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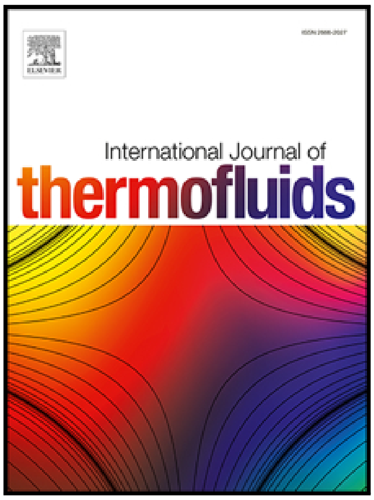

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The role of green buildings in achieving the Sustainable Development Goals

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Abstract

The Sustainable Development Goals (SDGs) are a group of 17 objectives established by the United Nations (UN) and specified in resolutions adopted by the UN general assembly on September 25, 2015, and January 1, 2016. These broad aims, which collectively encompass 169 goals, are interconnected even though they have their own unique objectives. Numerous environmental, social, and economic development challenges are covered under the SDGs. This paper discusses the role of green buildings in achieving the UN's SDGs and investigates the issues related to their design and barriers. It is clearly demonstrated that the reliance on renewable energy resources is one of the key elements of green buildings. Additionally, the integration between these resources is considered a promising approach to achieving net zero energy consumption. This paper also aims to emphasize the positive effects that these green buildings have on people, the environment, and the economy, which ensures their survival. It also discusses several aspects related to green buildings, including materials, site evaluation, and greening existing buildings.

Keywords: Sustainable Development Goals; Green buildings; Construction; Raw Materials.

1. Introduction

Green Buildings (GBs) can be defined as “the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation, and deconstruction”. Apart from GBs emphasizing energy, water, and air quality, they also seek to enhance the social and economic sustainability of buildings [1]. Moreover, GBs are economically reliable and give investors the opportunity to fund big business ventures [2]. The building’s performance does not only include resource consumption and waste [3], but also the building’s occupants’ health and comfort [4]. Thus, both industry professionals and researchers have given GBs a remarkable attention [5-7].

Generally, the building sector uses 40% of all energy produced, 12-16% of the accessible water, 32% of non-renewable and renewable resources, 25% of all wood, and 40% of all raw resources. The building industry also generates 30–40% of all solid waste and releases 35–40% of CO_2 [8], which has led to a rise in worldwide knowledge of the significance of sustainability and GBs [9]. Furthermore, the development of GBs has a favorable effect on the environment and climate [10] and provides the building industry with a number of fiscal and social advantages. These include preventing global warming and climate change, reducing pollution, preserving nature, utilizing renewable energy sources, enhancing health, comfort, and well-being, reducing poverty, boosting economic growth, increasing rental income, and lowering healthcare costs are a few of these [11].

For several nations, the GBs' slow growth is now their top worry. Although numerous important success variables that affect GBs promotion have been identified in earlier research, there is still no agreement on the factors' relative importance [12]. Building construction and design techniques have undergone significant changes since the GBs movement's inception [13]. Contradictions in what qualifies as green funding for GBs present the main obstacle [14]. This highlights the pressing need for the construction industry to create and execute sustainable standards [15].

For the purpose of developing national policies and raising awareness among the individuals, it is crucial to comprehend how the seventeen SDGs relate to human life, environment, economic growth, industrial sector, water conservation, energy efficiency, resources consumption, and climate action. The development of action plans to translate the SDGs from the global to the local levels is essential. The evaluation outcomes from the GBs, however, simply reflect their importance on SDGs. Hence, the current research presents the contribution of GBs in the achievement of SDGs stated by the UNs including their design and barriers. The aim of this study is to discuss in detail the impact of GBs on SDGs and to identify the technical, social, and environmental barriers encountered in such buildings. In addition, the objective behind this work is to highlight the environmental, social, and economic impacts of these GBs on humans and the environment that guarantee the sustainability of these buildings.

2. Methodology

The analysis and investigation of scientific research related to green materials and construction can help develop the current knowledge, highlight the research gap in this area, and provide a clear vision to stakeholders, policymakers, and any other interested individual. This review complies with the Preferred Reporting Items for Systematic Reviews (PRISMA). In the first stage of this review, SCOPUS and Web of Science, have been explored as search engines using pre-specified keywords "green building", "sustainable development", and "barriers". This review was further refined to the environmental, civil engineering, and material science fields and was restricted only to the scientific work published in English during the period from 2000 to 2024. Finally, the main findings of these articles (up to date) were reported.

The selected studies were deeply investigated in the below sections. Section 3 explores the GB design, characteristics, and advantages. Section 4 reports in detail the contribution of GBs in the achievement of the SDGs. Section 5 investigates the main barriers to the wide implementation of these buildings. Based on the above-mentioned sections, the main conclusions and future perspectives are reported in the last section.

The importance of this review arises from exploring the impacts of GBs on the SDGs which are concerned with facing the global challenges such as hunger, poverty, health, education, energy, climate change, etc. Therefore, this paper addresses some important questions; what are the links between the GBs and the SDGs? What is the role of GBs in achieving these SDGs? What are the main challenges toward achieving these SDGs?

3. Green buildings

3.1 Green site evaluation

Green sites can increase sustainable characteristics as well as decrease pollution effects while they participate in improving climatic conditions. Planners and decision-makers frequently pursue to maximize the advantages of urban green areas through developing scenarios and approaches for green facility-oriented developments in different urban regions [16]. For these reasons, many studies have dealt with them. Geophysical factors, availability, blue and green services, residential facilities, agricultural compatibility, and land use/cover of the study region were identified as the primary variables affecting urban green land suitability. This led to the development of a strategy for the suitability assessment of urban green land. The findings indicated that the majority of the locations are considered to be of poor and limited suitability [16].

A framework including four scenarios was developed for integrating green infrastructure preservation into scenario design to model the land use behaviors and landscape connection. The scenarios were compared and included business, source preservation, corridor preservation, and combined source [17]. The selection of green infrastructure sites that take into account hydrologic risks in the context of place-based knowledge and historical facts was optimized using a hybrid strategy [18].

Although site planning and design (SPD) are essential stages in creating a viable location, few studies have focused on the crucial SPD factors in GBs. A sustainable site is a significant problem in GB practice, and SPD constitutes a vital stage in the creation of a feasible location [19]. Numerous important variables influencing SPD in GBs have been found [20, 21]. Reduced water contamination, safety of human health concerns, reduced air and dust emissions, adequate consideration of natural space, and reduced building sounds were ranked as the top five most crucial GBs items in the SPD. On the other hand, five fundamental key factors of SPD in GBs were determined through factor analysis and included: use of land resources, efficient use of space, exploitation of natural resources, creation of green parking and thermal environments, and environmental conservation concerns. Lastly, the selection of a green site is affected by many risks that are related to several issues such as land utilization, site evaluation, open space, green vehicle parking, passive building construction, land spacing and agriculture, storm water management, neighborhood daylight access, culture heritage, microclimate around buildings, and environmental management plan [22].

3.2 Greening existing buildings

For improving and managing greening existing buildings (GEBs) and filling the research gaps and future requirements, the Building Information Modeling was used for existing buildings' sustainability and green upgrading due to its comprehensive approaches for assessing and tracking the environmental sustainability effectiveness [23]. Many strategies were introduced for GEBs which can result in significant energy savings ranging between 40% and 60% [24]. High-rise office buildings in Indonesia's major cities are motivated to use energy-saving techniques that can be implemented without incurring additional costs, such as adjusting the room temperature set point, air conditioning operating program, and chilled-water set point, as well as more expensive alternatives, such as replacing lamps, glass, chillers, and installing window film, which can actually reduce the Energy Efficiency Index by up to 40% [25]. Furthermore, GBs through greening rooftops demonstrated a significant potential for the replacement of poorly insulated buildings. Using a transient modeling software, the energy efficiency of the structure and the variable thermal activity of the green roof have been assessed [26].

On the other hand, many risk factors were introduced to control the greening of existing buildings [27]. Sixty-six risk variables were divided into seven risk categories that included fiscal, societal, environmental, managerial, operational, design, and renovation risks. By means of evaluating risk factor properties like risk factor presence, influence on the GEBs procedure, and long-term impact on building performance, they were able to identify the impacts. The findings of this research indicated that environmental management in the greening procedure is the most significant risky category. The assessment and findings showed that environmental variables were the most significant critical risk factors.

3.3 Green buildings materials

The employment of green products in buildings is becoming more and more feasible because of advancements in green technology [28]. There are numerous environmentally friendly materials that may serve the sustainable characteristics of GBs. Some of them result from industrial waste while others are derived from old buildings demolition. These materials may help in reducing the consumption of depleting resources and increasing the utilization of renewables while some of them can improve the building material characteristics such as compressive and tensile strengths, in addition to eliminating waste materials.

