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The Development of Green Building Technologies in Bangladesh: A Systematic Review

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Abstract

Following the 1960s global energy crisis, extensive research and initiatives have been undertaken to enhance energy efficiency and reduce environmental pollution. Understanding the construction process of eco-friendly buildings is essential for promoting their increased implementation. This review study aims to thoroughly examine the current literature on green buildings and identify several recurring themes: the conceptualization and scope of green buildings, the measurement of their advantages compared to traditional structures, and various strategies for implementing green building practices. The government has implemented measures to promote green-building technologies for sustainable development practices in the construction industry. However, the uptake of green buildings in Bangladesh continues to face criticism due to insufficient and sluggish government support. This systematic review study thoroughly analysed 71 relevant articles from reputable academic journals published between 2012 and 2024 and constructed a conceptual framework for the adoption of GBTs in the building sector. This study ultimately provides valuable insights into green buildings for researchers, stakeholders, governments, and policymakers, thereby contributing to the advancement of green building literature. Several areas require further investigation to address the specific needs of particular demographic groups and ensure long-term adaptability, including the collection of more comprehensive evidence on the life-cycle costs and benefits of green buildings.

Keywords: Construction Industry, Economic Factors, Environmental Factors, Green Building Technology, Social Factors, Technological Factors.

Introduction

In past decades, the Architecture, Engineering, and Construction (AEC) sector has employed the terms "sustainability" and "green" interchangeably. Identify this common interchangeability and absence of explicit distinction, especially in the construction industry (1). Population, industrial activity, uses of resources, and pollution may degrade living standards by increasing global awareness of environmental issues and climate change (2). Climate change and its effects on the built environment are now widely recognized as global issues (3). The Paris Climate Agreement aims to limit global warming to 1.5°C, and buildings must reduce energy use by 30% by 2030 (4). Nearly 40% of demolition debris and GHG is created from the building industry (5). Furthermore, the construction industry significantly consumes natural resources; therefore, sustainable construction practices must be prioritized globally (6). Sustainable construction is embraced in developed nations; however, many developing countries, including China, India, Sri Lanka, Indonesia, Malaysia, Thailand, Pakistan, and Bangladesh, face challenges in addressing environmental degradation and implementing green building policies and agendas(7, 8). Bangladesh, a rapidly developing country in South Asia, confronts the challenges of urbanization and sustainable development (9). Bangladesh has several significant projects, including power plants, deep-seaports, high-tech parks, and rapid transit projects (MRTs). Additionally, Bangladesh has consistently held the top position in environmental air pollution worldwide over the past decades (10). The construction sector in Bangladesh accounts for a significant portion (10%) of the nation's total greenhouse gas emissions (11). Several studies have focused on the adoption of green building practices to minimize environmental damage and reduce buildings' dependence on primary energy sources. Traditional construction methods are detrimental to the local environment, ecological balance, and

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community well-being (12). However, green building practices aim to mitigate these negative environmental impacts. Green buildings (GB) are designed, built, and maintained to reduce or eliminate adverse effects on the climate and environment (13). GB enhances building energy efficiency, indoor air quality, and the management of construction and demolition waste (14). Green buildings are characterized by their design and operational practices, which emphasize creating the healthiest environment (15). Thus, improving structural ecological efficiency has become the main objective of green building adoption (16). The construction industry in Bangladesh faces numerous challenges in addressing the development issues of insufficient housing and inadequate infrastructure, while striving to operate in a socially and environmentally responsible manner (17). Green buildings reduce environmental impact, conserve natural resources, and create a healthy living environment (18). Green and eco-structured buildings have surfaced as viable solutions to these challenges. Therefore, sustainable construction practices are essential in Bangladesh. Despite the growing interest in green building technology worldwide, the understanding of its adoption in Bangladesh remains limited (10). Current research primarily focuses on technological features and environmental benefits, yet it does not thoroughly examine public awareness and perceptions. The effectiveness of policies, financial challenges, and the responsibilities of key players, including real estate developers, are also not well studied. This study aims to address these gaps by focusing on the benefits of green buildings, raising public awareness, identifying influential factors, and developing a conceptual model for adoption, as well as evaluating policy initiatives that support the adoption of green building technology in the construction industry in Bangladesh. The vulnerability of Bangladesh to natural disasters such as floods, cyclones, and earthquakes underscores the importance of adopting resilient and sustainable construction methods that can withstand these environmental challenges and provide safe, durable housing for the population (9). Embracing green building technologies and circular economy principles can help minimize the construction industry's environmental footprint (10). Bangladesh is raising awareness of its status as a developing nation, although the implementation of green buildings is still in progress. A limited amount of research has been carried out on green buildings in Bangladesh. This study aims to examine how building professionals generally perceive green buildings. Therefore, it is essential to analyze the previous literature related to the adoption of green building technology and its necessity to research the current situation and prospects. Based on the above discussion, this paper presents the following research questions: What are the key benefits of adopting green building practices? What significant challenges does the green building development sector encounter? How have green building rating systems progressed? This systematic literature review (SLR) paper makes a significant contribution to the existing literature by developing an integrated framework that encompasses the antecedents and moderators of this construct to examine and integrate the findings from the studies in our selected sample (19). This study is organized as follows: First, it explains the background information of the study; second, it presents the literature search and selection strategy; third, it justifies the conceptual framework and highlights the significance of GBT's adoption in the building sector; fourth, it discusses the research implications; and finally, it concludes with practical recommendations.

