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Review

Innovation in Green Building Sector for Sustainable Future

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Abstract: Recent advancements in green building technologies (GBTs) have grown substantially, as an outcome of the environmental, economic and societal benefits. It has the potential to move toward sustainable development, specifically related to climate change. In GBTs, the main objective is to use energy, water and other resources in a balanced way, without using them extensively. This will improve the environmental conditions. Green buildings (GBs) are beneficial when it comes to energy consumption and emissions; low maintenance and operation costs; boosting health and productivity; etc. There is a lack of a critical review of the past or present research work in the area of the Green Building Technology (GBT) sector to identify the future roadmap for sustainable green building technologies. A critical review, with the help of proper research methodology, was identified. The scope of this study is to analyze the existing work on different issues, and find different key issues in green building research, which has minimal use of natural resources, is cost-effective and is designed and constructed for a longer duration, considering future prospects. This paper examines the state of green building construction today and makes recommendations for further study and development which will be necessary for a sustainable future. In order to encourage research, this study also identified a few possible future research directions in sustainable development.

Keywords: sustainability; green building; resources; environment; waste reduction; health; zero energy building

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1. Introduction

Recently, the sustainability concept has become highly significant. GBs are an important part of the sustainability concept. The GB concept requires all our resources are used in a balanced proportion, without using them extensively and would also improve the conditions of our environment and lifestyle. The operation of GBs promotes a healthy environment by reducing the load on water, land and energy resources. There are seven main components of green building, related to Life Cycle Assessment (LCA); site and structure design efficiency; efficient materials; indoor air quality enhancement; energy efficiency; water efficiency; and waste reduction. According to the Environmental Protection Agency (EPA), "green building refers to creating structures and using processes that are environmentally friendly and resource-efficient throughout a building's life cycle, from site to design, construction, operation, maintenance, renewal and deconstruction. GBs practice design such classical buildings which keep economy, utility durability and comfort in concern". A Green Building (GB) is also called a "sustainable or high-performance building". The design of GBs is performed in such a way that our environment and lifestyles get better and upgraded by reducing environmental pollution, using efficient uses of natural resources and improving health productivity. A systematic review of the GBs has been reported in this paper. Similarly, the overall research and development work conducted on GB technologies has been discussed. It is expected that utilizing the renewable energy technologies in the buildings with proper planning will provide a sustainable solution for the GB Field. Zuo and Zhao, 2014 [1], have reported that green building is a practice that is eco-friendly, improves occupant's health, recycles and reuses sustainable material, reduces CO_2 and other harmful gas emissions and encourages more plantation and greenery. Leadership in Energy and Environmental Design (LEED), Building Research Establishment, Environmental Assessment Method (BREEAM) and Green Building Council of Australia (GBCA) are rating tools that keep improving and adding new features to make the best out of GBs. GB can be achieved through three categories: technical, managerial and behavioral. It plays a crucial role in achieving net zero energy building. As the population and pollution is increasing, it is important to adopt the GB concept, and for that purpose awareness, knowledge and implementation is the key. In terms of environmental benefits, GBs saves 20–30% in water and saves 40–50% in energy, compared to conventional buildings. These buildings improve air quality by 8%. It also protects our biodiversity and ecosystem. From an economic point of view, the overall construction cost of GBs is lower than conventional building by $280–$410. Figure 1 shows the different approaches to achieve GB using various technologies. According to a benefits of GB article by United States Green Building Council (USGBC) which was accessed on 24 August 2022, buildings alone, in the United States, produce approximately 40% of the country's CO_2 emissions and use more energy and water than both the industrial and transportation sectors combined. However, LEED-certified buildings produce 34% fewer CO_2 emissions, use 25% less energy and 11% less water and recycle more than 80 million tons of waste from landfills. Figure 2 shows a pie chart that demonstrates the GB that helps to decrease carbon dioxide emissions, water consumed in the U.S. and energy. LEED projects are responsible for diverting more than 80 million tons of waste from landfills, and by 2030 that number will rise [2].

Figure 1. Various technologies and approaches, based on which, this review study has been conducted.

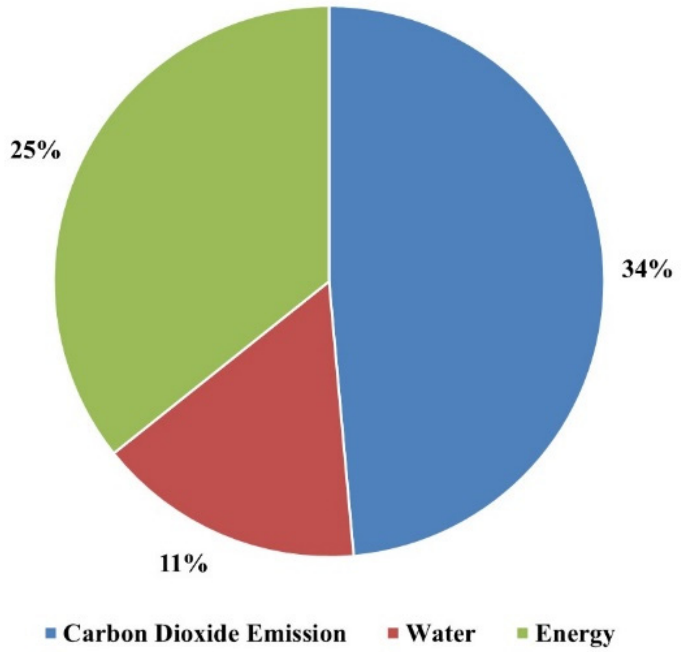

Figure 2. Effect of GB on various parameters [2] and remaining 30% others.