Reused materials, which can be produced from recycled wastes, have less negative environmental impacts than traditional materials, use less energy, and frequently emit no harmful emissions. In addition, they are also more monetarily viable [29]. On the other hand, 15% of all domestic energy use was accounted for by the service and residential industries, whereas the electricity consumption shared around 35% and the effect of using GBs participates greatly in saving energy and electricity [30].

A further realistic general view holds that GB materials are sustainable throughout their entire life period, where their sustainability can be measured and they are not hazardous to human health. More specifically, they must avoid causing indoor pollution at all. It was proven that buildings' materials can help in achieving many of the Sustainable Development Goals [31].

A classification was introduced for materials that can be used in GBs construction belonging to many groups such as sustainable building materials, GBs materials, alternative building materials, ecofriendly construction materials, low embodied energy building materials, and advanced building materials [31]. At the same time, the pre-use period of the building, and the environmental effect of the building materials (raw materials extraction, production process, and delivery to the construction location), were also receiving increasing focus.

The choice of structure materials is made early in the planning stage as well as during the implementation stages, and it is crucial to the accomplishment of the "Green Buildings" goal [32]. Many models and techniques were developed and used for a better selection of GB materials. An innovative hybrid multi-criteria group decision-making model was developed for the selection of environmentally friendly construction materials in the face of uncertainty [33]. For the sustainable growth of a residential scheme, a decision has been made to choose and use green materials [34]. A multi-criteria decision-making method is employed to select the suitable element types of green composite materials [35]. On the other hand, a multi-objective optimization-based decision-making system for optimizing the cement substitution components in concrete is also introduced. Finally, a sustainable criterion was introduced for evaluating the sustainability of green materials in concrete production [36].

Green concrete is considered one of the most familiar GBs materials and many studies improved its characteristics by replacing some concrete components or adding waste, recycled, or manufactured materials. These materials include geopolymer, electromagnetic functional materials [37], PVC waste powder and ground granulated blast furnace slag [38], palm-leaf and cotton-stalk nanoparticles [39], plastic, used engine oil, and wasted glass [40], pond ash and ground granulated blast furnace slag [41]. Agricultural wastes is a significant sector of sustainable building materials owning to their benefits and it help to conserve natural resources (see Figure 1).

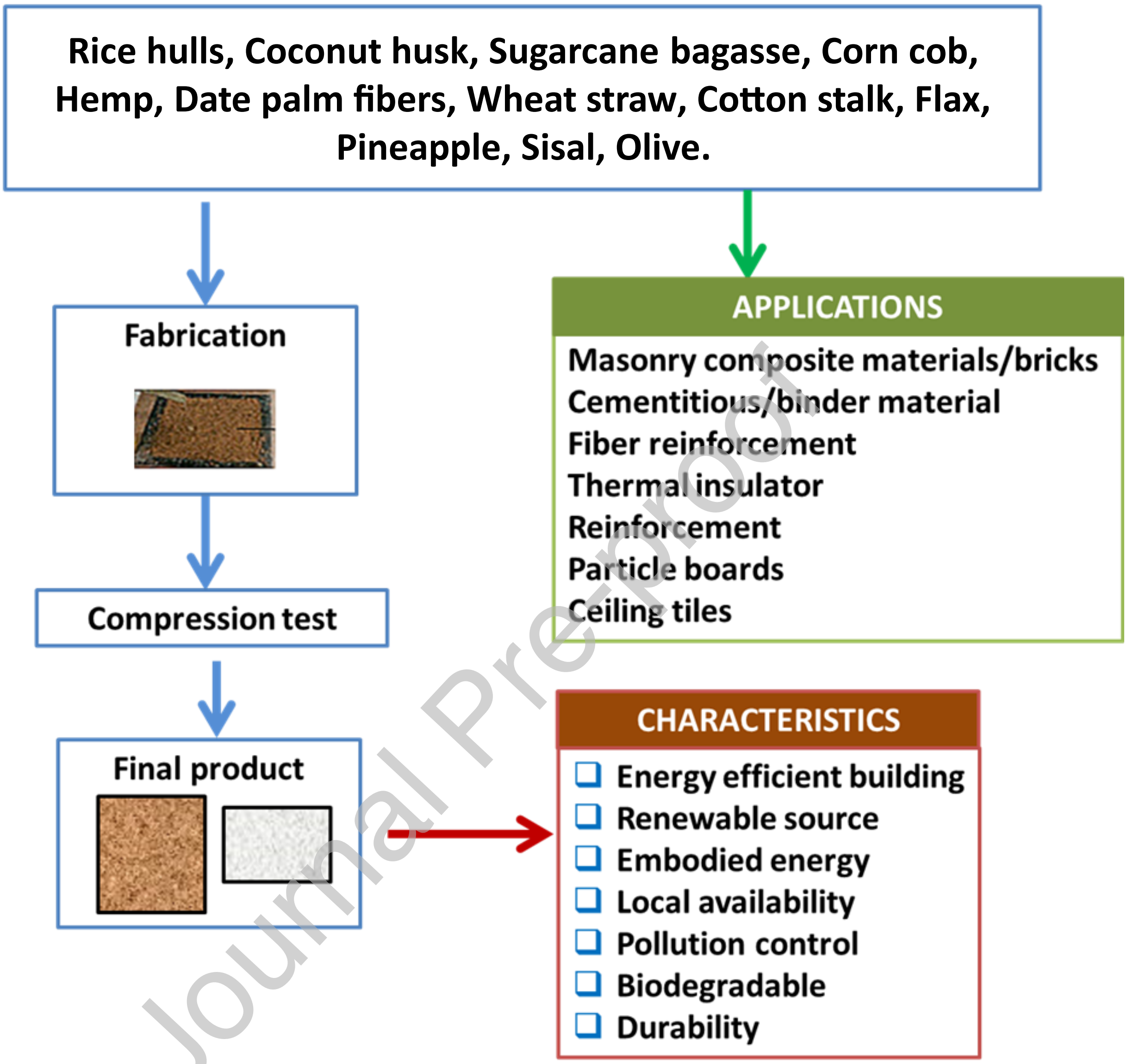

Figure 1: Process flow of sustainable production of green building materials from agro-wastes along with their applications and benefits [42-51].

3.4 The economic benefits of green buildings

The financial gains from decreased energy and water use, cheaper maintenance costs, better health, and increased productivity far outweigh the extra building costs needed to adhere to green design standards [52]. Energy efficiency is regarded as a major force behind the shift toward

GBs because of the significant environmental and financial advantages linked to decreased energy usage in GBs. However, the actual energy cost of GBs is significantly influenced by variables linked to building performance in real life and projected energy costs. There should be a clear terminology for linking the concept of green finance to GBs [2]. GBs can save more than 70% of energy in comparison to the industry standard. The GBs have a life cycle saving potential of over 5000 kWh/m^2. The economic advantages of lower energy usage in the GBs were presented with empirical proof [53]. Figure 2 shows a summary of the benefits of GBs. The green cost premiums were described as the cost premium associated with the GBs [54]. Furthermore, the cost and benefits of GBs were emphasized and analyzed based on the risks. There were numerous suggested approaches for completing GB projects with acceptable cost limitations and increased economic worth. The green concept was integrated into business operations to introduce important data and proof for the sector [55].

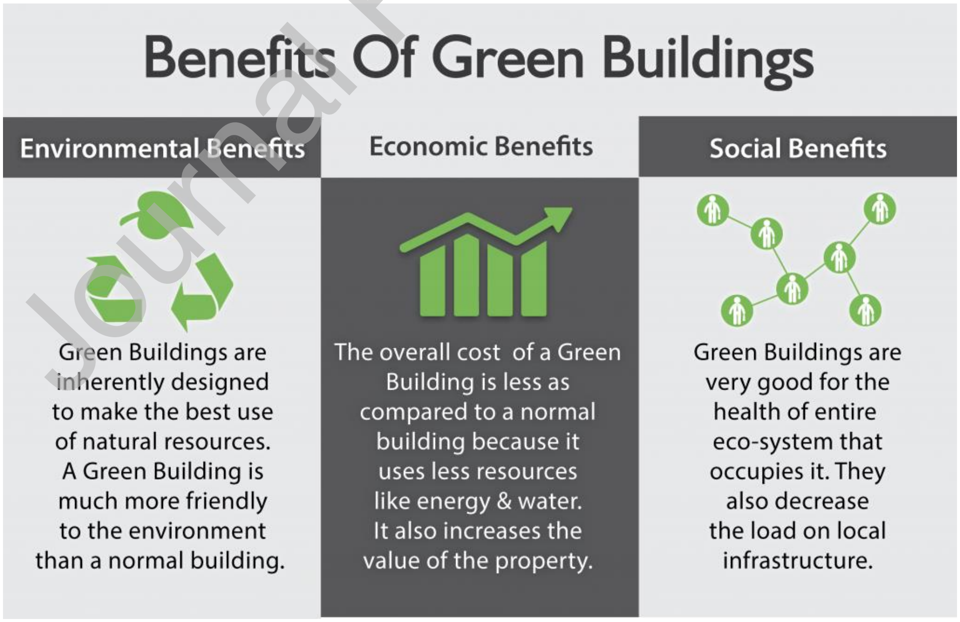

Figure 2: Environmental, economic, and social merits of GBs.

