation- Incorporating renewable energy sources, such as solar panels or wind turbines, into energy models requires accurate projection of their performance and reciprocity with the building components [4, 10].

## 1.3Motivation

The study conducted is motivated primarily with the increasing innovation and technical advancements to enhance the efficient use of resources, minimize negative impacts on environment and occupants, and implement regulations and standards and to elevate the economic benefits. Based on the review conducted for the study it is discussed as below-

(a) Energy crisis- The energy crisis of the 1970s was a period of global shortage of energy and economic instability that occurred because of a combination of factors, including rising oil prices, geopolitical tensions, and increasing demand for energy. The energy crisis caused widespread economic disruption, with many countries experiencing inflation, recession, and high levels of unemployment. It also led to a renewed focus on energy conservation and the development of alternative sources of energy. Governments and businesses have taken up backing in renewable energy sources [13]. This instigates the inception of the SB movement, as builders and designers sought to turn down the reliance of buildings on fossil fuels and bring down their environmental impact [14]. SB prioritize energy efficiency and the use of renewable energy sources, contributing to a reduction in greenhouse gases (GHG) emissions and combating climate change. Sustainable design incorporates strategies to make buildings more resilient to the impacts of climate change, such as extreme weather events and temperature fluctuations.

(b) SC-It refers to the modelling of a built environment to be designed healthy, resource and energy-efficient (EE), and optimized based on ecological principles [11]). SC also emphasizes the health and well-being of building occupants. Buildings are designed to improve indoor air quality, maximize natural light, and provide comfortable and safe spaces for occupants. This can lead to improved productivity, reduced absenteeism, and increased overall well-being for occupants [12]. Competitive pressure can also motivate companies in the construction industry to verify their methods and practices in terms of SC [15]. SC can also help companies comply with environmental regulations and standards, which can mitigate legal and reputational risks [16]. The trend towards SB and GB is powered by a growing awareness of the environmental impacts of the built environment, as well as an increased focus on corporate social responsibility and SD [17]. It is observed that building design and construction of SS generate an extra amount of costs in the short term. SC often involves using more expensive materials and implementing EE technologies, which can increase upfront costs [18]. However, the long-term benefits of SC can far outweigh these initial costs. SB designed for EE, which can lead to beneficial savings in energy costs whilst lifetime of the structure [19, 20]. They generate fewer GHG emissions, lower waste, and water consumption, and utilize renewable energy sources, which can contribute to a cleaner, healthier planet [21].

(c) Economic benefits- Incorporating power reduction and water usage, homeowners can lower their utility bills and reduce maintenance costs over time and thus promoting SB, societies can reduce their overall environmental impact and create a more sustainable future [22–24]. By implanting EE measures in buildings, power consumption can significantly decrease GHG emissions, reducing dependency on fossil fuels [25]. Simple efficient measures such as using EE lighting, improving insulation, and sealing air leaks can reduce EC in buildings by a significant amount [26]. These measures are less expensive and easier to implement, accessible to a wide range of building owners and operators [27]. Sustainable features can enhance the property value, attracting environmentally sensitive tenants and buyers.

(d) Indian construction sector and energy demand- The construction industry in India is an important benefactor to the country's economy and is expected to continue to flourish in the future years [4]. Buildings are a notable donor to global GHG emissions, and their reduction is essential to achieving sustainability goals and mitigating the impacts of climate change [28]. As per the International energy agency (IEA), operation and construction of buildings account for around 28% of global energy-related carbon dioxide ($CO_2$) emissions. In India, as in many other countries, major contributor to EC and GHG emissions is reported by the building sector [29]. According to a report by the IEA, the building sector in India accounts for more than 33% of the total electricity consumption in the country, and this demand is projected to increase significantly in the coming decades (over 70% by 2025) as the population grows and urbanizes. To address these issues, there is a growing need for SB practices in India [30]. Therefore, the current study attempted to bridge this gap.

(e) Innovation and technological advancements- Technology advancement and sustainable materials (SM) selection imparts innovative solutions for SB design, making it easier and more cost-effective to implement green practices [8].

(f) Environmental conservation- Sustainable design aims to minimize resource consumption, including energy, water, and raw materials, to reduce the environmental impact of building construction and operation [7]. Designing with consideration for local ecosystems helps preserve biodiversity and minimizes disruption to natural habitats.

(g) Occupant's well-being- Sustainable design focuses on creating healthy indoor environments with enhanced air quality, natural lighting, and lower levels of toxins, promoting the well-being of occupants [11].

(h) Certification programmes and schemes- Building certifications like LEED, BREEAM and GRIHA provide recognition for SB practices [8, 10].

(i) Long-term resilience and durability- Sustainable design often considers the long-term resilience of buildings to natural disasters, ensuring they can withstand and recover from events like earthquakes, floods, etc. [2, 3]. SM and construction practices contribute to the durability and longevity of buildings, reducing the need for frequent maintenance and replacements.

## 1.4Objectives

The study conducted for SD encircles environmental, social, and economic goals, which intends design and creation of buildings and infrastructure that minimize negative impacts on the environment, enhance the well-being of occupants, and contribute to long-term economic viability. The objectives for the study aligned as energy efficiency, occupant awareness and well-being, sustainability standards and certification compliance, technological integration, and software simulation.

### 1.4.1Research questions (RQ)

The current study attempted to bridge the gap in line with the objectives by reviewing the RQ as designed below:

*RQ1: How design strategies can be designed to achieve sustainability goals?*

*RQ2: How can BIM (tools) contribute to enhance design of buildings?*

*RQ3: What are literature gaps in existing literature? What are future research directions?*

The research considered to achieve a systematic and methodical literature review concerning SC, design strategies, sustainable infrastructure development, BIM tools implementation requirements and resources, GB rating systems (GBRS), used in designing, renovation, repairing and construction of buildings. The preferred reporting items for systematic review and meta-analysis (PRISMA) methodological approach conducted for the study includes four stages identification, screening, eligibility, and inclusion, as represented in the flowchart in *Figure 1* and discussed in section 2. Further, section 3 explores the literature review based on the selected articles, followed by discussion, research gaps and limitations in section 4. Section 5 represents the conclusion and future research directions.

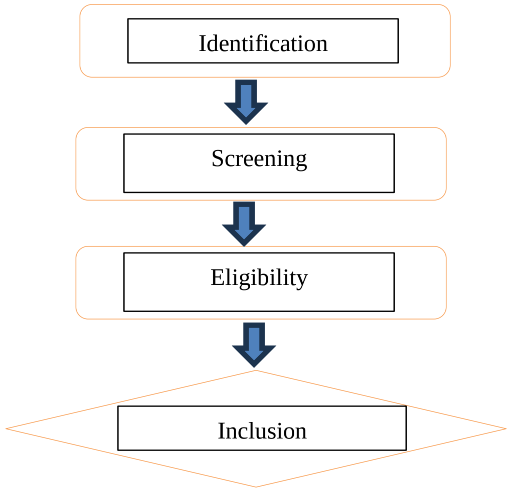


**Figure 1** Flowchart PRISMA Approach

## 2.Review methodology

The overall research of this study considered a systematic literature review utilising the PRISMA methodological approach consisting four main stages along with the inclusion and exclusion criteria as shown in *Figure 2* and discussed in this section.