2. Energy Efficient Buildings

Building energy efficiency is the key to obtaining sustainability, which can reduce CO_2 emission and lower air pollution issues. Meena et al., 2021 [3], stated that using solar energy in solar water heating applications can reduce the harmful effects on the environment caused by using electricity. The authors (Jamil et al., 2016 [4]), in their paper, deal with the *United Arab Emirates* renewable energy technologies which have been adopted, used and those on which research is ongoing. The study done by Alam et al., 2021 [5], states that industrialization, urbanization and social and cultural advancement all contribute to the rapid rise in energy demand, which results in high per capita energy consumption. Due to population growth and high energy demand (as fossil fuels are limited), there is a shift towards renewable energy technologies, such as photovoltaic cell, concentrated solar power, wave power and fuel cell energy, etc., which, if executed with better planning and proper utilization, will be a landmark in sustainable energy utilization for the world. The study done by Chen et al., 2019 [6], highlighted the relationship between per day energy consumption and environmental variations. Illuminations, CO_2, temperature, Particulate Matter (PM) and $PM_{2.5}$ are the environmental parameters. The results revealed that Relative Humidity (RH) affects 1.4 times as much as CO_2. This study can be useful to reduce energy requirements in green technologies by controlling environmental factors beforehand. Han and Zhang, 2020 [7], have conducted a study on the impact of smart sensing networks for controlling ventilation, AC and lighting. Environmental system modelling was analyzed in this article. It can control buildings' operational energy and cost, along with favorable outcomes of controlled ventilation and indoor air quality in real building applications. Therefore, smart integration with smart technologies will not only decrease cost and energy requirements but will also increase comfort levels in less time. In the same line, Wang, 2020 [8], conducted a study on GB design, based on the 5G network and IoT system, whose most critical impact is energy efficiency. Here, the network manager assists sensors to manage assets and thus reduce waste in GBs, which can result in saving real-time energy costs. Further, it can generate data on energy consumption and production at each level, which can be further studied for more management and optimized usage. After that, Palmero-Marrero et al., 2020 [9], aim to improve energy efficiency through the use of renewable technologies. They have used two renewable energies, i.e., geothermal and solar energy, to fulfilling the requirements for electrical and thermal energy needs. Using this method, energy sustainability at lower costs can be obtained. Geothermal energy is a nearly universal source of renewable, dependable, ecologically beneficial and sustainable energy [10]. The present study focuses on these sustainable methods for better rationalization of energy consumption and efficient solutions. Arias-Gaviria et al., 2021 [11], have studied the concept of Sustainable Building (SB) and Energy Efficiency (EE) in four cities in Colombia. Many studies have been conducted to analyze Heating, Ventilation and Air Conditioning (HVAC) systems to enhance energy efficiency. The study was extended to analyze the cooling operation of a multiterminal HVAC system in a Net Zero Energy Building (NZEB) in Beijing. By comparing both configurations, State Assessment and Accreditation Centre (SAAC) and Ground Source Heat Pumps (GSHP), it was concluded that the SAAC system could save 47% more energy than GSHP for the same weather conditions. Leung 2018 [12], in their study, performed a pilot test which was basically related to Green Audit Award (GAA) assessment, including Greening Existing Buildings (GEB) strategies. He has concluded that the finding suggests that GEB strategies can save 40–60% of energy with a 20–30% carbon intensity reduction. Raj et al., 2021 [13], stated that by using Building Performance Simulation for various building energy systems and by executing various design strategies, a morphological chart is set up to demonstrate the improvement in building energy efficiency solutions for energy efficiency to attain the 3E gain. The author Asman et al., 2019 [14], has focused their studies on the Environmentally Sustainable Building Design Practices (ESBDP) concept for office building in tropical regions. It was found in the study that all the components of ESBDP were relevant and reduction, reuse and recycling of waste had the highest impact, followed by water conservation, energy efficiency and humane adaptation. Building Integrated Photovoltaics (BIPV) integrate energy generation into a building's functional performance. BIPV concept can be used to meet 6–22% of maximum power demand. Similarly, when a hybrid renewable resource is coupled with a vehicle, it results in improved power flexibility with economy.