Development of Green Building

Definition and Concept of Green Buildings

The term "green building" is the generic name for the idea of "sustainable buildings" in terms of architecture, construction, operation, maintenance, renovation, and demolition of buildings, taking into account the environment and the productivity of sources, minimizing harmful environmental effects and taking into account the comfort and well-being of the inhabitants at all times (20). The origins of green construction can be traced back to the energy crisis of the 1960s, which prompted extensive research and initiatives to improve energy efficiency and reduce environmental impact (8). In the literature, the terms "green building," "sustainable building," and "high-performance building" seem to be used interchangeably (21). Concerns regarding the construction industry's impact on human health, energy use, and the global climate crisis have led to

GB becoming a prominent area of research. A green construction strategy effectively promotes a healthy environment while conserving energy and resources (22). Green construction aims to integrate energy-saving measures, conserve water, minimize waste, mitigate pollution, enhance resource efficiency, and improve indoor environmental quality throughout the building's life cycle (21, 23). In addition, green buildings (GB) have been considered a viable way to achieve environmental, economic, and social sustainability in the construction industry (24). Understanding the significant challenges of adopting GB technologies (GBTs) to succeed and gain popularity is critical. Amal and Kunal noted that "Green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment by efficiently utilising energy, water, and other resources, protecting occupants' health and improving employee productivity, and reducing waste, pollution, and environmental degradation." (25). Thus, one of the fundamental principles of environmentally friendly construction is to utilize a highly cohesive workforce that considers all aspects of the building's lifecycle. Some scholars have attempted to elucidate the concepts of GBs and sustainability. However, this approach may result in a limited comprehension of GBs, potentially impeding their development. It is posited that while GBs evolve, the environment remains a central concept (26). Generally, Green Building (GB) principles, including sustainable land development, water efficiency, energy efficiency, reduced material resource utilization, and indoor environmental quality, are employed to evaluate Green Buildings (GBs). Sustainability is a continuous development concept that depends on the building practices of various countries. It comprises four dimensions: environmental, social, economic, and institutional. Depending on different development scenarios, the concept of sustainability can encompass all aspects of human activity (27). Conversely, a sole emphasis on energy conservation and environmental aspects, while ignoring social, economic, and institutional factors, impedes the progress of green buildings (GBs). Many GB concepts are thriving and progressing well, yet numerous obstacles and misunderstandings surrounding GBs remain. The preceding discussion and literature indicate that energy efficiency, lower maintenance and operation costs, and the extended lifespan of GBs are the primary factors that drive their adoption. These definitions suggest that GB is a promising contractual method that will aid in sustainable development in the construction industry. Globally, various countries have adopted different definitions of green buildings based on their environmental contexts and resources. Table 1 presents a range of GB definitions gathered from different organizations.

Table 1: Definitions of Green Building

Country	Organization	Definition	Source
USA	World- Green Building Council (WGBC)	"Reduce negative impact and enhance positive impact. -Negative: design, construction, and operation stages; -Positive: climate and natural environment."	(28)
	U.S. Green Building Council(USGBC)	"A green building is a building that, in its design, construction, or operation, reduces or eliminates negative impacts, and can create positive impacts, on our climate and natural environment."	(29)
	U.S. Environmental Protection Agency (EPA)	"An environmentally friendly structure creation practice. -Be resource-efficient throughout the entire life cycle."	(28)
UK	Building Research Establishment	"BREEAM, GB certification may embody the concept of green buildings as more sustainable environments that enhance the well-being of the individuals who reside and work in them, aid in the protection of natural resources, and render property investments more appealing."	(28)
Europe	European Commission	"A Sustainable Building contributes to preserving the environment and also increasingly extends to the well-	(8)

	Delegation	being of the occupants, both in terms of space usage and air quality."	
Germany	German Sustainable Building Council (DGNB)	"Sustainable building means consciously using and introducing available resources, minimising energy consumption, and preserving the environment."	(30)
France	Haute Qualite Environment (HQE)	"Certificated sustainable building enhances the overall quality of life of the structure, including its performance across four key areas. The certification scheme evaluates energy, environment, health, and comfort."	(31)
Australia	Green Building Council Australia(GBCA)	"Green building incorporates principles of sustainable development, meeting the needs of the present without compromising the future."	(32)
Japan	Architectural Institute of Design Japan (AIJ)	"A sustainable building (green building) is designed (1) to save energy and resources, recycle materials, and minimise the emission of toxic substances throughout its life; (2) to harmonise with the local climate, traditions, culture, and surrounding environment; and (3) to be able to sustain and improve the quality of human life while maintaining the capacity of the ecosystem at the local and global levels."	(8)
China	Assessment Standard of GBs	"Green building refers to a building that saves resources to the extent within the entire life cycle of the building, including energy, land, water, and materials, while protecting the environment and reducing pollution so it provides people with a healthy, comfortable, efficient use of space and works in harmony with nature."	(33)
Singapore	Inter-Ministerial Committee for Sustainable Development (IMCSD)	"Green buildings are energy and water-efficient, with a high-quality and healthy indoor environment integrated with green spaces and constructed from eco-friendly materials."	(28)
Malaysia	Green Building Index(GBI)	"a green building is any development project or building that eliminates or reduces the negative environmental implications in its design, construction, and later occupation."	(34)
India	Indian Green Building Council(IGBC)	"A green building improves energy efficiency, limits water consumption, and maximises the use of recycled and locally available, recyclable, and nontoxic materials".	(35)

Overview of Green Buildings in Bangladesh

Bangladesh has been selected as the primary country for this study because of its significant potential and progress in the targeted area. The government has shown remarkable economic growth over the past decade, with a GDP growth rate averaging 6-7% annually (36). This positions it as one of the fastest-growing economies in South Asia, surpassing many neighboring countries in terms of economic resilience and industrial expansion. Additionally, Bangladesh has experienced rapid urbanization, with 42% of its population now living in urban areas (37). This urban expansion has led to a heightened focus on sustainable development and the adoption of green technologies, making it an ideal case for research in this field. Adopting sustainable construction methods and practices is crucial for minimizing environmental impacts and supporting the development of emerging nations (38). The promotion and implementation of green buildings (GB) in developing nations, such as the construction industry in Bangladesh, cannot be