- Stage-1- Identification: - Involved search using web of science (WoS), Scopus and other relevant sources. Implemented keywords relevant to this study's scope, aim and objectives. The keywords were concluded "energy performance (EP)", "Structural Design", "SC", "Energy Efficiency", "Building Energy Conservation", "Design Optimization", "Environmental Factors" and "BIM". The exhaustive search concluded with 585 articles, then different criteria were used to exclude irrelevant materials like keywords, platforms-WoS, Scopus, SCI and others, period and subject areas. Research articles selected for this study span the period from 1961 to 2023, reflecting the growth, relevance, and trends in the field over this extensive timeframe.

- Stage-2- Screening: - Involved article screening using initial screening and second stage screening as shown in *Figure 3*. Performed screening based on language preference of the article, irrelevance to building science, excluded 65 articles. Further manual study screening helped to exclude 204 articles based on insignificant information in relation to the aim of the study.
- Stage-3- Eligibility- Involved thorough study of the articles following third screening to select for the aimed work based on relevant, significant, applicable, pertinent and appropriateness towards the objectives of the desired research. It concluded with the exclusion of 210 articles.
- Stage-4- Inclusion- Involved the selection of articles perfectly aligned for the research aim, scope, and objectives. These articles were studied and examined to extract the information for the desired research and literature review was developed with 106 articles to identify further research, significant findings, and conclusions.

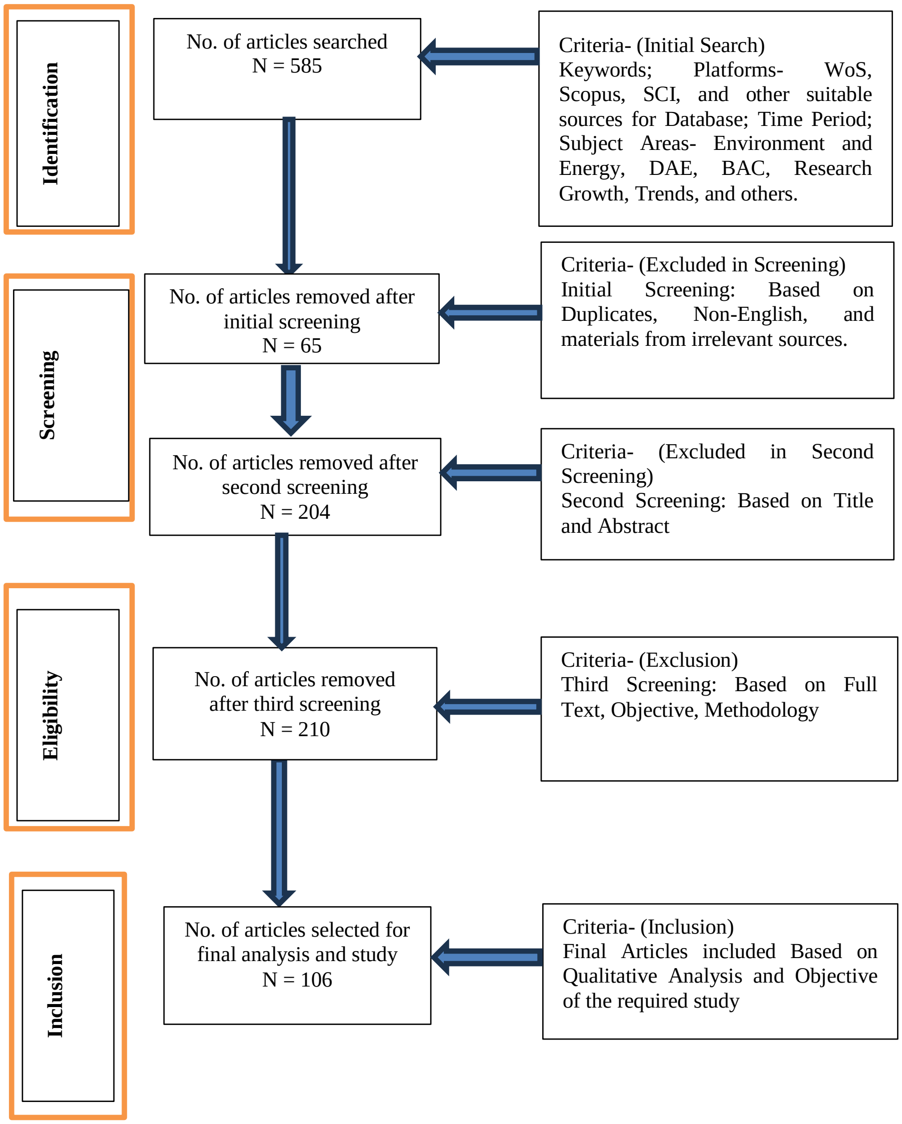


**Figure 2** PRISMA with inclusion and exclusion criteria

Based on the applied inclusion and exclusion criteria for the research articles, using the PRISMA approach, further key research areas ranged as energy and environment (EAE) (36%), design and engineering (DAE) (30%), building and construction (BAC) (22%) and others (12%) have been shown in *Figure 3*. The graphical representation in *Figure 4* shows the year wise distribution of the research articles reviewed for the study, additionally it signifies and reflects the literature trends and research growth in the selected time duration. *Table1* shows the list of different journals, proceedings, and books referred to the systematic and methodical literature review concerning the objectives of the study.