The authors Liu et al., 2021 [15], conducted a study proposing a time-of-use grid penalty cost model. The results concluded that a battery system improves the hydrogen system efficiency. In one study, artificial intelligence integration was also studied by Wu, 2021 [16], for the communication system in green hospitals. The medical equipment was managed by IOT to control the operating status and remotely handle them through the system. So, with the help of technology integration with green hospitals, remote device management and cloud applications were realized. Madathil et al., 2021 [17], investigated solar grid-tied, Net Zero Energy Buildings (NZEB). The author proposed consumer centric buildings with a multi-objective approach to maintain net zero annual electricity consumption. NZEB accomplish optimal load scheduling for grid-tied PV-NZEB systems that rely on renewable sources to produce energy. With new strategies, a net annual savings of $2209 is obtained using green practices in building. Flowcharts and tables are shown to obtain an understanding of people familiar with this concept. The main barriers are cost knowledge and interest. Motivation, practice, attitude, values and culture are bottom-up approaches. The set of possible outcomes to overcome the barriers in developing sustainable development in Malaysia were studied. This paper focuses on better unsolar-integrated NZEB of 2 years. Uba et al., 2021 [18], within the paper, take into consideration the energy consumption in offices and commercial buildings, which led the researchers to focus more on this aspect. The research by Robert et al., 2018 [19], was conducted in Ghana and was selected and modelled using Sketch Up. Daily energy consumption for the year 2018 was generated with energy plus and the synthetic Neural Network Model, which had weather variables and days as O/P neurons modelled in MATLAB. The results of the two experiments were compared and resulted in the maximum deviation profile in lightning, cooling and equipment as 13%, 8% and 4%, respectively. As observed, the first two factors were more dependent on human behavior and weather than the third one. Carmichael et al., 2021 [20], in their study, demonstrate behaviors and practices of industry regarding GB practices. Zheng et al., 2021 [21], conducted a study, which introduces Energy

Service Companies (ESCOs) and their role in building the energy efficiency retrofit sector. This paper suggests that substantial attention is required to overcome the barriers of meso- and micro level research. They have suggested reformation in general public subsidy, sustaining of native subsidy scheme and considering the building sector into national Emission Trading Scheme etc. practices to overcome policy-level barriers. Krarti and Aldubyan, 2021 [22], performed a study focusing on carbon neutral communities in Saudi Arabia. They have selected four locations in Saudi Arabia for studying energy efficiency for achieving carbon neutral design. They have suggested the use of renewable energy in their power mix. The results suggest combinations of energy policies in Saudi Arabia for carbon neutral communities.

3. Sustainable Development

Sustainable development is defined as "to maintain our economic, environmental and social needs, allowing now and future generations too to use them", from Brundtland Report, "Our Common Future". A study by Janjua et al., 2021 [23], talks about sustainable buildings' performance, manufactured using recycled materials and byproducts from industries. Also, it was concluded that for park buildings, a sustainable building design with reduced energy demand and high thermal efficiency with use of recycled/ byproduct materials is the main requirement (Bhochhibhoya et al., 2020 [24]). This aimed to provide important insights into the sustainability performance of hotel buildings in Nepal. In Iran, the findings of Fatourehchi et al., 2020 [25], showed that safety issues were the most important criteria that was considered within a social sustainability assessment for residential buildings. The research article, which specializes in using natural resources efficiently, was studied by Gupta, 2017 [26], suggesting plantation and green roof for regulating overall temperature and supply for better air quality is an attempt towards natural resource conservation and reducing the carbon footprint. This study is regarding the sustainability indicators for measuring GB manufacturing in Malaysia and was also performed by Asadi et al., 2020 [27]. The results showed that EE and Indoor Environmental Quality (IEQ) were the most significant criteria in Green Building Index (GBI)-IEQ. Chi et al., 2020 [28], in their article, focus on waste minimization during construction of GB and various definitions are given for GB. In the US and China, LEED certification comparison of waste minimization performance is shown. The research further emphasizes that a GB rating system should be implemented at the end.

4. Improving Building Efficiency

The NZEB objectives have raised the standard of GB performance. Ferrara et al., 2021 [29], in their study, established a methodology for coupling energy and acoustic. The focus is on comfort-driven NZEB design for the future. They have developed a new optimization methodology for co-relating energy, cost and acoustic in NZEB optimal design. For optimization, they have used TRNSYS and GenOpt tool. A set of possibilities was evaluated by Abdou et al., 2021 [30], for upgrading the existing residential building into NZEB for different climatic conditions. For this purpose, they have considered three major criteria, i.e., economic, energetic and thermal comfort, and used TRNSYS coupled with MOBO for building optimization. The results suggest that NZEB is technically possible in all Moroccan climatic zones and the cost of using renewable energy depends on operating and maintenance conditions. In a study, the target of reducing carbon emissions in China by 2060 was analyzed with the contribution of NZEB standards. Three development scenarios were studied, which included: BAU, S1 and S2 Gtce by 2060, respectively, so it can vastly contribute to the carbon emission target for the countries. Also, according to Zhang et al., 2021 [31], NZEB incorporates solar energy for achieving energy efficiency. Sustainable buildings incorporate a variety of energy techniques and practices to eliminate their carbon footprint on the environment. Saini et al., 2021 [32], expressed that the use of eco-friendly building materials in the NZEB lessens the impact on the environment, while also lowering total costs and presenting a chance to feed extra energy back into the grid.