An economic study was conducted on “going green”, which included cost-benefit evaluations from the perspectives of the building life cycle and of the key market players [56]. From the building life cycle viewpoint, "going green" is more likely to be viewed as profitable, but from the point of view of developers and residents, it is still uncertain whether it is economically viable due to knowledge, behavior, and policy considerations. The study identified a number of important issues that warrant further investigation, including institutional frameworks for encouraging green practices in the construction industry, more thorough data about the life cycle expenses and benefits of GBs, the inclusion of associated long-term or intangible benefits in the assessment of economic feasibility for developers and residents, and an investigation into the dynamics of GB adoption.

Although there are obstacles to the advancement of GBs, including higher costs and a scarcity of data, insights, and awareness [57-59], the sustainability advantages of GBs and other governmental and non-governmental decisions help to advance GBs onto the primary stages of national and international development targets. Empirical studies have identified a number of distinct factors that are causing the present push for GB growth in various nations [60, 61].

4. Contribution of the GBs to the achievement of SDGs

A significant political agreement related to the future of international sustainability was signed in Sep. 2015 by the United Nations (UNs). The 2030 Agenda listed seventeen Sustainable Development Goals (SDGs) (Figure 3a) that have been adopted by the majority of the countries around the world. These SDGs focus on improving the life style and health of individuals, protecting the ecosystems, conserving water, energy, and resources, developing sustainable communities/cities, promoting innovation, industry, and economic growth, mitigating climate change, and achieving peace and justice around the world. However, the world is facing numerous crises that impact human life and the environment, which include climate change, lack of water, COVID-19, the energy crisis, the Russia-Ukraine war, and conflict predominate. All of these crises are significantly impacted by the seventeen SDGs outlined by the UNs in 2015. Recently, several researchers have studied the effect of various sectors on the achievement of SDGs, including business, water security, waste management, and household energy mix. A significant portion of studies related to the SDGs focus on the utilization of renewable energy sources and strategies to expand their global usage. The contribution of GBs to the 17 SDGs has been discussed in a previous study in 2020 (Figure 3b) where rating tools have been used to evaluate the impacts of GBs on the SDGs. Although the study represents a practical tool that can scientifically assess the GBs contribution to the SDGs, many more studies are still needed to cover all aspects of this research area.

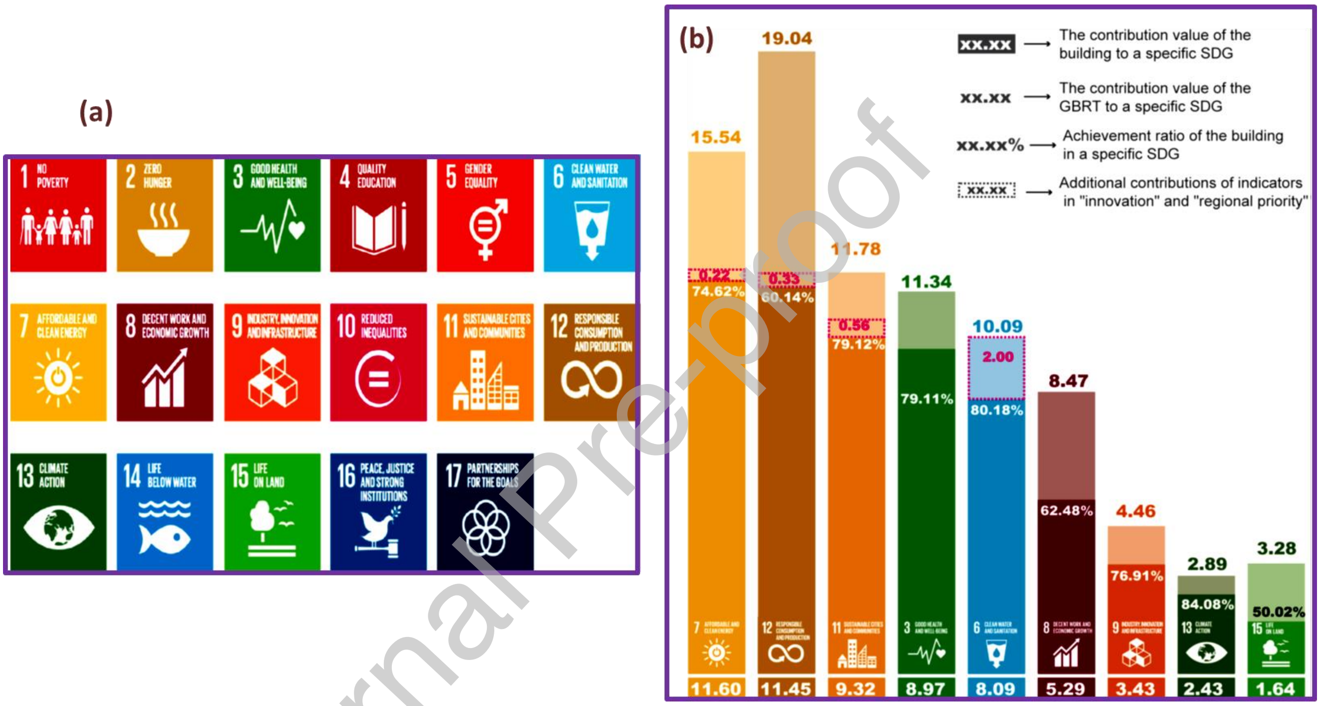

Figure 3: The (a) sustainable development goals [62] and (b) evaluating rates for the GBs contributions to SDGs [63]. (With permission number 5551320507138)

- **SDG1: No Poverty**

The first SDG, which is generally assessed by the number of people living on less than $1.25 per day, calls for ending serious poverty for all humans everywhere by 2030 [64]. According to national concepts, this SDG aims to cut the percentage of men, women, and children of all ages who live in poverty by at least half. Assuring that all men and women have the same access to financial assets as well as to fundamental amenities like buildings, it also intends to create adequate social security systems and strategies at the national level for everyone and set minimum restrictions for them [65]. Eradicating poverty could end carbon emissions by raising the concept of GBs around the world [66]. Reducing the manufacturing of cement/clinker and other building materials will reduce CO_2 emissions considerably. Reducing the consumption of energy, electricity, and water will increase the share of men and women in the profits from these vital resources [67]. GBs are affordable and serve all levels of people, not due to cheap construction materials or infrastructure, but because they are designed to be cost-effective. Actions to eradicate poverty will be accelerated by developing GB policies at the national, regional, and international levels that incorporate pro-poor and gender-responsive development approaches [68, 69]. Encouraging locals to install PV solar panels in houses and use solar heaters will reduce kWh per capita annually, bringing it below the worldwide level of ~3.081 kWh, especially in developed countries [70, 71].

- **SDG2: Zero Hunger**

Under-nutrition has been on the rise since 2011 according to UN official reports after declining for decades. This may be attributed to various stresses on health, which include climate change, the locust crisis, the Ukraine-Russia war, and the COVID-19 pandemic. Three pathways have been identified to overcome this issue: (i) led by agriculture; (ii) intervention in social protection and nutrition; or 3) a combination of these two approaches [31, 63, 64]. Zero Hunger is the key sustainable indicator because it is easy to measure and difficult to achieve, governments must bear the cost of smart GBs that are affordable and save resources, energy, electricity, and water. One-third of the world's population is facing hunger due to a lack of resources and investment in agriculture and energy sectors [72-74]. These threats indirectly reduce purchasing power and the ability to produce and distribute food, homes, and facilities, affecting the most vulnerable populations all over the world and decreasing their access to the basics of life. Maximizing building and construction may reduce the availability of agricultural land, in this case, GBs are an appropriate solution to reduce hunger and lead to a decent life. Most countries have deserts with a high percentage, and they are not used for economic, agricultural, or tourism purposes, which is why starting a new life in this desert begins with affordable housing to attract people and investment. The Sustainable Development Goals are a closed syndrome; each goal is linked to another. The scope of the issue and the benefits of developing for urban growth outside of the existing cities have received a lot of attention. New cities must be subjected to a high-level national plan that meets the SDGs in terms of population, affordable homes, and jobs. Leading the world to correct track of reducing hunger is too hard due to the lack of resources, health, and economic share; in addition, population displacement and illegal immigration lead to the un-housing of more than one-third of the world population. All the efforts must be set together for a better life and zero hunger.