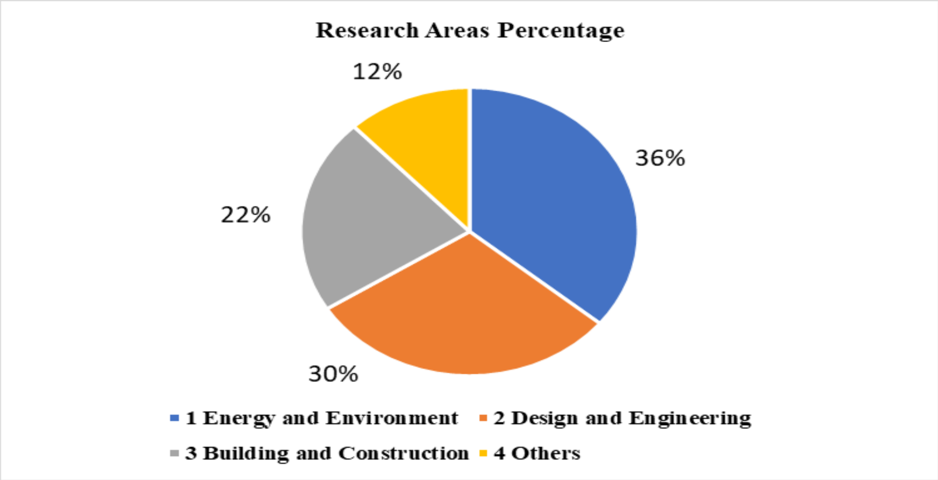


**Figure 3** Key research areas as per PRISMA approach

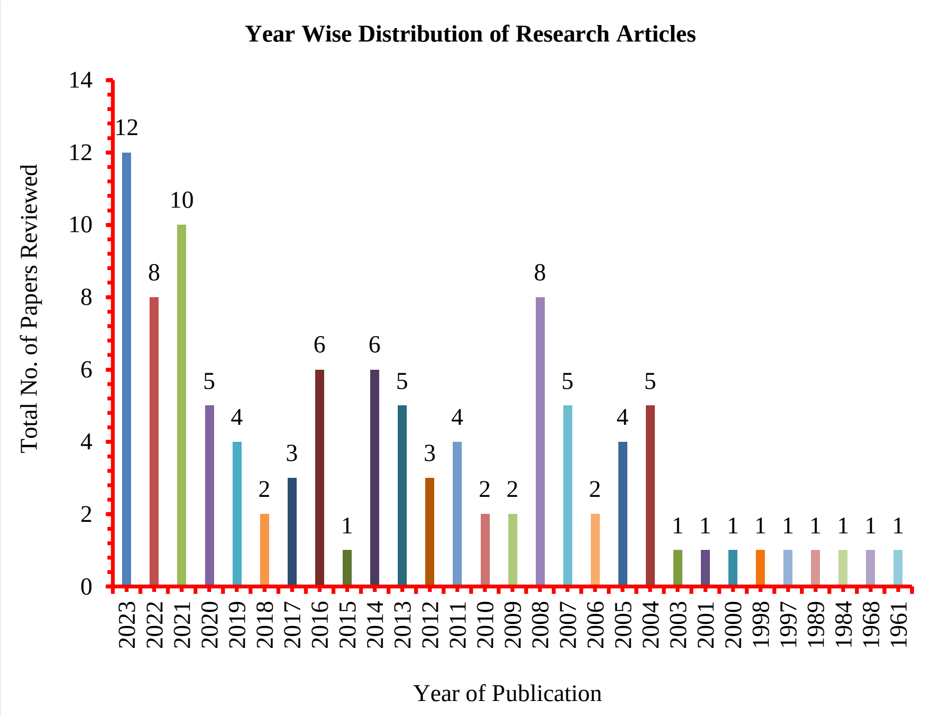


**Figure 4** Number and year wise distribution of research article

**Table 1** Journal wise distribution of research articles

| S. No. | Journal Name | No. of Articles |
|---|---|---|
| 1 | Engineering, Construction and Architectural Management | 2 |
| 2 | International Journal of Sustainable Construction Engineering Technology | 2 |
| 3 | IOP Conference Series: Earth and Environmental Science | 1 |

| S. No. | Journal Name | No. of Articles |
|---|---|---|
| 4 | American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) | 1 |
| 5 | Applied Sciences- MDPI Journal | 1 |
| 6 | Architecture Research | 1 |
| 7 | Automation In Construction | 3 |
| 8 | Book On Sustainability | 5 |
| 9 | Building And Environment-Journal | 4 |
| 10 | Building Research & Information | 2 |
| 11 | Buildings-MDPI Journal | 2 |
| 12 | Business & Information Systems Engineering | 1 |
| 13 | Case Studies in Construction Materials | 1 |
| 14 | Computer Aided Civil and Infrastructure Engineering | 5 |
| 15 | Conservation: Integrating Social and Ecological Justice | 1 |
| 16 | Contractor's Standards USA | 2 |
| 17 | Council Of Tall Buildings and Urban Habitat | 6 |
| 18 | Developments In the Built Environment | 2 |
| 19 | Ecological Indicators | 1 |
| 20 | ECONSTOR | 1 |
| 21 | Energy | 1 |
| 22 | Energy And Buildings | 4 |
| 23 | Energy Strategy Reviews-Journal | 2 |
| 24 | Environment Science & Technology | 1 |
| 25 | European Publications | 1 |
| 26 | Frontiers In Built Environment | 1 |
| 27 | General Buildings Information Handover Guide | 1 |
| 28 | IEEE (International Conference on PerCom Workshops) | 3 |
| 29 | Innovative Infrastructure Solutions-Springer Journal | 1 |
| 30 | International Conference Proceedings | 1 |
| 31 | International Energy Agency Programme on Energy in Buildings and Communities | 1 |
| 32 | International Journal for Numerical Methods in Engineering | 1 |
| 33 | International Journal of Advanced Research | 1 |
| 34 | International Journal of Architecture and Planning | 1 |
| 35 | International Journal of Civil Engineering Research | 2 |
| 36 | International Journal of Construction Management | 3 |
| 37 | International Journal of Project Management | 2 |
| 38 | International Journal of Renewable Energy Research | 1 |
| 39 | Joint Center for Housing Studies of Harvard University | 1 |
| 40 | Journal of Architectural Engineering | 2 |
| 41 | Journal of Building Energy | 3 |
| 42 | Journal of Building Engineering | 3 |
| 43 | Journal of Building Information Modelling | 2 |
| 44 | Journal of Chemical and Pharmaceutical Research | 1 |
| 45 | Journal of Cleaner Production | 1 |
| 46 | Journal of Computing in Civil Engineering | 2 |
| 47 | Journal of Engineering, Design and Technology | 3 |
| 48 | Journal of Management in Engineering | 1 |
| 49 | Journal of Physical Activity and Health | 1 |
| 50 | Journal of Structural Engineering | 2 |
| 51 | Journal of the Operational Research Society | 1 |
| 52 | Proceedia Engineering | 2 |
| 53 | Structural Engineering International | 1 |
| 54 | Sustainability- MDPI Journal | 4 |
| 55 | Sustainable Cities and Society | 1 |
| 56 | The Structural Design of Tall and Special Buildings | 1 |
| 57 | The Whole Building Design Guide | 1 |
| 58 | U.S. Environmental Protection Agency | 1 |

## 3.Literature review

The section explores research articles to enhance building's construction practices, design, EP, BIM (tools)and several other environmental solutions to achieve sustainability in construction resulting SD by adopting the PRISMA approach with significant inclusion-exclusion criteria in-line with research growth and publication trends.