overstated, considering that developing countries contribute approximately 60% of the total greenhouse gas emissions from the construction sector (39). The positive impact of green buildings on the environment and human health (40). Additionally, it highlights the significance of green buildings in sustainable development and their contribution to mitigating the negative environmental impacts on the construction industry (10). The goal of green construction is to integrate energy-saving measures, water conservation, waste reduction, pollution reduction, resource efficiency, and enhanced interior environmental quality throughout the building's life cycle (21, 23). However, the sluggish development of green buildings in Bangladesh can be attributed to various barriers and problems (41). Previous research has identified significant barriers to the implementation of green building technologies in the construction industry, including a lack of green building data, skills, stakeholder awareness, expertise, top management engagement, knowledge, and well-documented green construction regulations, as well as limited availability (42). According to the World Air Quality Report 2024, Bangladesh is the second most polluted country in the world, as ranked in recent years, which was 15 times more than the World Health Organization (WHO) guidelines (43). It is necessary to reduce pollution by implementing sustainable building or GBTs in the construction sector (41). For this purpose, some organizations are working on adopting green buildings or green industry in the construction sector slowly, such as the Sustainable and Renewable Energy Development Authority (SREDA), Bangladesh Green Building Council (BGBC), Department of Environment (DoE), Bangladesh Environment Lawyers Association (BELA), Bangladesh Green Building Academy (BGBA), Ministry of Energy and Mineral Resources, Ministry of Housing and Public Works (PWD), Institute of Architects Bangladesh(IAB), and World Bank(WB) (41). These organizations collaborate to implement environmentally friendly buildings in the development area. Therefore, based on the economic growth trajectory, increasing urbanization, policy support, and commitment to sustainability, Bangladesh stands as the most suitable country for this study. The following section discusses the green-building certification system.

Green Buildings Certification Systems in Bangladesh

Green building certification must satisfy environmental impact minimization requirements by reducing energy, waste, and water consumption (44). Green buildings encompass planning, design, construction, and maintenance, with a primary focus on energy and water usage, indoor environmental quality, material selection, and site placement within the community (45). These components represent the essential criteria for numerous credit categories in green-building certification systems. The Institute of Building Research's Environmental Assessment Method (BREEAM) was the first rating system established in the UK in the 1990s, providing a structured framework for analysing the installation and effectiveness of green buildings (GB). Subsequently, governments and third-party organisations in several nations devised comprehensive GB evaluation methods to enhance the quality of construction (8). Some of the established green building rating systems worldwide (46). Table 2 outlines the rating systems used by various countries:

Table 2: List of Certification Names with Respective Countries

SL	Country	Certification Name
1	USA	LEED
2	UK	BREEAM
3	Singapore	BCA GREEN MARK
4	China	GBCI
5	South Korea	KGBCC
6	Hong Kong	BEEM PLUS
7	Australia and New Zealand	GREEN STAR
8	Malaysia	GBI
9	Indonesia	GREENSHIP/EDGE
10	India	IGBC/GRIHA

11	Japan	CASBEE

The Bangladesh Green Building Council (BGBC) was established in 2009, bringing together all the leading stakeholders on a platform to strive towards making the country "greener" (10). The Council provides certification and training programmes to encourage architects, builders, and developers to embrace sustainable building practices. The Green Building Rating System enables investors, companies, and individuals to identify buildings that demonstrate a commitment to sustainability. This system served as a benchmark for evaluating environmentally friendly constructions by utilising a credit and point system. Each credit in the rating system assessed the efficiency of building operations and awarded points when the criteria for specific categories were met. The points earned across all categories were matched, and the total score achieved by the building corresponded to its certification level in terms of sustainability. The LEED certification system has been adapted because Bangladesh does not yet have its own certification system. The green building information gateway in Bangladesh has reported that approximately 748 LEED activities, including certification and registration, and 164 buildings have already received LEED certification (47). The BGBC assigns ratings to buildings in the following categories: The certification levels and their corresponding point requirements are displayed in Table 3, and Table 4 illustrates how the points necessary for certifications are allocated across different categories.

Table 3: Required Points for LEED Certification

Name of Certificate	Average Points
Platinum	Over 80 points
Gold	60-79 points.
Silver	50 – 59 points.
Certified	40-49 points.

Table 4: Points Distribution of Green Certification Criteria (48)

No.	Components	Possible Points
1	Sustainable sites	26
3	Water efficiency	10
4	Energy and atmosphere	35
5	Building materials and resources	14
6	Indoor environmental quality	15
7	Innovation in design	6
8	Regional priority	4
	Total Points	110

Overall Benefits of Green Constructions

The expansion and evolution of urban areas have a considerable effect on our ecological surroundings. Similarly, manufacturing, designing, constructing, and running buildings substantially influence the environment, public health, and economic conditions. Using green buildings can maximize the social, financial, and environmental performance of buildings. Green buildings are designed to be healthier and provide a pleasant working environment (49). Adopting eco-friendly practices is further motivated by the many benefits associated with sustainable construction (25). These include the following:

Social Benefits

- Improved occupancy satisfaction, comfort, and individual productivity
- Expanding the market for environmentally preferable products.
- Improved daylight quality, thermal comfort (5%), and better ventilation.
- Limited waste generation due to recycling and reuse.
- 40% lower carbon emissions and 70% less construction waste

Economic Benefits

- Enhanced energy efficiency, decreased the need for additional energy infrastructure, lowered energy expenses for users, and reduced fuel and electricity costs by as much as 70 perent per year.
- 25-30% less energy use and water 30-50% without sacrificing comfort
- Increase the productivity of workers by approximately 25%.
- Site preparation, construction materials, and operating activities reduce costs by 25-30%.
- Enhanced water conservation techniques have decreased yearly water usage and sewage processing expenses.

Environmental Benefits

- Enhanced preservation of land, minimized consumption of resources and energy, and safeguarding of ecological assets.
- Improved indoor air quality and reduced air pollution levels.
- Acoustic and noise reduction of 66% and a faster recovery rate at medical facilities.
- Improved retail sales, rent of green building is a premium compared to traditional building
- Occupancy rate higher than that of conventional buildings
- Additionally, it contributes to reducing carbon emissions by generating fewer waste products and minimizing the emission of harmful gases into the environment.

Challenges of the Implementation of GBTs

Scholarly, this study has identified several limitations to the implementation of green buildings, including budget constraints, a lack of public awareness, and reluctance from project owners (47). Several challenges faced by the construction sector include limited involvement from stakeholders, particularly occupants; mismatched technology utilization due to a lack of knowledge; and inadequate training and education for occupants on green building technologies (8). It also highlights (i) the insufficient knowledge and technology, (ii) the substantial initial costs, and (iii) the lack of regulation of government policy to implement sustainable building strategies. For example, public awareness campaigns can increase market demand, reduce the costs of green technologies, and encourage further innovation (50). On the other hand, the complexity and ease of installation, operation, and maintenance of green building technologies affect their adoption rates. For broader use, user-friendly technologies, training, and support are necessary. The absence of computer tools and the complexity of BIM models can hinder the adoption of green BIM, emphasizing the importance of usability. Government subsidies, tax incentives, and other financial incentives can significantly impact the adoption of green building technologies (8). Increasing consumer demand for sustainable and health-conscious structures generates market potential for green construction initiatives; however, implementing this policy in developing nations is complicated (7). Additionally, there is a gap in education and training programs for green building professionals within the construction sector. Therefore, there is a need for specialized knowledge in sustainable construction, including vocational training programs and university curricula that focus on sustainability.