- **SDG3: Good Health and Wellbeing**

Ensuring healthy lives and promoting well-being for men and women of all ages is the key indicator for achieving SDG3. It has now become strong evidence that the way a home is designed can greatly influence the health and well-being of its residents [75, 76]. According to official reports issued by the World Health Organization (WHO), public health associated with poor indoor environment quality with a high PM_{10} ratio ($PM_{10,max} \geq 15$ ppm), may cause lung or respiratory system asthma leading to death. Pollutants can build up and reach levels that are higher than those normally found outside when a building is improperly ventilated [77]. This issue is commonly known as “Sick Building Syndrome”. Cleaning or refurbishing a home is an action that can add to higher concentrations of hazardous substances such as volatile organic compounds (VOCs) from domestic cleaners, paint, and varnish. Additionally, when bacteria die, endotoxins are released into the air, which can have a negative impact on health. Thus, ventilation is crucial when cleaning, sanitizing, and cooking in a building. GB features, like better lighting, higher air quality index, and greenery, have been demonstrated to positively affect health and wellbeing for all, and this protocol type has been pushed more in recent years [78, 79]. Limiting the two sources of pollution from buildings, particularly in urban areas, can lower pollution and boost air quality, both of which are good for residents' health. Direct emissions from buildings emit from; smoking, household cleaners paint, and varnish. In addition, indirect emissions from buildings are emitted from; building materials industries, electricity production, and other infrastructure manufacturing. Table 1 summarizes the air quality objectives limits according to WHO for public health. Hence, the emphasis should be on developing a world where buildings not only benefit the environment but also enable happier, healthier, and more productive lives. A clean and targeted zero-emissions environment could be achieved by implementing GBs and bearing the additional cost of photovoltaic panels and other facilities. Policy makers must realize that providing services to improve residential housing will have implications for financial status and life satisfaction that are depicted in SDG3.

Table 1: Air Quality Objectives (AQO) [79].

Pollutant ($\mu g/m^3$)		Time		
		1 h	24 h	Annual mean
Carbon monoxide	T	-	20,000 (8h)	-
	A	35,000	15,000 (8h)	-
	D	15,000	6,000	-
Nitrogen dioxide	T	1,000	300	-
	A	400	200	100
	D	-	-	60
Sulfur dioxide	T	-	800	-
	A	900	300	60
	D	450	150	30
Total suspended particulates	T	-	400	-
	A	-	120	70
	D	-	-	60
Ozone	T	300	-	-
	A	160	50	30
	D	100	30	-
PM_{10}		-	15 (RL_{max})	-
$PM_{2.5}$		-	25 (RL_{max})	-

(T) Tolerable range; (A) Acceptable range; (D) Desirable range ; (RL) Reference Level.

- **SDG4: Quality Education**

It is necessary to guarantee accessible and balanced high-quality education and to improve chances for continuous learning. in order to build more green houses. Education is the basis of any real development, a major reason for the progress of nations, and the most important ingredient for a person to achieve success in his life. In addition, there are many initiatives, summits, devices, and events related to education and training under the auspices of international organizations in various fields, focusing on developing countries and least-developed countries [80]. It is urgent to upgrade the existing schools, liberties, and universities, in parallel with establishing new ones, in order to activate E-learning and provide safe, accessible, and efficient learning environments for all [81-83]. Organizations and societies depend on labor that must have a sufficient level of education at the professional, academic, or postgraduate levels. Primary and secondary education should have little scientific part about building materials and resources as elective courses not obligatory. In high school education, another elective course about GB technology advantages and opportunities should be studied, in order to build a strong knowledge and awareness about green sustainability. Unfortunately, more than 77% of countries have no and/or insufficient data about the education progress till the undergraduate sector, due to a lack of archiving and weak information technology transfer [83]. Online learning sessions are a very important tool for effective education and the transfer of the latest updates overseas. E-learning philosophy is effective for wider endurance in secondary and high school, and easy to achieve the SDG4.

- **SDG5: Gender Equality**

SDG5 is the target for achieving gender parity, along with social, economic, and environmental sustainability, as well as for putting an end to all forms of violence, exploitation, and discrimination against women and girls worldwide. It also aims to do away with undesirable traditions like child marriage, forced marriage, and female genital mutilation, as well as to ensure that everyone has access to reproductive rights and medical care [84]. It seems that SDG5 can be considered as a target to achieve GB sustainability. The building materials industry is known to be the job of men and not of women because of its tough industry and its need for muscle. Women have good soft skills such as; IT, management, and procurement skills, which may lead to enlarging the industry, reducing additional costs and they will earn more money with a secured career path. The lack of strong institutional and systemic social cohesion continues to gradually undermine the capacities and services needed to achieve gender equality. GB technology is the outlet for various kinds of women's inequality and reaching justice [85, 86]. Women's goals and needs should be taken into account, and they should not only be considered as contributors to change rather than as its beneficiaries. It is essential and greatly valued to involve women and girls in achieving the SDGs. Reusing building components reduces occupational dangers for construction employees by reducing the need for new structures work, which is another illustration of these benefits. In addition, due to increased public awareness of their numerous advantages in relation to environmental concerns like global warming, green structures are now producing quicker sales and licensing than traditional structure units [87].

- **SDG6: Clean Water and Sanitation**

Ending open defecation, ensuring the availability of sanitation and hygiene, enhancing water quality, treating wastewater safely for reuse, promoting clean water supplies, developing a combined approach to managing water resources, and safeguarding ecosystems that depend on water are all part of SDG6. The expansion of support for water and hygiene in developing nations is a key component of this goal [88]. To be sustainable over 5 generations, the GB is built for extended durations, such as a lengthy half-life. The GBs can implement effective and environmentally friendly water and sewage schemes that conserve potable water, process rainfall or gray water, and enable the reuse of water that has been treated for bathroom flushing or irrigation. In reality, even in dry regions, structures and houses with systems that enable no consumption of water are growing to become more practical. Large-scale corporate objectives, water usage habits, and macro-environmental factors all have an impact on sanitation and water quality [89].

- **SDG7: Affordable and clean energy**

In a GB, the lighting system is based on low-energy lighting that utilizes natural light via strategic windows and implements energy conservation fluorescent light. Other strategies have been adopted to reduce the consumed energy such as using solar tubes that offer both lighting and heating purposes. The evapotranspiration phenomenon occurs on the vegetated surface, where part of the surface heat flux is released to the surrounding area as latent heat. Therefore, irrigation improves the thermal characteristics of the green roof, considerably enhances the overall efficiency of the building energy, and reduces the cost of cooling related to the air conditioners. Additionally, this vegetated layer acts as an insulator, which prevents the transfer of heat flux to the indoor air in summer, resulting in energy conservation owing to this technology [90].

The previous studies listed some parameters impacting the thermal functioning of the green roofs such as the roof design, weather conditions, and the specific layouts (type of plant used, substrate thickness, etc.). However, higher energy saving is recorded during summer rather than winter. For example, a reduction in energy demands up to 10% was recoded in summer compared to 5% in winter. In southern Mediterranean areas, the yearly decrease was determined to be 15.1%, with an energy saving in summer up to 18.7%. In Cyprus, the most significant energy consumption reduction has been recorded in the cooling season with a percentage of 20%. The highest energy saving was recorded in Saudi Arabia with a value of 35%. On the other hand, revoting a traditional building with a green roof yields 35% of cooling energy minimization while the heating energy was lowered by 2- 10%. The semi-intensive and intensive green roofs could minimize the annual energy consumption by 70%. It seems that green roofs appear as an efficient route for energy conservation. However, the yearly energy minimization achieved using all kinds of green roofs ranges from 20% to 24% [90].

With buildings accounting for almost 40% of global energy use and being responsible for approximately 30% of greenhouse gas emissions and 40% of solid waste in the world, promoting sustainable and efficient energy use in the construction sector is very urgent and serious. This is very essential to achieving the goals set out in SDG7, and thus, moving towards GBs achieves SDG7, which aims to guarantee access to clean and affordable energy [91].

GB certifications play a vital role in supplementing the assessment tools of sustainability that provide information amongst stakeholders via the early introduction of sustainability features and simplified communication in the planning procedure [92]. Also, sustainability certification systems (SCSs) like BREEAM or LEED contributed to developing new sustainable structures more commonplace, so an accurate assessment of the performance of current structures is essential for supporting this transformation to achieving long-term SDGs. An investigation was carried out to improve the present evaluation techniques and ensure that they matched the actual requirements and structural characteristics. The research was assessed based on prior information in the two research fields of constructed environment and assessment tools, scientific research was examined [93].