### 3.1BAC

There is a push from both governmental and non-governmental organizations for implementing sustainable innovation in the construction sector [31]. By implementing sustainable innovations, the construction sector can reduce its impact on the environment while also improving the energy efficiency and sustainability of buildings [32]. At each stage, it is important to consider environmental responsibility and choose sustainable practices to reduce the building's impact on the environment [33]. The sustainability level of building recovery is indeed evaluative, especially in case of existing buildings, as they typically have lower levels of energy efficiency than newly constructed buildings [34]. Redesign, renovation, or reconstruction of existing buildings can also have a significant impact on reducing EC and achieving SD goals [35, 36]. Retrofitting buildings with EE technologies can lead to significant reduction in utilization of energy and GHG emanation matter of fact, retrofitting old buildings is cost-effective compared with building new EE buildings from scratch [37]. Many countries and organizations have launched programs and initiatives to promote the retrofitting of existing buildings to make them more EE and sustainable [38, 39]. During the operational stage, EE systems like heating ventilation and air-conditioning (HVAC) and lighting can significantly reduce EC and carbon emissions [40]. Similarly, during the construction stage, selecting environmentally friendly materials and methods can reduce the building's embodied carbon footprint [41].

In addition, building renovation or re-design can provide an opportunity to incorporate SM and technologies, such as solar panels or green roofs, to further reduce the building's environmental impact [42]. However, it is important to balance these improvements with the costs of renovation, ensuring no compromise with the aesthetic quality of the building [43]. The payback period for these investments can be lengthy, which can be a challenge for building owners and investors [44]. Comprehensive renovation planning is essential to ensure that renovation project goes successful, achieving the desired outcomes [40]. Building envelope re-design involves upgrading the building's external walls, roofs, windows, and other components that separate the indoor environment from the outdoor environment [45, 46]. By taking a holistic approach to building envelope renovation, building owners and investors can maximize the potential benefits of SB design and renovation [47]. The year wise distribution of research articles reviewed on BAC research criteria among the total number of research articles reviewed for the respective year is represented graphically in the *Figure 5*, additionally it displays the research growth and literature trends.

### 3.2DAE

Sustainability involves multiple interdependent factors, including energy efficiency, water efficiency, indoor air quality, material selection, social, economic considerations. Therefore, it can be challenging to compare the sustainability benefits of one decision to another, especially when these decisions may have trade-offs between different sustainability factors [48]. System dynamics, a modelling method developed from systems thinking ideas to make building sustainability decisions [49]. Another challenge is predicting the time ahead building energy performance (BEP) during the phases of design, in view of unavailability of information regarding final design. This can make it difficult to make informed decisions about sustainable design strategies, as designers may not have a complete understanding of how different design decisions will impact the building's sustainability performance [50].

Systems thinking, holistic approach regarding problem-solving on the General Systems Theory [51], a philosophy of science and engineering based on the idea of combining the knowledge gained through analysis and the understanding gained through synthesis to address the root causes of problems and minimizes cost [52,53].

The study showed that implementation of improved design strategies can result in improving sustainability performance of existing and new buildings [54]. It also requires the use of integrated design processes, which can help ensure that sustainability is considered throughout the entire design process [55]. This requires the use of performance simulation tools, which can help predict a building's energy, water, and indoor environmental quality performance [56, 57]. However, these tools can be complex and require a significant amount of data and expertise to use effectively [58]. Therefore, it can be challenging to provide designers with early feedback on building performance in a way that is both accurate and easy to use [59, 60]. Addressing these challenges requires a collaborative approach that involves stakeholders from different disciplines, including architects, engineers, builders, and building owners. Finally, it requires the use of performance simulation tools that are accurate, user-friendly, and accessible to designers [61–63]. By addressing these challenges, we can improve the sustainability performance of buildings and create a more sustainable built environment [64–66]. The measures adopted in design evolution involved increase in energy savings, minimizing carbon emissions with modifications in design strategies establishing the interface between indoor and outdoor environments [2,24,67,68]. Thus, it plays a critical role in BEP depending on building envelope, ventilation, lighting, and orientation [37, 46, 69–72]. The year wise distribution of research articles reviewed on DAE research criteria among the total number of research articles reviewed for the respective year is represented graphically in the *Figure 6*, additionally it displays the research growth and literature trends.