Literature Search

Search Strategy

This study employed a systematic review process search strategy, as illustrated in Figure 1. Initially, electronic searches of relevant publications on green buildings or sustainable buildings were conducted from 2012 to 2024, using predetermined inclusion and exclusion criteria. Hence, 2012 is considered the base year of the study and from 2012 to 2024 is the fixed study period. Several search engines are available in online libraries, including Scopus, Web of Science, PubMed, and Google Scholar. In this study, Google Scholar and PubMed databases were systematically utilised with the assistance of Harzing's Publish or Perish software, as recommended by scholars (8). Some scholars posit that Scopus and Web of Science offer superior accuracy, attributable to their more comprehensive coverage of academic literature (51, 52). Some authors recommend utilizing databases and keyword searches to collect relevant information. This study employed two databases and keyword searches to identify relevant articles. The inclusion criteria for the studies are works published between 2012 and 2024, in English only, related to the adoption of green buildings, whether fully or partially. Using the proper Boolean operators, a keyword search for "green buildings," "sustainable buildings,"

"environmental impacts," "economic impacts," "social impacts," and "the construction industry" yielded 282 publications from Google Scholar and 115 publications from PubMed, totaling 397 records. TITLE-ABS-KEY ("Green Building" OR "Sustainable Building" OR "Sustainable Construction" OR "Green Building Technology") AND (LIMIT-TO ("Construction Industry") AND PUBYEAR ≥ 2012 AND PUBYEAR ≤ 2024 AND (LIMIT-TO (LANGUAGE, "English"))). All data were downloaded to the EndNote reference manager.

Selection Criteria

The systematic review process for selecting pertinent articles for the present study comprised three primary stages. The selection criteria were followed based on the PRISMA statement (53). Initially, we utilized the EndNote software to automatically filter articles from the chosen databases, complemented by a meticulous manual review process to ensure the comprehensive elimination of duplicate entries. We employed a methodical approach to review the selected studies, utilizing skimming, scanning, and double-checking techniques. This process involved examining the titles, abstracts, and keywords of the identified research to understand their content concisely based on our subjective assessment. Furthermore, research studies that fell outside the scope or were not pertinent to the objectives of this paper were excluded based on predetermined criteria. Subsequently, we acquired the complete texts of articles that met the eligibility requirements. Figure 1 illustrates the systematic PRISMA approach for evaluating and filtering the collected records. This process significantly narrows the initial pool to 71 articles, subsequently subjected to content analysis. The study's primary objective is to survey existing research on green building technology across various disciplines, including the social sciences, environmental sciences, business, and economics. The research scope covered the timeframe from 2012 to 2024.

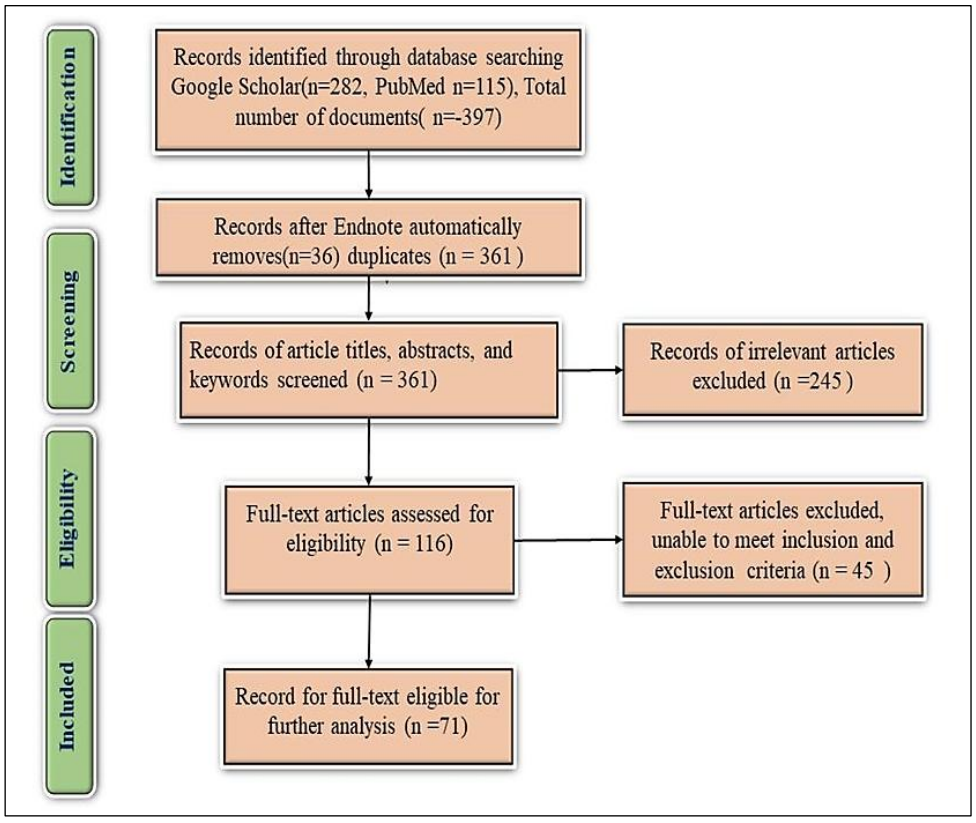

Figure 1: PRISMA Framework for the Study Process

Quality Assessment

This investigation was predicated on original research articles, review papers, and conference proceedings. To ensure the quality of the review, all duplications were identified using EndNote software. The article abstracts underwent a systematic evaluation to ensure the quality and relevance of the scholarly literature included in the review, before analyzing the publication. Each academic paper underwent a comprehensive

assessment and examination. The subsequent exclusion criteria limited the documents to those published exclusively in English. Data searches on Google Scholar (n = 282) and PubMed (n = 115) identified 397 records. After removing duplicate entries from EndNote software, 361 publications were retained. Subsequently, a thorough examination of titles, abstracts, and keywords led to the exclusion of 245 irrelevant documents. This process resulted in 116 full-text articles being selected for further evaluation. The concluding phase entailed examining the substance of the selected publications. Each document was assessed to determine whether it concentrated entirely or partly on sustainable development, green buildings, or green construction practices. Most articles were excluded from the study as they did not satisfy the inclusion criteria. Out of the remaining articles, 45 were discarded, leading to 71 publications focused on Green Buildings. Finally, 71 documents were selected for further analysis in this study. The exclusion and inclusion criteria employed in this study are shown in Figure 1.