An attempt to find solutions for existent buildings to mutate them to GBs as inventive solutions to reduce energy use and save natural resources in India has been estimated, in addition to the assessments of green renovation (GR) of present structures [94]. Three mechanisms have been applied in India; LEED (Leadership in Energy and Environmental Design system), IGBC (Indian Green Building Council), and GRIHA (The Green Rating for Integrated Habitat Assessment) to achieve environmentally sustainable development. Figure 4 represents the groups and elements of the GBs evaluation.

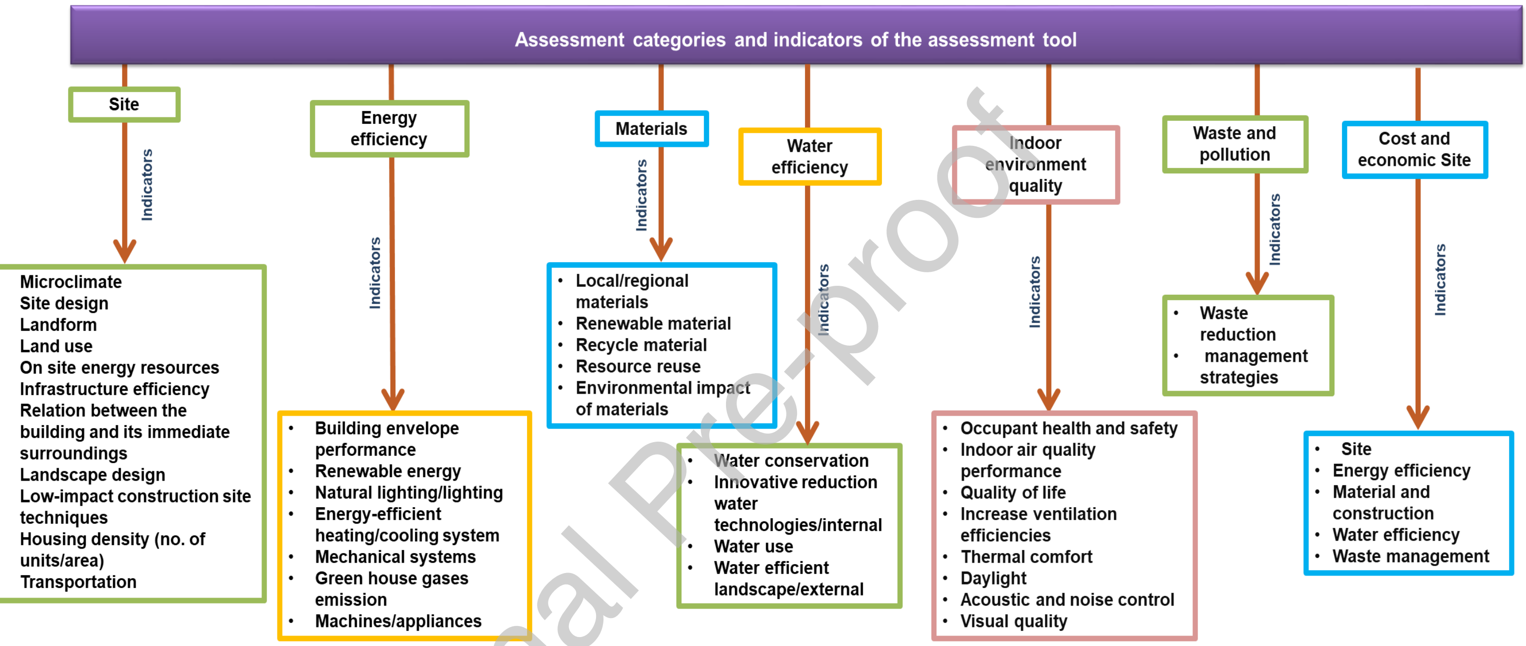

Figure 4: Categories and indicators of the assessment tool [95].

Recently, the term sustainable architecture with an environmental approach was created due to the expansion of sustainability concepts to reduce environmental pollution and energy waste, and thus, the call for fostering techniques to enhance environmental sustainability has been raised. The building industry has given a chance for experts to accomplish the SDGs more usefully via the Building Information Modeling (BIM) technique. The attributes of BIM that the most contribute to the improvement of the most significant parameters of environmental sustainability were investigated. Then, both the environmental sustainability standards and BIM attributes were estimated in the two questionnaire models, after which the study findings were estimated by using the Structural Equation Modeling (SEM) method in Smart PLS software [96]. The findings showed that the BIM features like, energy efficiency assessment, virtualization of buildings simulation and retrofit, or even the maintenance operation act an influential role in encouraging environmental sustainability.

The LEED developed by the 69 United States Green Building Council (USGBC) as a non-governmental certification scheme, is the world's most widely used GB rating system that is used to demonstrate the carbon footprint and energy efficiency of buildings [97]. Several experimental assessments of LEED licensed schemes have been issued, although LEED certification cannot be standardized for all nations, project types, project sizes, or certification levels, it is a key to track these parameters. There are 4 versions of The LEED for New Construction and Major Renovations; version 1 (LEED-NC v1 1998); 2.0 (v2 2000), version 2.2 (v2.2 2002), version 3 (v3 2009), and version 4 (v4 2013) [98].

High-performing GBs demonstrate that LEED Zero Energy and Zero Carbon (0E -0C) certifications mean the fulfillment of net zero targets in construction operations by performance renewable energy and maximizing energy efficiency. Currently, there is a trend towards net positive buildings, and thus net zero buildings have become the more suitable definition of GBs than that of energy-efficient buildings and although these ideas have major environmental advantages, they notably ignore the environmental effects on building construction life cycle. Yet, net zero to net positive growth is predictable in the outcome of practical advantages for the climate, the interventions related to renewable energy, and the reduction of energy requests lead to additional life cycle effects through the demolition and construction stages [99].

The current GBs rating schemes in Saudi Arabia, particularly Mostadam and LEED, have been investigated. Being the biggest economic power in the Gulf, it has issues with high energy density, massive amounts of demolition and construction waste in addition to the large amounts of water consumed. The study looked at any classification system that responds to the requirements of the Saudi building industry to achieve more effective preservation of energy and water. It also aimed to evaluate the amount of consciousness and readiness from the stakeholders' perspective in the building industry field to employ the two rating methods used for building properties in Saudi Arabia. However, there is satisfaction with the agreements reached by the involved parties with respect to the state of GB rating system implementation in Saudi Arabia and the readiness to use both globally accepted evaluation methods like LEED and nationally accepted approaches like Mostadam [100].

The relationship between water and energy efficiency in GBs to achieve the UN SDGs in Jordan has been investigated by using the quantitative descriptive method. Moreover, in order to investigate the contributions of the application of LEED v2.2 EA (energy and atmosphere), and WE (water efficiency) to the achievement of the UN SDGs in Jordan, a new Comprehensive Contribution to Development Index (CCDI) was suggested [101]. The findings indicate an affirmative relation between LEED v2.2 requirements and credits in each of WE and EA classes with the UN SDGs6–9, SDGs12–13, and SDG15, offering that the suggested CCDI is a credible and strong method for the assessment of the role of EA and WE in LEED v2.2- certified GBs in achieving the SDGs in Jordan.

Extensive studies have recently investigated the economic effectiveness of GBs. Oftentimes, the results note that the GBs premium is variable over time and depends on the period of study and markets under examination. Moreover, almost no investigation has been dedicated to examining the contribution of obligatory building energy evaluation revelation policies on the price premium of GB. So, there is a question as to whether the obligatory energy-rating revelation policies for buildings will affect the economic showing of GBs. It investigated how to assess the GBs premium by taking into account the mandatory energy performance requirements of the commercial building disclosure program (CBDP) using MCSI/IPD NABERS statistics for the timeframe (2005-2020) [102]. In Australia, structures with a NABERS ranking of four stars or greater had a better total profit than structures with a lesser NABERS rating. Adequate social performance will eventually lead to adequate economic fulfilment. Additionally, the modeling showed that the GBs premium is more powerful since the beginning of CBDP, reflecting the significance of obligatory building energy performance revelation.

The LEED certified building can save energy 28% more than that of the national average level [103]. In another study, the saved energy reached up to 30% compared to that of traditional buildings [104]. The energy data of 100 LEED licensed projects reported that LEED certified buildings can save energy from 18% to 39% per floor area compared to traditional counterparts [105].