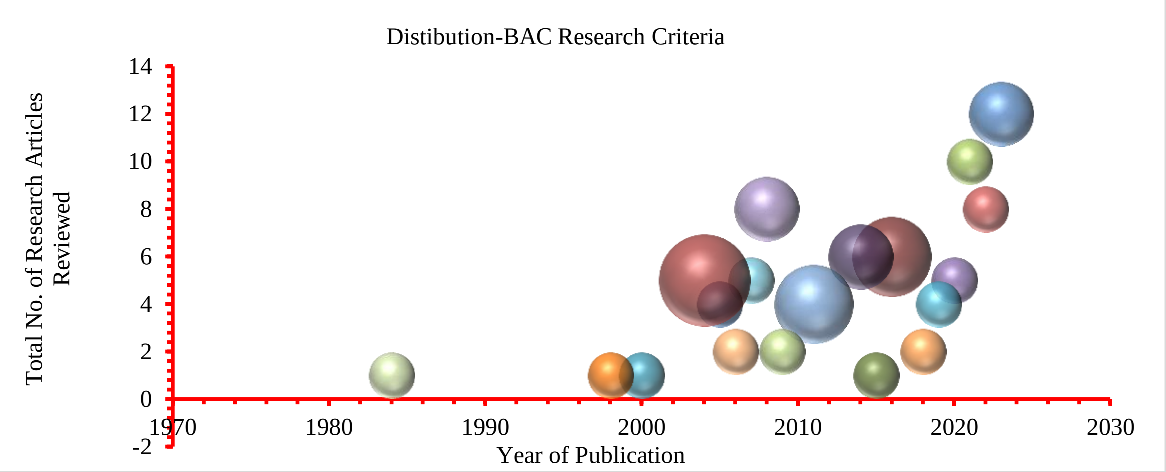


**Figure 5** Research articles distribution- BAC research criteria

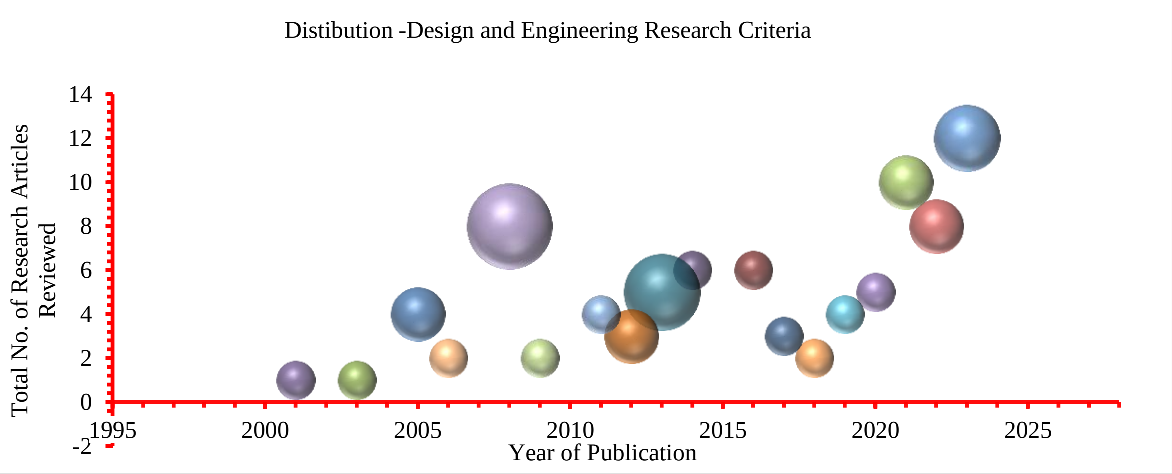


**Figure 6** Research articles distribution- DAE research criteria

### 3.3EAE

Establishing suitability of building systems and equipment is an influential step in reducing the consumption of energy in any building [44, 73, 74]. Building occupancy patterns may change over time, or renovations may be made to the building that affect its energy behaviour [36, 75]. Therefore, it is important to monitor and measure the actual EC of the building over time to ensure that it continues to perform as expected [76, 77]. If the actual EC is significantly higher than the calculated EC, it may indicate that the building systems and equipment are not operating optimally [78–80]. This can be addressed by conducting a detailed energy audit to identify areas for improvement, such as upgrading equipment, improving insulation, or optimizing building controls [81, 82]. By regularly monitoring and optimizing building systems and equipment, users can control EC, lower operating charges, and further building sustainability is improved over the long term [23, 83]. Computer simulations, systems for building monitoring, end-use sub-metering systems, building audit information, and bills of utility are among the methods for energy quantification (EQ) [84]. These methods involve collecting data on a building's EC and using it to calculate (EP) indicators [85]. Computer simulations use software to model a building's EC based on its design, construction, and occupancy characteristics [86]. This can help to estimate the building's EC before it is built or renovated [8, 87]. Building monitoring systems use sensors and meters to collect data on a building's EC. Data collected, used to identify areas for energy savings and track the impact of energy efficiency measures [37, 88]. End-use sub-metering systems measure the EC of individual systems or equipment within a building, such as lighting or HVAC systems. This data can be used to identify areas for energy savings and track the performance of individual systems or equipment [85]. Building audit information involves conducting a detailed audit to identify areas for improvement. This typically involves a comprehensive analysis of the energy systems, equipment, and operations [68, 57]. Utility bills provide data on a building's EC over time [38]. This data can be used to track EC trends and identify areas for improvement. By using these methods to quantify building EC, building owners and operators can identify opportunities to improve energy efficiency, reduce operating costs, and improve the sustainability of their buildings [89]. Scholars have proposed different approaches in various studies like calculation-based approach, hybrid approach, and measurement-based approach. Measurement-based approaches rely on actual measurements of EC in a building, such as metering or sub-metering of energy use. These measurements can be used to provide a more accurate and detailed understanding of the BEP and to identify opportunities for energy savings [90]. The data obtained from measurement-based approaches can also be used to calibrate energy models and to validate the results obtained from calculation-based or hybrid approaches [44]. Hybrid approaches can provide a balance between accuracy and complexity. Ultimately, the need for EQ, insights into how a building is using energy and what improvements can be included to reduce EC and costs [31, 63, 91].

Compared to calculation-based and hybrid approaches, data-driven EQ measurements can provide more accurate and detailed insights into the EP of a building [92]. The existing legislation in many countries typically requires the use of calculation-based or hybrid approaches for EQ in EP Criterias [85]. However, careful validation and calibration of these models would be necessary to ensure their accuracy and reliability before they can be widely used in energy performance criteria (EPC). The year wise distribution of research articles reviewed on EAE research criteria among the total number of research articles reviewed for the respective year is represented graphically in the *Figure 7*, additionally it displays the research growth and literature trends.

### 3.4The role of GBRS in designing and constructing sustainable structure (DCSS)

GBRS evaluate the sustainable design and performance of buildings, making them comparable and helping to promote sustainability in the built environment. GBRS typically assess and predicts a BEP over its entire lifecycle, using a set of criteria and metrics that evaluate its environmental impact, resource efficiency, and occupant health and comfort. By using GBRS, buildings can be designed and constructed to consume fewer natural resources while providing occupants with comfortable and healthy indoor environments [73, 23]. This can lead to reduced EC and water consumption, lower operating costs, and improved environmental performance over the building's lifetime [93, 94]. For example, in the energy and atmosphere category, structural engineers can help to reduce a building's EC by optimizing the design of building envelopes and HVAC systems. In the materials and resources category, structural engineers can contribute to deciding SM and the reduction of construction waste. The lifecycle estimated contribution of embodied energy and operational energy (OE) are 20% and 80%, respectively; thus, generate significance of GBRS to promote DCSS [3]. The distribution of various criteria constituting GBRS based on conducted study is represented in *Figure 8*. *Table 2* shows the summary of the organizations developed by United States Green Building Council (USGBC) around the world to achieve sustainability, to monitor and assess the building performance on several parameters.