Data Extraction

During the data extraction phase, 71 articles were selected based on the following criteria: only original papers, review papers, conference papers, unpublished papers, and case studies were excluded. The articles needed to be written in English and related to the social sciences, business, or economics. Additionally, the extracted articles were published between 2012 and 2024, encompassing both global and local contexts.

Discussion

This study aims to identify trends in Green Building (GB) studies from 2012 to 2024 by systematically analyzing selected GB research articles. Instead of conducting a comprehensive review of all GB-related investigations within the specified timeframe, the study examined several papers to identify patterns and developments in the field. As a result, the findings here rely solely on the analysis of the GB research paper obtained through the specific sampling method discussed in section 3. From the literature, most studies have highlighted the obstacles to the adoption of GBTs. Therefore, this paper focuses on the concept of green buildings, the principles of green construction, certification systems, and factors influencing the adoption of green building technologies (GBTs), referencing the concept of the triple bottom line. In addition, this study emphasized technological and policy regulations. This investigation demonstrated that green buildings are designed to achieve multiple objectives, including enhancing occupant health, improving employee productivity, and utilizing energy, water, and other resources more efficiently. Most studies demonstrated that green building practices are primarily motivated by economic efficiency and environmental sustainability, with non-economic factors, such as social influence, proving to be more influential than financial considerations. Nevertheless, conventional building practices are inconsistent with green building standards. This study highlights the importance of implementing eco-friendly construction criteria and assessment methods to enhance building efficiency and promote environmental responsibility. Its findings are presented in the form of yearly publication patterns and research contributions from various nations, organizations, researchers, and study areas.

Yearly publication trend of GB-related papers

The publication patterns of GB research are illustrated in Figure 2. Among the 71 papers examined, a single publication appeared in the 1997s. This scarcity can be attributed to the GB concept's recent emergence during that decade, resulting in limited publications. In contrast, the subsequent period from 2012 to 2024 saw the publication of the remaining 70 papers, indicating a growing interest in GB among researchers in recent years (54). Figure 2 shows the regional context publications.

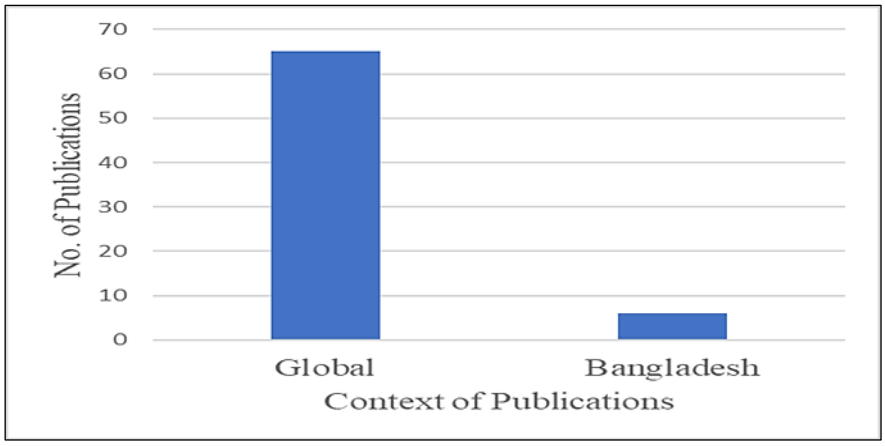

Figure 2: Number of Publications Based on Regional Context

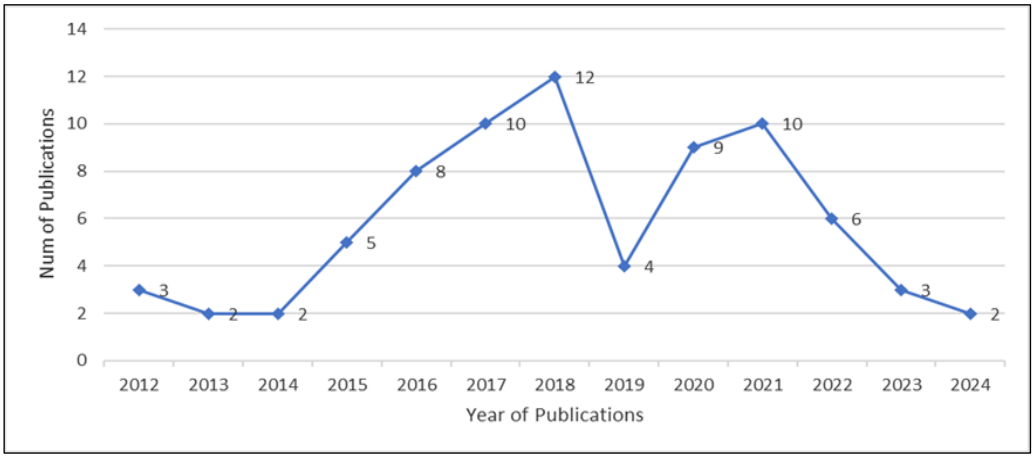

Figure 3: Year-wise GB Publications Movement from 2012 to 2024

Figure 3 shows the year-wise frequency of research papers in this study published from 2012 to December 2024. The number of publications increased rapidly i*n* 2017, 2018, and 2020, with appearances in various journals. This indicates the growing interest among researchers in this field.