- **SDG8: Decent work and economic growth**

The business of GBs has many economic benefits; for example, assessment and preliminary review to identify the basic requirements, planning (goals, LCA, and consecutive plan), and auditing after transformation showed that GBs can improve the occupants' productivity as they live in green circumstances which are characterized with conserved water and energy, minimized waste and low maintenance [52]. GBs offer numerous incentives to construction developers all over the world. For example, the Green Mark Incentive Scheme for current and new GBs in Singapore can gain incentives up to $3 Million according to the specific standards of the building [106]. In the USA, GBs can gain tax credits, according to the building area an LEED certification level [107]. Faster leasing and sales of these green units can help developers reduce their financial risk by generating returns that can be used to pay off loans and other debts. Therefore, the interest that has accumulated is reduced, which opens the door to bigger profits [87].

GBs have several benefits in addition to the direct environmental advantages, as structures become more comfortable and therefore the people working in these buildings are more productive, increasing overall economic profits. Besides, the rental and asset values of GBs are becoming more expensive than those of traditional structures, leading to advancements in design, marketing, and use of financially feasible technologies and products that save the environment and lessen the risks to human health [108].

Twenty-two professional building owners investigated the challenges they face and the prerequisites to upholding successful achievement, in addition to a survey focused on their present progress toward the SDGs through a group workshop [109]. The findings indicated that SDGs 7, 8, 11, 12, and 13 were the five highest priorities among the building owners, along with that nearly 94% of building owners had achieved, or even desired to achieve the SDGs to sundry levels. Actually, the base barriers facing the building owners were the shortage of local tools, elements, and ways to aid the achievement of the SDGs in construction, the knowledge of building owners about the SDGs, and the additional costs associated with the achievement of the SDGs. The key practical solutions proposed to deal with the barriers were the creation of new methods and tools that support the SDGs in the construction industry.

In GBs, the ratio of output to input is regarded as productivity. In the case of the built environment, the output is the operating performance of the building and the input is the operating cost of the building. The effect of indoor environmental quality (IEQ) on work effectiveness has also been revealed by various researchers. The relation between the building's performance and the productivity of its residents, with reviewed studies indicating that GBs assist in raising occupants' productivity via reducing operational costs as a result of the decrease in energy costs [78].

SDG3 and SDG8 among the 17 UN SDGs are the two fields in which IEQ can make a significant contribution, as IEQ can positively impact work productivity, especially in an office environment. The health, inhabitant contentment, and work in the newly renovated office building marked BREEAM Silver certification scheme was studied for the best sustainable office building design aligned with the agenda 2030. Additionally, the desired characteristics of IEQ compared to the present settings were discussed to advise future planning [110]. The findings revealed that human satisfaction with the IEQ was not sufficiently achieved and that occupants of the office environment preferred a higher temperature, less noise, more daylight, and cleaner air. Actually, there are still various issues related to interior conditions; thus, further ameliorations are required to acquire the satisfaction of inhabitants and positively impact comfort, occupant health, and work productivity.

From the occupant's perspective, the evidence for certified GBs performance rest conflicting, with many questions about how 'healthy buildings' can be effectively evaluated, encouraged, and designed. The actual barriers that may hinder the effectiveness of green-rated buildings have been identified, the basis has been laid for researchers and developers of the green- rating scheme to seize current and future opportunities, and a new framework has been established for green licensed buildings [111].

The contributions of geopolymer concrete (GeoC) as GB materials and its modern applications to achieve the SDGs and its role in developing the potentials of circular economy strongly to the achievement of 12 of the 17 main SDGs, among which is goal 8. A comprehensive review of the current body of knowledge on GBs research was discussed, with a focus on the African status. The economic issues and social sides of GB have been investigated, as well as, approval and implementation and custom GB rating tools have been studied [112]. The research recommended that new researchers need to develop more details to determine the cost–benefit proof for GBs adoption, the use of information communication technology (ICT) in GB research, and the conceptual understandings supporting GB deployment.

A financial modeling showed that GBs will incur extra cost of up to 10%. Moreover, the cash flow analysis reported that GBs design saves US\$1.38/ft^2/annum compared to traditional buildings. Concerned maintenance, the technical and economic performance of GBs in terms of water efficiency, energy efficiency, and cost, perform better than traditional buildings [113]. The GBs including low-energy offices recorded energy saving more than 55% compared to traditional buildings [114]. GBs have many more economic benefits in terms of productivity where the absenteeism is considerably lowered and the productivity has increased by 25% when residents transitioned from traditional buildings to GBs [115].

- **SDG9: industry, innovation and infrastructure**

The globally accepted SDGs, especially SDGs 7, 9, and 11 emphasize the prudent use of energy in assorted sectors, including the construction industry (CI), which consumes nearly half of the energy produced in the world. In Green Building Studio (GBS), an investigation of a hospital facility was used to examine the efficient use of energy in the building sector and how improved energy performance can be achieved by modifying different factors and elements, such as glazing, components, orientation, and heating, ventilation, and air conditioning (HVAC) systems [116]. It also discussed the usage of the BIM process to create sustainable plans to lessen energy squandering in structures. At first, in the literature, the useful elements of the BIM models on GBs were set and subsequently classified according to specialist opinions which were collected using a set of forms. The set advantages were confirmed by performing an energy assessment on a hospital layout via 3D BIM. The results showed that using this approach, a significant portion of the cost of energy, electricity, and CO_2 gas may be saved. It has been set that a rapid and durable planning method, enhanced energy performance, improved building performance, and better layout alternatives are the main advantages of adopting BIM through these schemes. Also, a Cronbach's alpha value of 0.822 was found, which confirms the findings. The suggested strategy might result in the sustainability of future buildings and the enrichment of a GB culture that emphasizes conserving energy.

The function of the building sector in achieving the 2030 SDGs has been investigated, as the CI has been supplied with a new lens by the SDGs by which global desires and needs can be converted to real solutions. It uses a sequential illustration design with an initial phase of the quantitative tool, and then with a phase of qualitative data collection [117]. After conducting comparative studies of the literature related to the 17 SDGs, a survey was prepared and managed between 130 participants, followed by validation of these data by holding semi-structured meetings with 16 experts in sustainable buildings. Second, analyses of data derived from the semi-structured validation meetings were conducted via comparisons of quantitative data with qualitative data. The results indicate that the CI has a conclusive contribution to achieving nearly all of the 17 SDGs. However, the roles were predominant in the 10 main of the 17 SDGs, which are SDGs 3, 5, 6, 7, 8, 9, 11, 12, 13 and 15. Besides, the research provided more insights into the latest developments of the CI's role in achieving the SDGs. In the area of digital information technology (DIT) use, the CI has lagged behind other sectors [118]. The digital development of smart GBs has been analyzed to facilitate the creation of contiguous eco-development zones in green eco-cities where it classifies the primary elements of Intelligent Green Buildings (IGB) and abstracts the implementation and contribution of Digital Twins (DTs) within IGB [119]. The results showed that while the DTs have been applied, they have not yet been completely incorporated into the IGB architecture. Designing IGBs, such as green buildings, must prioritize sustainable growth and improving people's quality of life.

Based on the efficacy of the Internet of Things (IoT), the environmental effects of GBs in smart cities have been evaluated. The results indicated that the utilization of IoT systems can lower the unfavorable environmental sides in GBs. The challenges and issues related to the implementation of the green concept in Nigeria were explored. Problems associated with green concept implementation, detecting the current use of green practices in building scope, the crucial success drivers in the implementation of the green concept, advanced elucidations of incorporating green concepts in constructions, and the barriers involved in the development of the green concept in construction have been discussed [120]. Now, the key issue of GBs is how to operate itself. Therefore, the IoT with 5G networks presents new opportunities (Figure 5a) to integrate the intelligence of a GB design [121-124]. The design of GBs for energy-saving measures was shown to reduce the impact of energy use in buildings by collecting residential building data through low-cost sensors and leveraging human activities for energy efficiency.

The use of artificial intelligence (AI) in GB is an efficient approach to boost the competence and sustainability of the Architecture, Engineering, and Construction (AEC) sector, but so far there is no in-depth study on the latest research on AI in GB. The integration between AI and GB has been revealed, along with an emphasis on research hotspots and research gaps that may be addressed in future studies that incorporate AI and GB [125]. The findings indicated that this study adds to the field of GB knowledge and reveals the need for more research in this area to boost the activity and sustainability of the AEC sector. The primary challenges toward the use of AI in GBs are illustrated in Figure 5b [126].

Figure 5: The main challenges toward the implementation of (a) IoT and (b) AI in GBs.

- **SDG10: Reduced inequality**

The achievement of SDGs in developing countries requires urgent addressing of economic and social issues, not environmental issues only. Hence, to achieve sustainable development in developing communities as well as developed ones, the economic and social challenges should be at the top aims of these countries' agendas. Thus, the policies and building assessment routes should be modified to encourage the building and construction industry onto the sustainable track. Some helpful recommendations have been made to develop GBs assessment tools, such as developing assessment frameworks based on scientific research, technical knowledge, and multi-stakeholder participation. The general strategies and SDGs should be highlighted as major aims. A national assessment framework should be developed according to the culture, issues, practices, institutions, players, and nature of each country. Countries can utilize the work and ideas of other countries as inputs to their discussion [95].