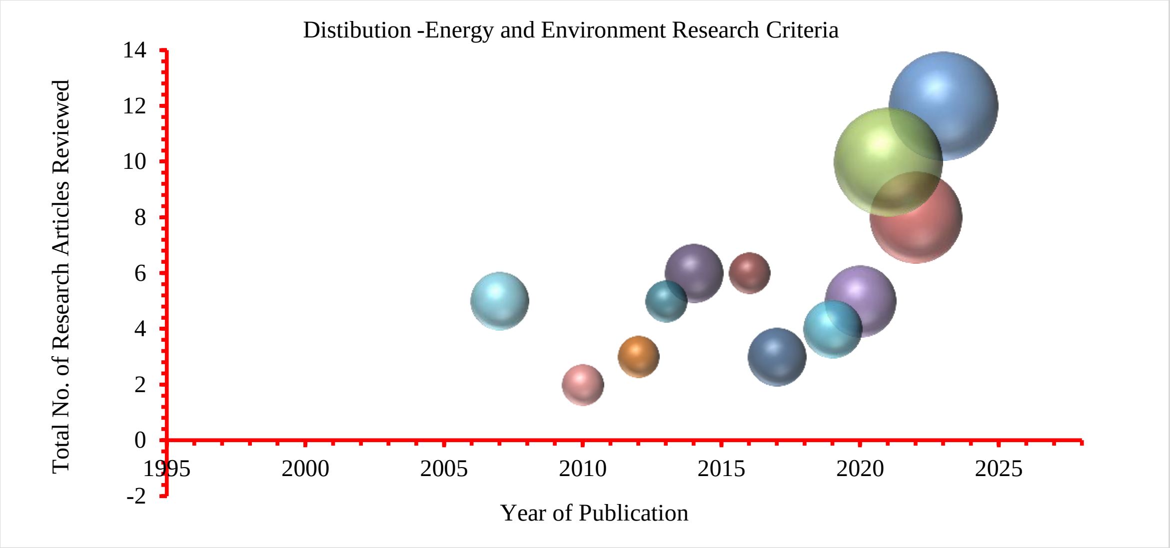


**Figure 7** Research articles distribution- EAE research criteria

**Table 2** Organizations developed by USGBC around the world for sustainable construction [76]

| **Developed organizations** | **Summary** |
|---|---|
| BREEAM | • First developed, UK-1990 by the BRE.<br>• Assesses the environmental performance of buildings across a range of categories, including energy use, water consumption, materials, and ecology.<br>• Also checks factors such as pollution, transport, and management processes.<br>• The assessment is based on a scoring system, and buildings can achieve ratings ranging from "Pass" to "Outstanding".<br>• Adopted in over 70 countries around the world and assess the sustainability of varying range of building types. |
| Green Building Council of Australia (GBCA) | • Is a comprehensive framework for designing, constructing, and operating SB in Australia.<br>• Introduced by the GBCA in 2003 and became the country's most widely used GBRS.<br>• Covers a wide range of sustainability criteria.<br>• Uses a rating system similar to LEED and BREEAM, with buildings able to achieve ratings ranging from 4 to 6 stars, and in some cases, a "Green Star - Performance" rating for ongoing operational performance. |
| LEED | • US developed, it has since become a global standard for SB design and SC.<br>• Now used in over 180 countries around the world and has certified over 103,000 projects. |
| Other notable SB standards | Include the living building challenge, the passive house standard, and the WELL building standard. |

**Figure 8** GBRS criteria distribution

### 3.5 Integrated practice and decision (IPD)-making using BIM (tools)

Defines BIM as a process that entails creating, developing, and managing digital representations of physical and functional aspects of a facility [95]. BIM can be resourced for a variety of purposes, including design visualization, cost estimation, scheduling, and construction planning [32, 91]. It can also improve project coordination, reduce errors, and rework, and enhance the resulting quality of construction projects [96]. IPD involves collaboration among different project stakeholders throughout the building lifecycle, with the aim of improving project coordination, reducing errors and rework, and enhancing overall project quality. This approach requires a change in the traditional siloed approach to building delivery, where different project stakeholders work in isolation, and information is shared manually and often fragmented [97]. With BIM, stakeholders can work together in a digital environment to create a single source of truth for project information [44]. This information can be accessed and analysed in real-time, enabling stakeholders to establish informed decisions and improve project outcomes [58]. Additionally, BIM can facilitate automation and machine learning, enabling more efficient and accurate design and construction processes [98, 89, 62]. BIM constitutes a transformation in the conventional approach of building delivery, enabling collaboration and data sharing among different project stakeholders throughout the building lifecycle [99].

Approach to standardize the practice of BIM are at pace in various organizations and countries, with the aim of promoting collaboration, improving project outcomes, and facilitating interoperability among different stakeholders [100].

The works discussed in this paper, integrating sustainable design and the BIM process is essential to achieve efficient, effective, and environmentally friendly building design and construction. By implementing an interoperable operation, it is possible to combine IPD - making by BIM design, visualization, and analysis, allowing for a more streamlined and collaborative approach to SB design [101, 65]. This approach could also result in cost savings, improved energy efficiency, reduced waste, and reduced GHG emissions [102, 84]. By integrating energy simulation analysis with BIM, architects and engineers can examine the BEP at the early design stages and make necessary changes to achieve EE buildings [78,103]. BIM can also be used to identify the optimal orientation of the building, shading devices, and glazing types to optimize BEP [104].

The visualization capabilities of model can help designers make more sustainable design choices, and also assist in communication with stakeholders about the design and its environmental impact [105,106]. The year wise distribution of research articles reviewed on others or miscellaneous research criteria among the total number of research articles reviewed for the respective year is represented graphically in the *Figure 9*, additionally it displays the research growth and literature trends.

The study of the reviewed articles based on the PRISMA methodological approach and discussion as per the research criteria, limitations and advantages, the summary is tabulated in *Table 3* representing significant findings aimed to strengthen collaborative work between design and construction team, simulation of BIM (tools) to enhance design relevancy, to emphasize environmental concerns and occupant well-being, to elevate energy-efficiency, technological innovation and implementation, GBRS adoption, to raise occupant awareness to achieve SD.

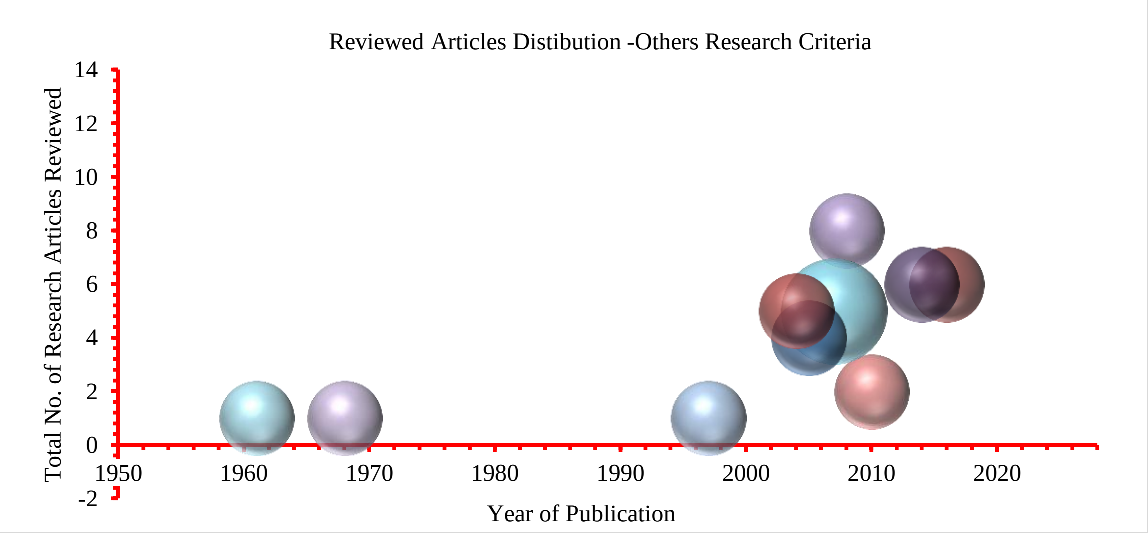


**Figure 9** Research articles distribution- other research criteria

**Table 3** Reviewed articles summary

| S. No. | Research criteria | References | Significant findings |
|---|---|---|---|
| 1 | BAC Practices | [31–47] | Need of Collective effort and work between the design and the construction team, and the expertise in simulation using BIM (tool), lead to enhance the environmental and overall performance of the building. |
| 2 | Design Optimization | [2,24,37,46-50,51–72] | Addresses environmental concerns, improves resource efficiency, enhances economic viability and occupant well-being |
| 3 | EP | [8,23,31,36–38,44,57,63,68, 73–92] | Plays important role in sustainable and resilient energy future, environmental conservation, economic efficiency, technological innovation, policy development, and global energy security |
| 4 | GBRS | [3,23,73,93,94] | Adoption of GBRS contributes to nurture sustainability, mitigating environmental impact, enhances energy efficiency and advances economic and social well-being |
| 5 | IPD-making using BIM (tools) | [32,44,58,62,65,66, 69,78,84,89,91,95–104] | BIM (tools) integration is a methodology that expedites the design process to effective and enhanced outputs, delivering an optimal building envelope design |