Figure 4 shows the papers based on research methodology published from 2012 to December 2024. According to the research methodology, the papers comprise empirical studies (44%), case studies (7%), review papers (34%), conference papers (10%), and book chapters (6%).

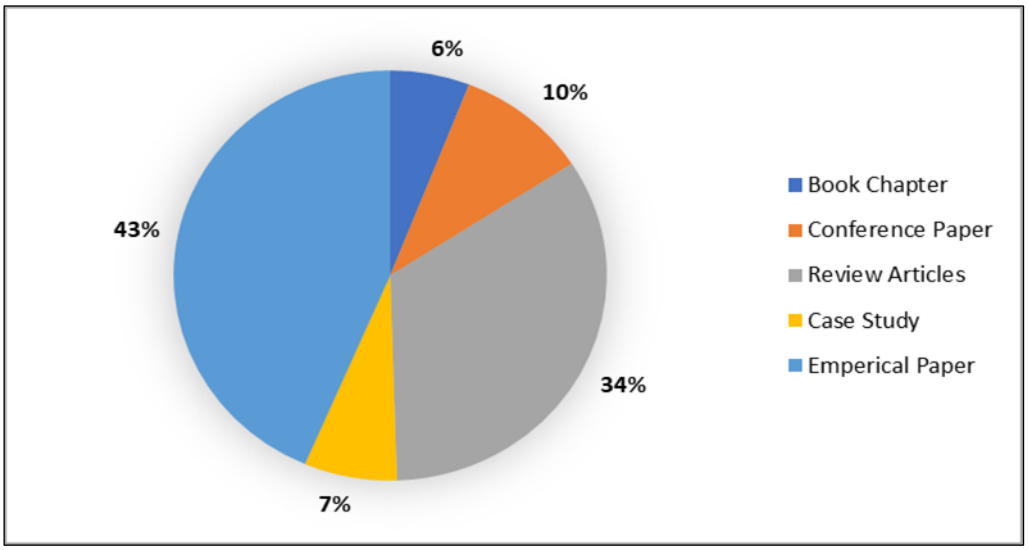

Figure 4: Distribution of Research Documents of This Study

Summary of key Journals with the Number of Relevant Papers

Table 5 presents the key journals with the number of publications in this study. The highest publications were in the Journal of Sustainability, followed by the second-highest in Building and Environment and the Journal of Cleaner Production. Table 5 also shows that most articles were published in the global context, rather than in Bangladesh. This area is highly regarded among researchers in a diverse range of fields.

Table 5: Summary of Key Journals with the Number of Relevant Papers

		Domain	
Name of Journal	**Publications**	**Global**	**Bangladesh**
Journal of Cleaner Production	4	√	
Building and Environment	3	√	
Renewable and Sustainable Energy Reviews	3	√	
Energy and Buildings	2	√	
Journal of Climatic Change	2	√	
Materials Science and Engineering	2	√	
Sustainable Cities and Society	2	√	
Current environmental health reports	1	√	
Habitat International	1	√	
Advances in Science and Technology Research Journal	1	√	
Architecture and Civil Engineering	1		√
Atmosphere	1	√	
Automation in construction	1	√	
Automation in construction	1	√	
Bangladesh Journal of Environmental Research	1		√
Business Innovation and Engineering Conference (BIEC)	1		√
Cleaner Engineering and Technology	1	√	
Computer and Education	1	√	
Conference India	1	√	
Earth and Environmental Science	1	√	
Elsevier	1	√	
Energy Strategy Reviews	1	√	
Engineering Construction and Architectural Management	1	√	
Environment Development and Sustainability	1	√	
Environmental health perspectives	1	√	
IEEE Transactions on Engineering Management.	1	√	
International Exchange and Innovation Conference on	1	√	
International Exchange and Innovation Conference on Engineering and Sciences (IEICES)	1	√	
International Journal of Business Administration	1	√	
International Journal of Business and Economy	1		√
International Journal of Construction Management	1	√	
International Journal of Engineering Applied Sciences and Technology	1	√	
Jeddah Saudi Arabia	1	√	
Journal of Emerging Trends in Economics and Management Sciences	1	√	
Journal of Energy Technologies and Policy	1	√	
Journal of Engineering	1	√	
Journal of Green Building	1	√	
Journal of Management in Engineering	1	√	
Journal of Surveying, Construction and Property	1	√	

Journal of Sustainability Science and Management	1		√
Management Review Quarterly	1	√	
Review of Environmental Economics and Policy,	1	√	
Springer	2		√
Sustainable Cities and Society	1	√	
Sustainable City	1	√	
Technology|Architecture + Design	1	√	
International Journal of Engineering Applied Sciences and Technology	1	√	

Factors Affecting Adoption of Green Buildings

Governmental agencies at various levels, nonprofit organizations, and major multinational corporations are now adopting and implementing green-building policies because of their economic viability and numerous additional advantages that appeal to a wide range of entities. The initial emphasis on sustainability revolved around technical aspects, including materials, building components, construction processes, and energy-related design concepts (55). However, there is growing recognition of the importance of non-technical matters, often referred to as "soft issues." Acknowledging the significance of economic and social sustainability, as well as the preservation of cultural heritage within the built environment, is essential (2). All of these factors were considered equally significant. The sustainability of global advancement hinges on continuous improvement in the realms of the environment, economy, society, technology, policy and regulatory (56).

Environmental Factors: One of the most significant advantages of green buildings is their effect on climate and the natural environment. The building sector is the most crucial for substantially reducing greenhouse gas emissions compared to other major emitting sectors (57). The potential for emissions reduction is estimated to reach around 84 gigatons of CO2 (GtCO2) by 2050 through direct interventions in buildings, including energy efficiency measures, fuel substitution, and the implementation of renewable energy (58). For example, the Green Star certification in Australia results in 62% fewer greenhouse gas emissions than the average Australian building. It uses 51% less potable water than those built to meet minimum industry standards (59). Green buildings that achieve Green Star certification in South Africa have been demonstrated to save, on average, between 30% and 40% of energy and carbon emissions annually, as well as between 20% and 30% of potable water each year, compared to the industry standard (60). Green buildings are designed to minimise the use of natural resources, such as water and energy, while reducing their environmental impact. Sustainable building practices protect natural habitats and biodiversity by minimising the ecological footprint (10). Green buildings can improve air and water quality by reducing pollution and promoting sustainable water management (25). Based on the previous discussion, environmental factors influenced the adoption of GBTs in the building sector.