4.1. Solar Devices

NZEB emphasizes using active and passive solar power. With green building's focus on sustainability and green energy, which involves solar energy as most favorable renewable energy resource. Many researchers have studied this, and the research remains ongoing. Some are as follows: Mewes et al., 2017 [33], have studied that the aim of the research was focused on the use of solar Photo-Voltaic (PV) panels. They have installed PV in existing buildings to measure the electricity generation. Research showed that energy production with the help of PV installation is significantly lower than the building energy consumption. Shukla et al., 2018 [34], reviewed Building Integrated Photovoltaic System (BIPV) applications in South Asian countries. They concluded that ambient temperature, shadowing effect, direction of PV and slope of PV play an important role in high efficiency and higher power output. Balabel et al., 2021 [35], have studied that in Saudi Arabia, Solatube technology is the most important technology for sustainable buildings. Jeong et al., 2017 [36], highlight a hybrid energy supply system in GBs. For hybrid energy, they have used solar and wind energy to achieve the NZEB goal in high rise buildings and warehouses. It was concluded that a renewable energy source has low economic feasibility in high rise buildings and warehouses. The huge demands of these buildings were satisfied using conventional energy sources (diesel generator).

4.2. Facade System

Convertino et al., 2021 [37], have studied the effect of green facades on the energy consumption of buildings, especially concerning Evapotranspiration (ET), which was performed to make cities greener, involving the use of green infrastructures. The study developed tools specifically for green facades for simulation purposes. Another breakthrough was the definition of formulae for quantifying the evapotranspiration in a green façade. Also, a broad study was conducted by Balali et al., 2020 [38], to acknowledge and prioritize the well-mannered building facades to achieve Sustainable Development Goals (SDGs) for Iran. Roosmalen et al., 2021 [39], have studied high-rise building facades and concluded that Regenerating Gene (REG) potential and thin prefab curtain walls provide the extra advantage of saving space and quick on-site application on a large scale.

5. Factors Affecting Green Buildings (GBs)

There has been various research performed, and is still ongoing, about the factors that influence the design of GBs. The factors are decided, keeping in consideration the internal as well as external situations. Zhang et al., 2021 [40], investigated the internal and external influencing variables to assess the GB development. The results of study show that internal variables are governed by human personal perception, but external variables were affected by social and organizational factors. In the next study by Carmichael et al., 2021 [20], the authors demonstrate behavior and practices of industry by evaluating green practices. Flowcharts and tables are shown to obtain an understanding of people familiar with this concept. Cost, knowledge and interest are the main barriers. Motivation, practice, attitude, values and culture are bottom-up approaches. This paper focuses on GB practices. After having discussed the gap between the theoretical and practical implications of the GB concept, next comes the papers that separately discuss the factors that affect GB design. Wang and Zheng, 2020 [41], focus on energy environment satisfaction. The study recommends adopting HVAC systems as per type of air-conditioning system. Then, Song et al., 2021 [42] studied the impact of noise and air pollution on Natural Ventilation (NV). This study gives ideas of how to optimize the utilization of NV to achieve energy efficiency and healthy buildings. Saka et al., 2021 [43], provide details about the policy of government, providing incentive in the construction sector for promoting GB. Rana et al., 2021 [44], performed an extensive review regarding FIs for GB in Canada, for promoting sustainable development and carbon mitigation strategies. FIs were divided into four types: tax, loans, grants and rebates. FIs are important for authorities, policymakers and utilities for improvement. The development of GBs can be improved through government initiatives, private companies or non-governmental organizations and other stakeholders, etc., aiming at the reduction of carbon emissions, according to Franco et al., 2021 [45]. Economic benefits in long term and suitable government policies will be motivation towards green practices, according to Mustaffa et al., 2021 [46]. For example, in the study of Jain et al., 2020 [47], where the reason for a big difference in green transition between Singapore (a frontrunner) and Delhi (still in initial stage) was explored. In Singapore, government policies were found favorable for green practice, but in Delhi government policies were found to lack of coherence and intensity, which moderately support GBs. Similarly, Razmjoo et al., 2021 [48], disclosed that different tactics and adopting changes in government policies would help in NZEB or GBs. Therefore, a dynamic approach is needed by political and non-political institutions. Another example is that LEED certified construction waste minimization projects in the US and China observed a significant difference at the certification levels of gold and silver, as these two countries are not similar in PEST context, according to Chi et al., 2020 [28]. The results of previous research showed that promoting GBs on external factors, such as cost and building code, was analyzed in New Zealand by Abdelaal and Guo, 2021 [49]. The study also showed that in New Zealand, there is positive environment for green building design standards and assessment. Practical implications were introduced to reinforce the Knowledge, Attitude and Practice (KAP) levels in New Zealand, for promotion of GB design standards and certifications. In addition, to accomplish the goal, many challenges need to be faced in fast urbanizing countries like China (Geng et al., 2012 [50]), where there is a rapid increase in urbanization (47% in 2008 to 50% in 2012 and 74% in 2050) (Li and Yao, 2009 [51]). According to Ahmad et al., 2019 [52], there are six major paradigms, which include drivers, barriers, risks, benefits, Critical Sources Factors (CSFs) and Planning and Development Authority (PDAs) for GB adaptation. In the previous research by Zhao et al., 2019 [53], results demonstrate a paradigm for the adoption of GBs. For the development of old residential buildings, one study expands valuable references to develop new policies for green retrofit technologies and policies (Tan et al., 2021 [54]). It further examines the positive impact on adoption of green retrofit technologies with adoption of proper green retrofit policies.