## 4.Discussion, research gaps and limitations

This study reported a review of existing research related to the design and construction of a SS, GHG emissions, GBRS, SB and GB worldwide. In reference to the thorough study conducted in this research, the findings observed during the study have been answered as per the RQ planned in the introduction section of the study. Further, *Figure 10* displays author’s analysis and representation as per the conducted study and discussed in this research article.

*RQ1: How design strategies can be designed to achieve sustainability goals?*

Ans: *Table 4* represents five (5) design strategies to put into practice by the structural engineers to achieve sustainability goals. Strategy 1 brings attention to design SS by considering EE parameters while developing design trials and analysis. Strategy 2 concerned with encompassing green materials to strengthen occupant’s livelihood. Strategy 3 emphasises on development of resilient structures to combat climatic variations. Strategy 4 underlines the implementation of SM in construction sector. Strategy 5 fosters adoption of SC practices by utilising renewable energy and enforcing waste reduction instructions by structural engineers.

*RQ2: How can BIM (tools) contribute to enhance design of building?*

Ans: BIM (tools) contribute to enhance design of building as follows:

(i) Collaborative project development: - BIM (tools) establishes bridge between architects, engineers, contractors, and stakeholders to help them developing and considering design strategies at initial stages of the project for new construction and incorporating the same for re-design and renovation of existing buildings for sustainability.

(ii) Optimization of structure’s EC: - BIM (tools) considers the EE techniques for improving the EC performance by implanting strategies like passive solar design, natural ventilation, and daylight enhancement.

(iii) Sustainability certification compliance: - BIM (tools) aligns assurance of the application of sustainability regulations and certification in accordance with sustainability standards like LEED, GBRS, BREEAM, etc.

(iv) Smart building solutions: - BIM (tools) enables the integration of smart building technologies, which helps in energy usage control, indoor-environment, occupant comfort, thermal comfort HVAC and improves energy efficiency of the building.

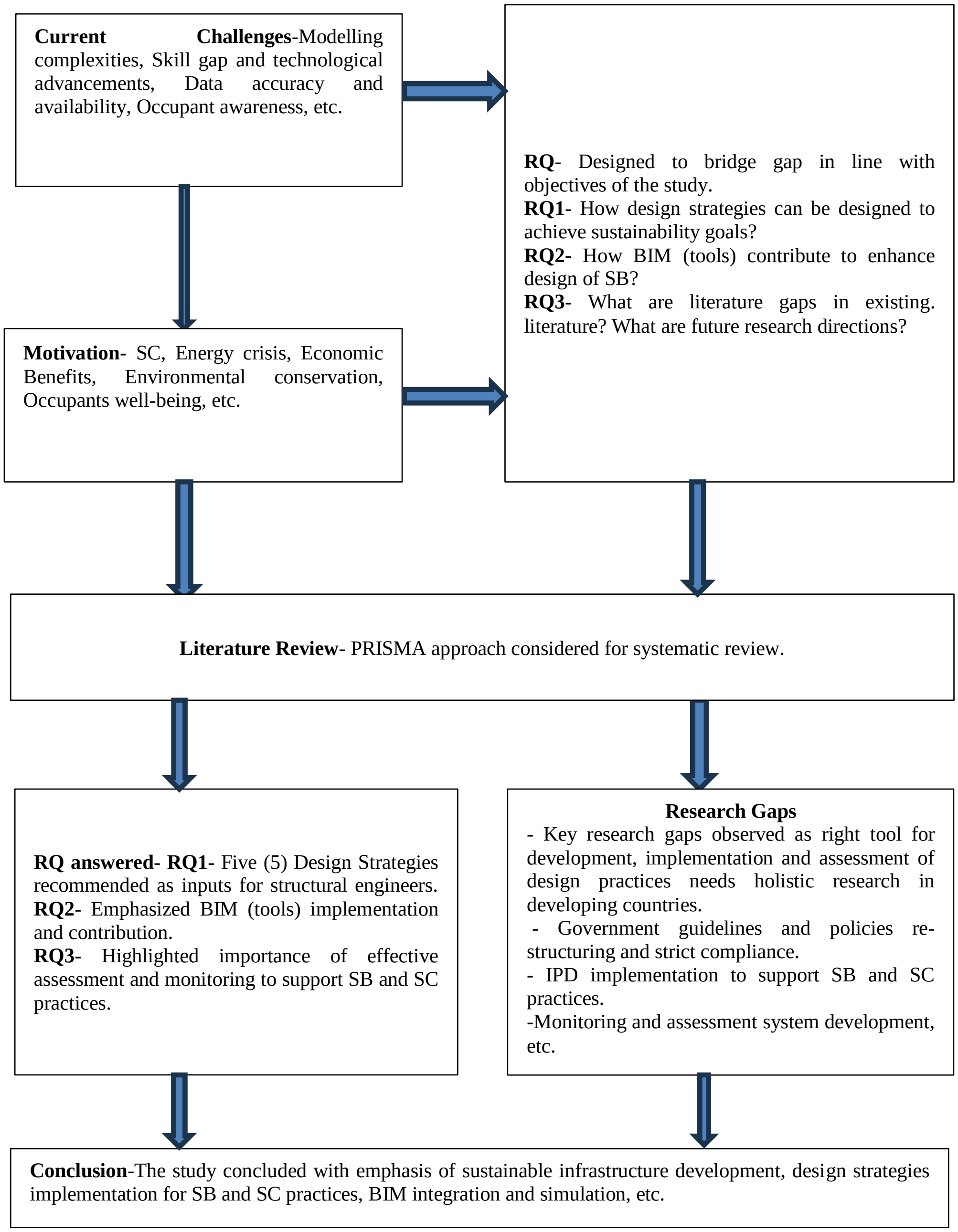
(v) Integration of renewable energy: - BIM (tools) helps designers to check the feasibility of renewable energy sources incorporation into building’s design like solar panels and wind turbines at early stages.

(vi) Construction planning and waste minimization: - BIM (tools) help in efficient planning and coordination in construction practices with reduced generation of waste and maximizing resource utilization.