Social Factors: Green buildings often feature improved indoor air quality, natural lighting, and thermal comfort, which can enhance occupant health and productivity, with blue light positively affecting mood, performance, and sleep (61). Green building projects incorporating green spaces and promoting sustainable practices can foster community engagement and create a sense of place (62). The advantages of green buildings extend beyond economic and environmental concerns, showcasing significant positive social impacts. Many of these advantages relate to the health and well-being of individuals working in green offices or residing in green homes. Employees in green, well-ventilated offices experience a 101 percent increase in cognitive scores (brain function) (63). Research indicates that enhanced indoor air quality (lower concentrations of CO2 and pollutants, along with high ventilation rates) may improve performance by as much as 8 percent (64). Heightened public awareness of the advantages of green buildings can stimulate demand and promote broader adoption (10). Consequently, many studies emphasise the necessity to examine further the social factors affecting GBT adoption.

Economic Factors: Current studies have emphasized the financial aspects of GB, as this is a crucial element that shapes how stakeholders

approach its adoption and implementation. Studies indicate that the primary factors influencing consumer choices are energy conservation, reduced maintenance costs, and enhanced property values (65). Among the key factors driving the adoption of GB, cost reductions and maintenance are particularly influential (66). Conversely, fluctuations in energy costs and efforts to innovate are the primary factors shaping the decisions of developers (65). The common perception is that advanced technology comes with a hefty price tag, and green buildings (GBs) are often considered costly structures. Some studies suggest that certified GBs fail to deliver energy or cost savings. However, opposing viewpoints argue that GBs can substantially reduce energy consumption and expenses while offering eco-friendly construction solutions. According to previous studies, green buildings provide economic benefits that are pertinent to various individual groups. These include reduced utility costs for tenants or households through energy and water efficiency, decreased construction expenses, increased property value for building developers, higher occupancy rates or lower operating costs for building owners, and employment opportunities. We have aimed to strengthen the link between green buildings and the economic benefits they can provide. Global energy efficiency measures could save an estimated €280 billion to €410 billion in energy expenditure (67). Building owners report that green buildings, whether newly constructed or renovated, achieve a 7 percent increase in asset value compared to traditional buildings (68). Reduced energy and water consumption leads to lower operating costs, rendering green buildings financially appealing over time (69). Previous studies have shown that green buildings yield a higher return on investment compared to traditional buildings due to enhanced property values and lower operating costs (69). Government subsidies, tax breaks, and other financial incentives can significantly influence the adoption of green building technologies (70). Growing consumer demand for sustainable and healthy buildings creates market opportunities for green building projects (7). Therefore, it is proven that economic factors influence the adoption of GBTs.

Technological Factors: Various technological aspects significantly influence implementing eco-friendly construction methods in the building sector. The availability and affordability of green-building technologies are key drivers of adoption. As technologies mature and economies of scale are realized, costs decrease, making these technologies more accessible to developers and builders. For example, the cost of solar photovoltaic systems has reduced significantly in recent years, leading to broader adoption (71). The performance and reliability of green building technologies are critical for their acceptance. Demonstrated energy efficiency, water saving, and durability are essential for convincing stakeholders of the value proposition. Studies have shown that green buildings can significantly reduce energy consumption by adopting appropriate technologies (72). Integrating green building technologies seamlessly with existing building systems and construction practices is crucial. Compatibility issues can lead to increased costs and complexity, hindering adoption. Building Information Modeling can facilitate the integration of various technologies and optimize building design for sustainability (73). The complexity of green building technologies and ease of installation, operation, and maintenance can influence adoption rates. User-friendly technologies, combined with accessible training and support, are crucial for broader adoption. The lack of computer tools and the complexities of BIM models can impede the adoption of green BIM, emphasizing the significance of usability (73). Continuous innovation and the development of new green-building technologies are essential for driving further adoption. Research and development initiatives aimed at enhancing performance, reducing costs, and simplifying integration are essential for the future of green energy buildings. The ability to measure and verify the performance of green building technologies is essential for demonstrating their effectiveness and justifying investment. Advanced monitoring systems coupled with data analytics can provide valuable insights into building performance and identifying areas for improvement (74). These technological factors, along with other factors such as government policies, market demand, and stakeholder awareness, collectively influence the adoption of green-building practices in the

construction industry. Based on the above discussion, technological factors are the most important factors in the adoption of GBTs.

Policy and Regulatory Factors: Stringent building codes and standards that mandate or incentivize green building practices can significantly influence adoption rates (75). Supportive government policies, such as tax breaks and subsidies, can encourage developers to invest in green building projects (27). International agreements and commitments to reducing greenhouse gas emissions can drive the global adoption of green building practices (76). These factors interact with and influence each other, creating a complex landscape for green building adoption. Addressing these factors holistically is crucial for promoting widespread adoption and achieving a more sustainable built environment. For example, public awareness campaigns can increase market demand, reduce the costs of green technologies, and encourage further innovation. Government policies and incentives can create a supportive environment for green building adoption by addressing the economic and technological barriers. Therefore, positive government actions could enhance the adoption of GBTs along with other factors.