Occupant's Health and Indoor Quality

Seppanen et al., 1999 [55], analyzed the relationship between ventilation rates and occupant health in a building. The results demonstrated that illness symptoms are often related to low ventilation rates, perceptions of poor air quality and high CO_2 concentrations. One of the case studies showed that most of the offices studied are not able to cope with the requirements for healthy indoor air quality. The same is illustrated in Figure 3, a survey performed by Green Business Certification Incorporated (GBCI) organization in 30 offices in 9 cities in India, on the basis of their indoor environmental quality, daylight, excess to external landscape, thermal comfort and soundscapes, were overviewed and results were that out of 30 offices, only 1 office shows all the indoor air contaminants within limits [56]. Based on data, Steinemann et al., 2017 [57], concluded that Indoor Air Quality (IAQ) is better in GBs than in conventional buildings. However, "green" doesn't guarantee good indoor air quality. Ghodtari et al., 2012 [58], also stated that green features of buildings lead to better occupant health, increase satisfaction and improve quality of life. Khoshbakht et al., 2018 [59], stated that not all GB occupants were more satisfied than non-GB occupants. Awad et al., 2021 [60], tried to measure the indoor air pollution of buildings in Dubai. The results showed radon gas concentrations exceeded the standard. The concentration distribution of Volatile Organic Compounds (VOCs) and formaldehyde (CH_2O) was about ten times more than that of outdoors.

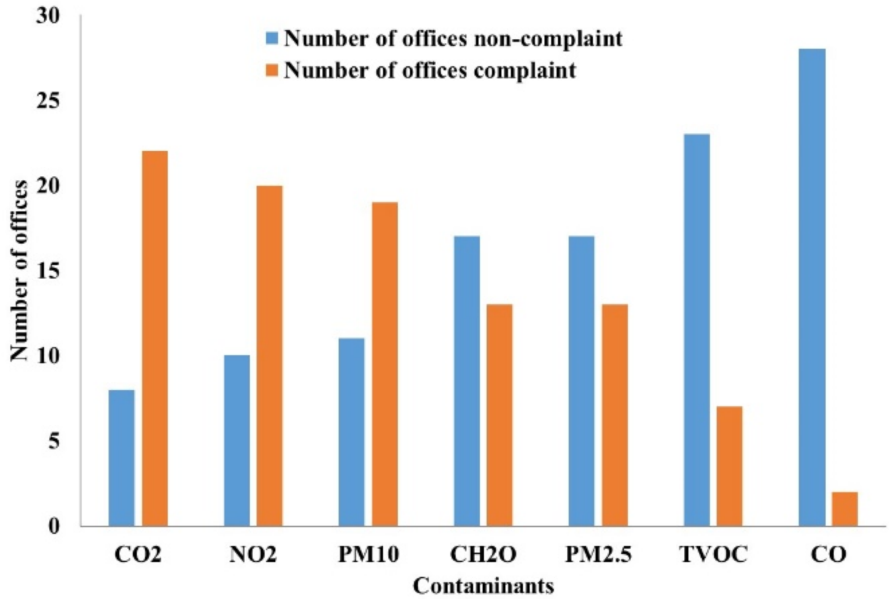

Figure 3. Indoor air quality status in case studies [56].

6. Model and Design in GB

Takano et al., 2014 [61], highlight that the selection of building material for a building is a very important aspect of construction, as it can affect its quality and cost. Similarly, for GBs, research is ongoing to provide some materials, which are cheaper and sustainable with the comfort standards required today. Babu et al., 2017 [62], highlighted the use of Green Mark (GM) as an assessment criterion for a real and actual building located in Singapore. Shao. et al., 2018 [63], had the main focus of understanding about the assessment model of GBs in China. In this article, a hybrid model with DAMP was used. Lee and Choo, 2018 [64], have performed various studies, which have shown insufficient content and a research gap on design methods, which demonstrates that it is difficult to identify the energy staging evaluation of designs, such as scale and size of buildings. Thus, through this study, we develop design methods that are easily able to identify energy staging in the early project period using Building Information Modeling (BIM) tools and also correlate energy performance with mass buildings. The key elements taken in this study are height of floor, ratio of window area and ratio of long side to short side and envelope area, which, when varied, showed the impact of design methods on performance.