- **SDG11: Sustainable cities and communities**

The conversion of ancient cities into sustainable cities seems to be a global trend as involves various approaches to give a better environment to new sustainable cities that become more livable spaces. Obviously, government policies are essential factors in furthering the sustainable goals of cities, with Green Building Councils (GBCs) playing a crucial role in enabling such alterations. Two developed sustainable cities, Hong Kong and Vancouver, were chosen as case studies to examine the responsibilities of the GBCs and local governments in driving the transformation of cities to accomplish the SDG11 [127]. A series of interviews were preceded with experts including leaders and government officials from GBCs in both cities. While visiting the site in both cities, notable new GBs were observed. The approaches of differences and similarities in both cities to achieve sustainable conditions were discussed in addition to the directions for the future and recommendations. Energy-efficient university campuses as the main constituent of the natural environment in cities will perform a leading role in developing sustainable cities in the future to reduce the depletion of key resources. So, it is necessary to evolve new decision-making methods and techniques for assessing the sustainability of campus buildings [128].

Green BIM, as a new decision-making tool, provides a unified framework for action of decision-making and ways to enhance the green display of buildings. The case study of three models of the most common university buildings in northern China was investigated to illustrate green performance assessment tools, which are essential in the initial phases of designing campus building congregations to attain the goal of low-carbon green Chinese campuses [129]. The results indicated that there is a need for a comprehensive method that combines factors in planning, system layout, building design, energy efficiency, and planning of energy preservation to enhance the green efficacy of university buildings to achieve the low-carbon green Chinese campuses goals.

Currently, Smart sustainable cities (SSCs) are the key mode of the development adopted by cities all over the world, as they respond better to environmental changes, ensure honest and clean government, enhance the quality of life, and create a global economic network [130]. In a smart city environment, the prospective effect of the integration of BIM and block chain on making buildings more sustainable in the context of City Information Management (CIM)/SSC was examined [131]. The results confirmed that decision-makers, constructors, supervisors, and designers can be aided by studying the entire life cycle to make accurate rulings for GBs in developing SSCs.

A series of numerous studies that explore various features of smart cities (Figure 6), including the significance of GBs for smart cities, have been discussed. The financial Incentives (FIs) for GBs in Canada can be taken as an example. The financial Incentives (FIs) for buildings in Canada can be divided into four classes: loans, rebates, grants, and taxes, while rebates are the most popular across all territories. These FIs available to three end-users (landlords and tenants, aboriginal people, and low-income) and for three kinds of buildings (non-profit, heritage, and energy-rated) [132].

Figure 6: The main characteristics of sustainable GBs [133]. (Open access)

There is an urgent desire to remove carbon emissions from the sector of renewable energy to reach net-zero emissions through industrial decarbonization and the development of SSCs by accelerating the construction of GBs and electric vehicles. Application of GBs in civilized zones and support for the use of electric vehicles are keys to moving towards SSCs in order to improve the environment. Various aspects of developing smart cities were investigated and new feasibility indicators aligned with GBs and electric vehicles in SSCs design were developed, submitting existing hindrances to smart cities growth, and finding solutions. The findings indicate that zero-energy development, concern with design criteria, application of effective parameters for GBs and electric vehicles, and the establishment of methods to lower the production expenses of electric vehicles that are aligned with continuing high-quality standards and load management are achievable and feasible policies in developing smart cities [134].

- **SDG12: Responsible consumption and production**

The twelfth goal is the effective utilization of natural resources sustainably and effectively, including the adequate decrease of waste through mitigation, recycling, and reuse. As a result, the use of industrial waste as supplementary cementitious materials (SCMs) in composite cement gave rise to the circular economy (even before the word "circular economy" existed) in the cement and concrete business [135, 136]. Additionally, one of the biggest waste sources in the world that can be turned into useful concrete is the waste from construction and demolition.

The building and construction sector consumes natural resources of stone, gravel, and sand up to 40% of that consumed worldwide annually and 25 % of the timber extracted from the forest [29]. Due to this continuous destruction caused by traditional buildings, the solution arises from reusing or recycling the exhausted building materials to minimize this aggressive consumption or aiming to develop sustainable green materials [29].

By utilizing various grading frameworks, GB applications aim to transform existing structures into ecologically friendly structures, reflecting the concept of sustainability in the building industry [137, 138]. It was addressed in [139] how GBs contribute to sustainable output. Based on the conversations done by the officials of the industrial battery business, INCI, which holds the first GB certified center in Turkey, an investigation was conducted into the opinions of the industrialists. The findings suggested that GB's buildings could be more efficient in sustainable production, that investments in environmental protection could raise interest rates for businesses, and that sustainable production might be a way to resolve the environmental development conundrum.

Green technology indexes for sustainable investments and greener output in the context of a developing country were evaluated [140]. The study focused on 8 leading indicators in green technology: agriculture and forestry, ecosystem sustainability, efficient use of resources, energy utilization, green transport, ecology safety, GB, and life health. The findings showed that agriculture, forestry, and energy use are important indicators. Also, this study is one of the primary studies conducted to evaluate the green technology metrics for more environmentally friendly output and profitable investments to meet the SDGs.

Rating tools of GBs have played a significant role in the construction process. A practical visualization tool based on GBs has been suggested as a way to evaluate GBs' contributions to the SDGs while giving the public apparent and reliable data about the trajectory and scope of these contributions. An analytical hierarchy process was used for the quantitative analyses of this contribution. Moreover, there are two active ways that have been suggested for enhancing the role of GBs in the SDGs [63]. The findings confirmed that SDG3, SDG7, SDG11, and SDG12 are significantly supported by GBRTs, with SDG12 being the most. At the same time, SDG7 is the most notable as it gives the most key pathway for GBRT's contribution to the SDGs. Finally, the identification system was illustrated as an actual case that incorporates important information, which includes the contribution of GBs to the SDGs.

Although a set of crucial success factors affecting GBs promotion have been identified in the literature, no agreement has yet been reached about the factors and their importance [12]. The findings showed that promoting GBs is linked with the roles of government and stakeholders. There is a need for cooperation and commitment on the part of stakeholders in the practice of GBs, and there are also sufficient incentives and compulsory demands at the legal level. It also provides consultations to practitioners and policy makers in good practices and formulating policies to enhance GBs.

Thermal energy storage (TES) schemes in conventional buildings are considerably based on traditional phase change materials (PCMs) that are developed from non-renewables. However, a remarkable focus on the production of green PCMs has been witnessed in recent years [141]. PCMs have been frequently employed to improve the performance of buildings and reduce their energy consumption [142]. For this reason, endeavors and specialists have developed various types of PCMs aiming to improve the thermal performance of these materials. These types include nano-enhanced, foam composites, encapsulated, and shape-stabilized PCMs. Consequently, this development has broadened the utilization and applications of PCMs, including renewable energy systems [143], heat sinks [144], refrigerators [145], and heat exchangers [146]. To encourage the conservation of natural resources, bio-based materials have been utilized owing to their non-toxicity, renewability, high latent heat, minimal super cooling, thermal stability in a wide temperature range, acceptable freezing/melting temperatures, cost-effectiveness, and self-nucleation [147-149]. On the other hand, there are still some challenges to the application of these green precursors on GBs such as unpleasant odor, biodegradability, leakage, and local availability. Future research should emphasize enhancing the mechanical properties of these bio-based wastes including encapsulation and supporting on other materials.

Other wastes like edible oils, genetically modified oil, and animal fat could be used. Significant technical advancement refers to the implementation of bio-based PCMs (bPCMs) in TES and building envelope applications [150]. Some alternative building materials are also developed from bamboo, hemp, and straw [151]. Building sector consumes half of the world raw materials, thus, GBs that utilize eco-friendly wastes in their construction save raw materials, including recycling of bamboo in flooring, and non-toxic materials, such as formaldehyde free cabinets and toxic-free paint. Other wastes like fly ash, destroyed bricks, and rice husk ash, are employed for the production of new building bricks and have been utilized as GBs materials to ensure sustainability [152].

- **SDG13: climate change**

In developing countries, the building sector consumes significant quantities of the nation's resources. For example, the traditional building consumes around 70, 40 and 12 % of the electricity, natural resources, and potable water of the nation, respectively, and generates 44 to 64% of the solid waste which is discharged to land fillers resulting in hazardous emissions up to 30% of greenhouse gases. In Europe, the building and construction industry shares from 25 to 40% of the total energy demand which is equal to approximately 35% of Europe's overall carbon dioxide emissions. This energy-based CO_2 is increased by up to 39% in the building sector around the world [29]. These percentage values are considerably increasing owing to the population growth, climate change (increased and fluctuating temperatures), and the recent events of the COVID-19 pandemic due to the much more time that populations spend in their home and the corresponding energy-consumed activities. Hence, construction of GBs becomes a mandatory issue to reduce the impact of urban heat as shown in Figure 7.