(vii) Environmental impact assessment and material selection: - BIM (tools) facilitates the assessment of environmental impacts, life-cycle analysis using integration of material at early stages.

**Table 4** Design strategies and structural engineers

| **Design strategies** | **Inputs for structural engineer** |
|---|---|
| Strategy-1 | Designing sustainable and EE buildings that minimize their environmental impact and reduce their carbon footprint. |
| Strategy-2 | Incorporating green infrastructure, such as green roofs and living walls, into building designs to promote biodiversity and improve air quality. |
| Strategy-3 | Developing resilient infrastructure that can withstand the impacts of climate change, such as flooding and extreme weather events. |
| Strategy-4 | Promoting the use of SM in construction, such as recycled or locally sourced materials. |
| Strategy-5 | Adopting SC practices, such as using renewable energy sources and reducing waste during construction. |



**Current Challenges**-Modelling complexities, Skill gap and technological advancements, Data accuracy and availability, Occupant awareness, etc.

**Motivation**- SC, Energy crisis, Economic Benefits, Environmental conservation, Occupants well-being, etc.

**RQ**- Designed to bridge gap in line with objectives of the study.
**RQ1**- How design strategies can be designed to achieve sustainability goals?
**RQ2**- How BIM (tools) contribute to enhance design of SB?
**RQ3**- What are literature gaps in existing. literature? What are future research directions?

**Literature Review**- PRISMA approach considered for systematic review.

**RQ answered**- **RQ1**- Five (5) Design Strategies recommended as inputs for structural engineers.
**RQ2**- Emphasized BIM (tools) implementation and contribution.
**RQ3**- Highlighted importance of effective assessment and monitoring to support SB and SC practices.

**Research Gaps**
- Key research gaps observed as right tool for development, implementation and assessment of design practices needs holistic research in developing countries.
- Government guidelines and policies re-structuring and strict compliance.
- IPD implementation to support SB and SC practices.
-Monitoring and assessment system development, etc.

**Conclusion**-The study concluded with emphasis of sustainable infrastructure development, design strategies implementation for SB and SC practices, BIM integration and simulation, etc.

**Figure 10** Block diagram- author's analysis and representation

*RQ3: What are literature gaps in existing literature? What are future research directions?*

Ans: - Research gap and future research directions observed for the study conducted:

- It has been observed that there is a need for comprehensive research in developing countries to create the appropriate tools for the development, implementation, and assessment of design practices by designers, aimed at contractors and builders.
- It is observed that there is a need to develop, restructure, and implement government guidelines and policies for construction practices. These should be adopted by contractors and builders in developing countries, ensuring strict compliance.
- The importance of developing effective assessment approaches to support sustainable building (SB) practices and enable informed decision-making by stakeholders and communities is highlighted.
- The need to develop a monitoring system to assist in and check the implementation of design and construction strategies by builders and contractors at different stages of building development has been observed.
- The need for developing alternative methods and decision scrutiny through building life cycle costing techniques prior to the actual construction phase of projects has been observed.

Limitations based on the conducted study- Only 106 number of papers ranging from 1961 to 2023 selected for the review considering inclusion and exclusion criteria in the PRISMA approach conducted for the study. This study may be explored by including a greater number of research articles and implementing different approach.

List of abbreviations arranged in *Appendix I*.

## 5.Conclusion & future research directions

This study highlights the importance of sustainable infrastructure development and its three main categories: defining SB, analysing their benefits and costs, and identifying ways to achieve SC. The study mentions various strategies in terms of energy-efficiency enhancing residential sustainability, energy reward systems, green homes, energy-saving appliances, renewable energy utilities, and public awareness campaigns. The critical role of designers in minimizing construction waste and leveraging modern technologies like BIM and Revit is noted. BIM is becoming more widely adopted by commercial contractors for various reasons, including client requirements, innovation, and the need to stay competitive. Its use has been shown to improve processes and profitability, as well as efficiency and effectiveness in project management. BIM is also supported by various software tools like Revit architecture, structural and mechanical, electrical and plumbing (MEP) and cost-X, which help to manage various aspects of construction projects. This study also stresses the need for developing countries to raise awareness about SB practices and trends. It is observed that a sustainable future requires sound infrastructure that addresses EC issues, is implemented, and monitored using clear frameworks, and benefits from innovative and sustainable design and construction practices. As detailed earlier, the main aim of the study was to study literature, gaps, & future research directions for SB, and the need for the design and construction of SS.

There is a need for more research to facilitate transparent decision-making in SB practices. By quantifying the impacts of structural design practices, stakeholders and communities can make informed decisions that promote sustainability and minimize waste. The findings of this review and its interpretations could be valuable for empirical research and case studies across various sectors.

## Acknowledgment

None.

## Conflicts of interest

The authors have no conflicts of interest to declare.

## Data availability

Not applicable.

## Author's contribution statement

**Ujjwal Bharadwaj:** Conceptualization, investigation, writing–review and editing. **Anshuman Singh**: Investigation, writing – original draft and supervision.

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## Appendix I

| S. No. | Abbreviation | Description |
|---|---|---|
| 1 | BAC | Building and Construction |
| 2 | BEP | Building Energy Performance |
| 3 | BIM | Building Information Modelling |
| 4 | BREEAM | Building Research Establishment Environmental Assessment Method |
| 5 | $CO_2$ | Carbon Dioxide |
| 6 | DAE | Design and Engineering |
| 7 | DCSS | Designing and Constructing Sustainable Structure |
| 8 | EAE | Energy and Environment |
| 9 | EAM | Energy Analytical Modelling |
| 10 | EC | Energy Consumption |
| 11 | EE | Energy-Efficient |
| 12 | EP | Energy Performance |
| 13 | EPC | Energy Performance Criteria |
| 14 | EQ | Energy Quantification |
| 15 | GB | Green Building |
| 16 | GBCA | Green Building Council of Australia |
| 17 | GBRS | Green Building Rating Systems |
| 18 | GHG | Green House Gases |
| 19 | GRIHA | Green Rating for Integrated Habitat Assessment |
| 20 | HVAC | Heating Ventilation and Air-Conditioning |
| 21 | IEA | International Energy Agency |
| 22 | IPD | Integrated Practice and Decision |
| 23 | LEED | Leadership in Energy and Environmental Design |
| 24 | MEP | Mechanical, Electrical and Plumbing |
| 25 | OE | Operational Energy |
| 26 | PRISMA | Preferred Reporting Items for Systematic Review and Meta-Analysis |
| 27 | RQ | Research Question |
| 28 | SB | Sustainable Building |
| 29 | SC | Sustainable Construction |
| 30 | SD | Sustainable Development |
| 31 | SM | Sustainable Materials |
| 32 | SS | Sustainable Structure |
| 33 | TBL | Triple Bottom Line |
| 34 | USGBC | United States Green Building Council |
| 35 | WoS | Web of Science |