The net energy zero building depends on the climatic conditions in the area it is going to be constructed. Thus, this factor should be taken care of wisely. Therefore, this paper also studies the 34 net energy zero buildings in the world and mainly focuses on the key features for hot and humid climates (Feng et al., 2019 [65]). Results concluded from this study show that passive design, day lighting technology and natural ventilation are often adopted. Some cases show less than 100 kWh annual energy consumption, while some even generate more energy than they consume. (Liu et al., 2019 [66]) The present study is focused on Green Office Buildings (GOBs). They have used a System Dynamic (SD) model to perform the study between occupants and facility managers for reducing energy consumption gaps. The article by Liu et al., 2019 [67], highlights START framework. It is related to GB study and practices. In this article, a comparative study was conducted for two countries, i.e., Singapore and China. The study concluded that both countries are facing common issues for achieving economic sustainability of GBs, due to market failure. Alkaabi et al., 2020 [68], conducted a study for commercial building in the extreme hot condition. The results suggested PV adoptions resulted in a 16% reduction in capital costs. Agyekum et al., 2020 [69], highlight the use of vernacular material. It concludes that for GBs, the vernacular material is timber, bamboo and laterite, and timber framed construction, sun dried brick walling and atakpame walling. This research analyzes the project design development and compares the two contractual approaches, i.e., design build or design bid build process, and identifies the best one. Two case studies in Italy and two in Spain are analyzed, under three different points of view: time, cost and level of sustainability. This paper also gives insights into the positive relationship between process integration and GB design developments. Wu et al., 2021 [70], studied access to indoor air quality in GOBs, based on grey method. Conventional buildings and 1-, 2- and 3-star rating buildings were selected for survey to analyze air quality in terms of smell satisfaction. Grey method-rated three-star buildings show satisfactory smell in comparison to conventional buildings. In terms of fresh air satisfaction, the three-star building type was the best among all three types of buildings. Overall analysis concludes that three-star buildings rank first, one-star buildings and ordinary buildings rank second and two-star buildings rank last. Loerke et al., 2021 [71], studied green facades using canopy evapotranspiration and shading to decreasing air and surface temperature. Tsvetkov et al., 2021 [72], studied mathematical modeling, combining heat and moisture transfer in walls. The results show that moisture transfer in wall decrease in the thermic properties of walls by 6–8%, made of insulated planks with connectors. The results of this work can be combined with another model to study in the Russian region, for low carbon energy technologies. Yang et al., 2021 [73], focus on the environmental policies that impact the decision making of construction companies for green practices. Taxes, subsidies and carbon trading will be better policies for development of a GB alliance. Han et al., 2021 [74], reviewed, in nature, and provided a detailed description of government policies, development, policy effectiveness and Chinese policy for energy conservation in GBs. Zhong et al., 2021 [75], in continuation of the present article, highlight the relationship between economic development and energy intensity. A suggestion for future work is an investigation of operational and embodied energy intensity. Liu et al., 2021 [76], highlighted a study of Turkey using STIRPAT model. They have investigated the relationship between Renewable Energy (RE) and Green Technology Innovation (GTI) and CO_2 emissions. All three parameters have integrated, and it was concluded that GTI and RE and CO_2 emissions are interdependent. Buckley et al., 2021 [77], highlight the renovation wave and green deal in urban areas, using UBEM model. UBEM suggests achieving a 60% reduction in CO_2 emissions by 2030. Zitars et al., 2021 [78], highlight a detailed study about the intention of GBs. The intention of GBs is to enhance occupant experience and a credit rating of buildings, based on seven functions of a setting. The article also highlights the issue of whether GB fulfills the occupant needs or not. Lee et al., 2013 [79], in continuation of previous works, evaluated the energy performance of GBs using MOBELM. The result shows that the effective design of building envelope can be made by MOBELM. AlAwam and Alshamrani, 2021 [80], demonstrated that 200 buildings were investigated using LEED scores. The process is converting LEED scores into monetary value. Conversion certificate level, building type and area were considered. The study concluded that while considering life cycle cost and operational cost of GBs, GBs are reasonable in comparison to conventional buildings. In this study, there is a lot scope for future work, wherein different types of building with different LEED certifications in different countries can be considered for study. Recently, Qi and Barclay, 2021 [81], reported the social barriers in development of GBs.