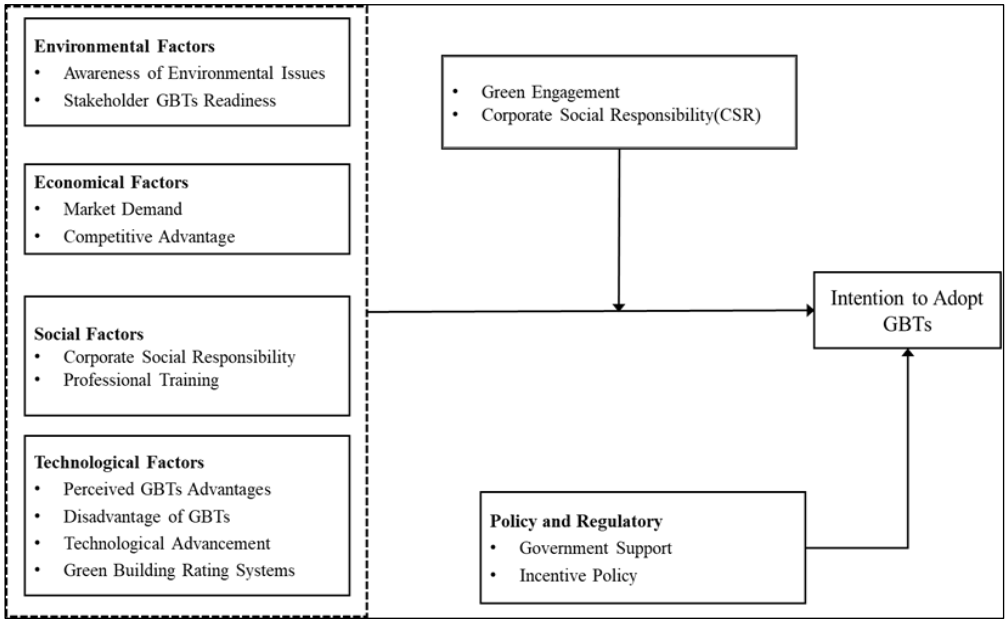

Figure 5: Proposed Conceptual Framework for Intention to Adopt GBTs

Development of a Conceptual Framework for the Adoption of GBTs

Conceptual frameworks for the adoption of green building technologies often draw upon established models and theories from various disciplines. The technology acceptance model and its extensions concentrate on perceived usefulness and ease of use as crucial factors driving technology adoption, and the theory predicts that attitude, subjective norms, and perceived behavioral control influence intentions related to technology adoption (77, 78). The diffusion of innovation theory highlights the importance of relative advantage, compatibility, complexity, trialability, and observability in influencing the adoption of new technologies, including GBTs (79). This study highlights the significance of considering the interests of all stakeholders, including clients, contractors, suppliers, and the community, when making decisions concerning the adoption of GBTs (50). Furthermore, Shaharul et al. (10) noted that these theories and models were integrated to develop comprehensive conceptual frameworks for adopting GBT in the construction industry. In complex GB projects, as cross-disciplinary collaboration intensifies, it becomes increasingly vital to foster collaborative relationships among team members to create a cohesive project (7, 42). The implementation of GBT is positively influenced by stakeholder involvement (62, 80). Drawing from the prior analysis, this research introduced a conceptual framework called the Green Building Technology Model (GBTM), which influences the uptake of eco-friendly construction technologies (62). Previous studies have shown that corporate social responsibility moderates the relationship

between antecedents and the intention to adopt technology. These studies have demonstrated the proposed constructs both theoretically and empirically. Consequently, these constructs are reliable for understanding developers' intentions to adopt GBTs within the construction industry. These studies found that green engagement plays a moderating role. Therefore, the proposed conceptual GBTM model has been devised to facilitate the effective implementation of the GBTs, as illustrated in Figure 5.

Conclusion

Systematic reviews provide a vital means for researchers and practitioners to utilize existing information for actions such as policy development and further research. This study primarily focused on the PRISMA protocol elements established to enhance and maintain the accuracy of systematic review investigations (81). A thorough analysis of research on applying green building technology to reduce environmental impacts in the construction sector of developing nations was conducted. It was particularly evident that most green building experts have overlooked several key components of the PRISMA procedure for systematic reviews. We identified multiple systematic reviews that failed to clearly elucidate their data-gathering methodology, resulting in insufficient transparency regarding data collection and study outcomes. Another constraint pertains to the chosen databases and journals utilized for the systematic reviews. Moreover, we identified significant omissions in the majority of the review publications concerning the dates of data collection, pilot testing, screening, and data extraction techniques (i.e., author deliberations). A flow diagram, as required for systematic reviews, detailing the processes of the systematic review process, was absent in several studies. Based on an analysis of 71 papers, this research identifies the main contributions and knowledge gaps within the existing literature, proposing a conceptual framework for implementing GBTs in the construction sector. The findings of this study can be categorised into three segments: the definition and scope of green buildings, their advantages and costs, and a proposed conceptual framework for achieving them. A comprehensive literature review reveals that most research on green buildings primarily addresses aspects of environmental sustainability, including resource consumption, water efficiency, and greenhouse gas emissions, as well as technical considerations and solutions. In contrast, research into the social and economic dimensions of sustainability remains relatively scarce, despite numerous publications underscoring their significance.

Future Recommendations

This study identified the environmental, economic, social, regulatory policy, and technological factors essential for adopting green practices in buildings. Considering the global trend towards environmentally sustainable practices, identifying the underlying causes is crucial for developing practical solutions. These challenges include energy scarcity, environmental degradation, climate change, population growth, and excess urbanization. The proposed conceptual model can measure the contribution of each component to green building practices. In developing nations such as Bangladesh, the advantages and increased awareness among stakeholders can address these challenges and meet the growing demand for sustainable buildings. Some scholars attribute Bangladesh's limited progress in GB adoption primarily to the absence of incentive policies, government support, and official endorsement of GB. Nevertheless, the implementation of GB in Bangladesh continues to be criticized for its slow pace and insufficient government involvement and support. The government should implement necessary measures to promote GB for sustainable development, such as ratifying regulations or providing support incentives. Moreover, it is advisable to emphasise the importance of enhancing social responsibility and ethical considerations to facilitate GB development. In light of the limitations of systematic reviews identified in the current study's analysis, we argue that there is an urgent need for consistency in systematic reviews within the domain of green building. At the same time, we acknowledge that the PRISMA protocol is mainly designed for researchers undertaking systematic reviews. Moreover, further research on green building is imperative in Bangladesh, and the government should prioritise the significance of green building-related research within the research and development sector.

Abbreviations

BGBA: Bangladesh Green Building Academy, BGBC:

Bangladesh Green Building Council, BREEAM: Building Research Establishment Environmental Assessment Method, GB: Green Building, GBTs: Green Building Technologies, GBTM: Green Building Technology Model, LEED: Leadership in Energy and Environmental Design.

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Author Contributions

Shaharul IM: Conceptualization, Literature Search, Analysis, Writing, Original Draft Preparation, review and editing; Sade AB: Review, editing, and supervision.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Ethics Approval

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