7. Certification Methodologies

Research by TAM et al., 2012 [82], basically deals with the factors that effect implementing the GB phenomenon, for which various surveys and research are conducted to gain awareness of social and economic factors, and from the conclusion, we come to know that on the one hand, this phenomenon is environmentally friendly and can improve social value to consumers, and on the other, it is more economically expensive than conventional buildings. Zhang et al., 2019 [83], provide a comprehensive review in their study on renewable energy assessment methods. Solar, wind and geothermal energy are all examples of renewable energy that are commonly included in rating systems. All rating methods take solar energy into account. Current grading systems do not take climate and location into account when evaluating renewable energy. The outcomes of this study will aid investors, users and policymakers in better understanding grading systems and promoting the development of GBs and neighborhoods. In the same way, the authors of this study, Norouzi and Soori, 2020 [84], highlighted different assessment standards of buildings in the world. The Nexus category is one of the key assessment metrics and the assessing methods and scoring processes are based on it. Ecological, social and economic assessment approaches are split into three groups based on their sustainability. In terms of an ecological factor, GRIHA (Green rating for integrated habitat assessment) has the highest rank, as this standard helps to decrease the carbon cost in the building sector. Furthermore, GRIHA ranks last in the social sector, due to its reliance on ecological elements, with 14.4 percent of the overall ratings. BREEAM, with 24.1 percent of the overall score, and GRIHA, with 5.8 percent of the total score, have provided the highest and lowest relevance in the economic criterion, respectively. Finally, the study examined the approaches for assessing building sustainability. Raouf et al., 2019 [85], draw our attention toward the gaps or links that still exist between the obstacles or hindrances and the GB rating system, i.e., BIM. The article is a literature review which basically discusses the limitations, main obstacles and shortcomings of BIM. The results also indicate that BIM research is fully automated. Certifying GBs, on one side, checks their genuineness and reliability, and the other side compares their benefits and sustainability, and increases their value and demand for consumers. Different studies were conducted to compare and check the standards and efficiency of certifications itself. The ECMF offers advice on how to deal with sustainability challenges in low- and mid-rise multifamily projects. Matos et al., 2021 [86], intended to assess building performance and priority maintenance operations, using Key Performance Indicators (KPI) and BIM as a supporting tool for Building and Construction Authority (BCA), as well as maintenance management in their study. The study's applications show the importance of BIM in facility management, as it allows for continuous information updates in the model, in this case for BCA purposes. It also offers a significant potential for prioritizing building maintenance tasks, increasing the service life of its materials and contributing to the creation of a sustainable built environment. Coming to the next assessment method, Amiri et al., 2021 [87], in their study, evaluate the suitability of LEED, using LCA for emission reduction. The research consisted of numerous steps that were carried out using a pre-designed model. The LEED framework awarded 14 and 8 points for material choices to the wooden and hybrid scenarios, respectively. Among these points, only three were directly accredited to embodied emissions. Because the importance of embodied emissions is expanding in tandem with existing carbon neutrality goals, the study suggests that GB certificates raise the weight of sustainable construction materials. To successfully use Earth Craft resources, Jefferson et al., 2021 [88], have conducted a data analysis based on an interview to understand the need of users. Similarly, Remizov. et al., 2021 [89], in this study, focus on the adoption of a GB assessment system to existing buildings, in the conditions of Kazakhstan. This study examines the BREEAM, LEED, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) and green globes certification systems, as well as their implementation and assessment measures for existing buildings in Kazakhstan. The problems faced by GB certification in Kazakhstan are also mentioned in this article and thorough investigation of these challenges could lead to solutions for implementing green operations and promoting livable building construction. Lee et al., 2013 [79], conducted a study dealing with the term "Green" in GBs. In this paper, the researchers try to define the greenness and categorize the various GBs into how much they each satisfy the green term under BEAM (Building Environmental Assessment Methods). According to Gupta, 2017 [26], the GB concept is reaching new heights day by day. This paper deals with, and aims to develop, this concept in Jammu city, too. Therefore, this study includes an investigation of the resources available, maintaining proper climatic conditions and air quality and reducing carbon footprints. Similarly, Sartori et al., 2021 [90], proposes two approaches: LCA and Green Building Rating System (GBRS), to analyze the environmental performances of the whole building. Some of the rating system requirements for LCA criteria, such as building life, service, fundamental units and so on, were also mentioned in this article. The purpose of this paper is to offer future research directions to promote the development of a schematic Environmental Impact Assessment (EIA) framework [91] within the design life cycle. This research solely looks at software tools from an LCA standpoint, not from a GBRS standpoint. The goal of a study by Sezer and Fredriksson, 2021 [92], was to look into the environmental impact of construction transportation and see if a construction project's building certification scheme has any bearing on its transportation arrangements. This paper's analysis is based on a 40-project multi-case study in Sweden. Terminals and checkpoints are examples of Construction Logistics Solutions (CLSs) that can help reduce the number of shipments and, hence, emissions. The findings of this article will be relevant to construction site managers, logistics consultants and transportation companies, as they will assist them in more effectively implementing CLSs, based on the phase and kind of project. The goal for future study is to collect this information from carriers or suppliers. This, however, necessitates a simple method of integrating purchases, delivery and transportation. A study by Liu et al., 2021 [76], assists designers and construction managers of GB construction to determine the best other building modernizations for improving energy order and comfort. Therefore, they suggested an energy-comfort optimization model, which can provide perfect decision support to the designers and the stakeholders in building modernization, to create less intake of energy, while maintaining a feasible indoor atmosphere. In the future, when working on newly constructed structures, it is more important to consider building typology in order to come up with the best design ideas. Goncalves et al., 2021 [93], investigated the effects of key unsureness sources involved in the process of assessing overheating risks in unresisting houses. The comfort criterion, modelling method and analysis methodology choices are all sources of uncertainty explored in this paper. The aim of studying this is to determine the applicability of ongoing modelling and survey methodologies in the evaluation of overheating. For overheating analysis, this study underlined the importance of appropriately modelling the airflow situation by integrating the thermal and airflow network models. Qiu and Kahn, 2019 [94], in their study, assessed the role of energy star certification in commercial buildings. It concludes that the occupants in energy star buildings consume 8% less energy. Diaz-López et al., 2019 [95], aimed to compare the ongoing status of a sustainable building evaluation method based on three groups. The results showed that LEED, in the case of Systems; Passivhaus, in the case of Standards; and ATHENA, in the case of Tools is most representative method. Olawumi et al., 2020 [96], focused on the evaluation method for sub-Saharan Africa with the help of a multi-expert consultation method in Nigeria. Seyedabadi et al., 2021 [97], determined that green gas emissions can be reduced by using green roofs. The study was based on the factors affecting green roofs. They considered the plant factor for green roof and requirements of sunlight and water, and dry and cold tolerance for providing a roadmap for the future. The result suggests that for green roofs, sedum acre is the best choice. If the purpose of study is to reduce the carbon footprint through green roofing, then Frankenia thymifolia was the best choice.

8. Positive and Negative Consequences

As has been studied by many researchers, there are positive as well as negative consequences in the development of GBs. On the basis of one of the previous studies, Manila's example was taken, where the planned consequences of GBs were identified as disaster management and environmental balance, while, for the time being, disruption in political regulation and market environments were unplanned and negative ones. Franco et al., 2021 [41]. In contrast to popular belief about the effect of GBs on occupant health, a study conducted in Jordan found that GBs resulted in a significant reduction in energy use and operational costs (Elnaklah et al., 2021 [98]). As studied, GB energy performance also has a positive impact on regional commercial estates. The study of Australia's certified commercial buildings showed that the trading real estate factors were notably related to the Energy Use Intensity (EUI). The findings showed that branding of 'GB' increases the appeal of duty buildings in terms of occupancy and makes their energy performance more notably of economic uncertainty, according to Gui and Gou, 2021 [99]. In the cost implications for a GB, the construction cost is higher at the initial stage, whereas the lifecycle and maintenance costs are cheaper (Weerasinghe et al., 2021 [100]). Wang et al., 2021 [101], proposed a novel network-based and long-term approach for studying the creative association of various types of companies. Subordinate data were gathered from 223 master plans in China that received Green Building Innovation Awards (GBIA). A targeted policy framework was presented based on these node-level findings and nettings, which included "de-activation," "shell," "mobilizing" and "synthesizing" tactics to encourage the creation of long-term green-building innovation networks and offer plans. Singh et al., 2022 [102,103] have studied the performance enhancement for solar air heater applied to green building applications. They have presented mathematical model for performance evaluation of solar air heater. In continuation Meena et al. [104,105] have studied the heat transfer enhancement techniques for solar air heater and other systems used for green buildings application.

9. Applications

We know that the industrial sector is the major consumer of energy. It consumes around half of the world's total delivered energy. As the demand for GBs is growing, this can be utilized in the industrial sector to reduce overall energy consumption.

1. A study, conducted in Sri Lanka, analyzed the cost implications via a modified life-cycle cost scanning of two GBs with different levels and one traditional building, differentiating them in terms of sustainable features and GTs, such as water efficient landscaping or optimizing energy performance, etc. The results showed that the green industrial building construction cost is about 29% higher and the life-cycle costs are 17% lower than those of customary buildings. The operational and maintenance costs of GBs resulted in 23% and 15% all-inclusive savings throughout the life cycle, according to Weerasinghe et al., 2021 [100]. Further, the GBs which contribute to green certification and lifecycle cost savings of manufacturing buildings were studied.
2. Buildings in the commercial sector and public service buildings can have a great application of GB infrastructure. Whitney et al., 2020 [106], studied modes of behavior that lead to better energy management activity. These were voluntary improvements in building, operational improvements and the identification of energy savings points.
3. Another application seen in a study was regarding the green hospitals in smart sustainable cities, which was based on artificial intelligence. The medical equipment can be handled through the remotely upgraded systems, also, the functions can be controlled at any time (Wu, 2021 [16]).
4. Parashar et al., 2012 [107], showed that the rat trap bond wall technique, insulated cavity wall and inclined green roof helped in bringing the temperature of the building down, keeping Chhattisgarh's temperature in account, and also, author Gupta, 2017 [26], conducted a study of green residence in Jammu. They have used the methods of green roofs, planting trees and methods for better air quality etc. Manna, 2019 [108], tried to make people conscious of the GB Movement in India, its design, the GB rating system and their process of certification.

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