Figure 7: A photo of a GB with its sustainable green roof [90]. (With permission number 5551320662362)

The building sector yields around 8.01×1011 t CO_2 annually worldwide. It was estimated that covering the walls and roof of the building with 25% PV panels to efficiently utilize solar energy would minimize the CO_2 emissions to nearly zero. Additionally, it was determined that the environment presently contains 402 ppm of CO_2, which contributes to global warming. In order to cool the planet at a reasonable pace, this number must be lowered to 300 ppm CO_2. Each building employing blackbody-assisted PV arrays will cut its annual CO_2 output by 40% [153].

- **SDG14 and SDG15: life below water and life on land**

Utilizing bio-based materials and nontoxic wastes, as mentioned in detail in the discussion of SDG12, will protect the human and the different ecosystems from the negative impacts of these wastes. TES systems are implemented in buildings with a great deal of reliance on conventional PCMs, which are made from rare and nonrenewable resources. Meanwhile, bPCMs are preferred over conventional PCMs to encourage recycling, construction of truly GBs, and preservation of natural resources. The main qualities of bPCMs that contribute to making them the best option for TES use involve renewability, non-toxicity, limited supercooling, significant latent heat, thermal stability through broader temperature ranges, appropriate melting and solidification temperatures, self-nucleating action, and limited flammability (see Figure 8). On the other hand, bPCMs face a number of difficulties that prevent widespread adoption, including biodegradability, odor production, leakage, and demand-supply problems [150].

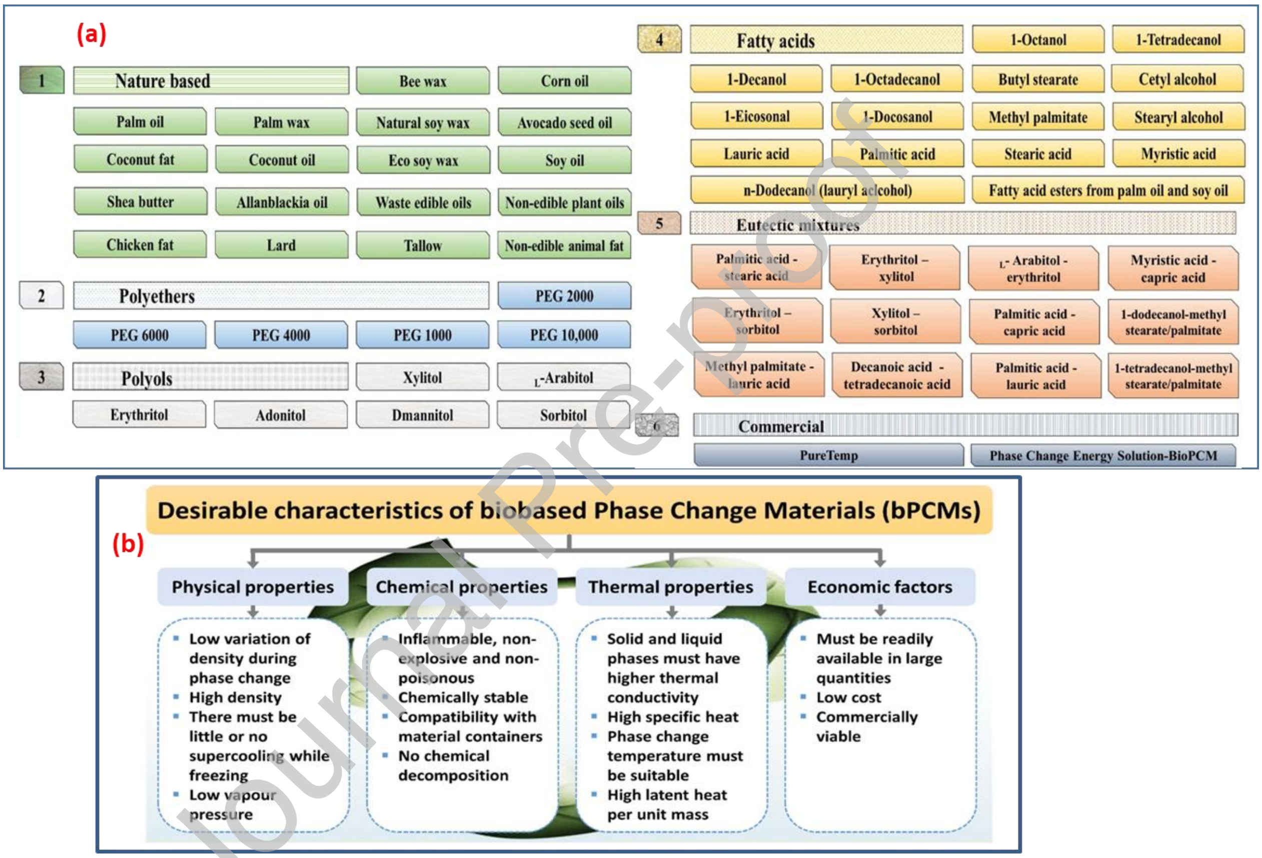

Figure 8: (a) Classification of PCM and (b) characteristics of bio-based PCMs [150]. (Reproduced with permission number 5551320906477)

The creation of value-added materials and biofuels using the biochemical route with the aid of grain and forest wastes as feedstock has been investigated in numerous studies. It was concluded that this route has several negative impacts regarding human health, soil carbon sequestration, nitrate and nitrous oxide pollution, and biodiversity and that municipal waste, including wastewater, is the best choice for the production of biogas [31, 63, 64]. For context, 400-500 g/day of human wastes can generate 0.4 m^3 Ch_4/day. Reclaimed wastewater can be utilized for different irrigation purposes such as rooftop gardening and building landscape. The innovative design of GB enables efficient management of wastewater which leads to zero-liquid discharge.

Over the past few decades, domestic and business construction growth has been expanding rapidly across the globe, in metropolitan, suburban, and rural regions [86]. As a result of the construction industry's usage of conventional energy, the risks of climate change are growing quickly [83]. Additionally, because it reduces and/or empties out the Earth's water strata, the household water that is provided for buildings by the draining of reservoir water contributes significantly to extreme global warming. The management of municipal water is also very practically focused and has a negative effect on the ecosystem. Similarly, conventional disposal of waste also contributes significantly to ecological contamination, endangering marine life and harming people's heath. The ecosystem and atmosphere are seriously threatened by the use of conventional energy, water, and gas sources for homes and buildings. Therefore, enhanced innovation is needed for the construction and housing industry to implement environmentally friendly technologies to resolve environmental problems and create a healthier, greener atmosphere. It's interesting to note that the aforementioned "Green Science" technology combination may be the most advanced method of meeting buildings' and homes' electricity, water, and gas needs without requiring external connections. This eco-friendly technology can be applied to any home or building, even if only 25% of its outer layer and roof are used for PV panels to satisfy the building's total energy needs. Also, direct groundwater extraction and treatment powered by PV panel electricity could be used to supply all of a structure or home's household water needs. The employment of ecological pollutants (human and domestic wastes) would then be converted into biogas through the process of methanogenesis to satisfy the total gas needs for cooking and HVAC systems in buildings and homes, and on-site purified waste water would be used for irrigation and gardening. A thorough cost analysis was done to assess the differences between independent and traditional building strategies; curiously, the findings showed that independent building strategies are significantly less expensive and provide superior technological benefits. Thus, it is recommended that this technology be used as widely as possible in the world to produce biogas, on-site groundwater extraction, and solar energy in order to develop an autonomous building solution that can satisfy all three pressing requirements [153].

The GBs contribute to the enhancement of urban biodiversity as well as protect the ecosystems via sustainable land use [154, 155]. It is worthy noting that minimizing the demolition and construction wastes is a key parameter of GBs sustainability [156, 157]. However, to reduce the negative effects of demolition and construction waste on land and below water, the recycling rate should increase above 90% which suggests reusing and recycling materials in the new GBs [154, 155, 158].

- **SDG16: peace, justice, and strong institutions**

Previous research has shown that GBs can produce impressive advantages, such as enhancing environmental conditions, efficient land utilization, habitat preservation, encouragement of material reprocessing and reuse, improved energy efficiency, and reductions in solid refuse and

CO_2 emissions. However, the active involvement of stakeholders, such as the government, developers, technology creators, and consumers, is crucial to the achievement of GBs sustainable progress. In brief, GBs can indirectly impact this goal [159].

Several researchers asserted that there are additional advantages of GBs that are not right away linked to costs. These researchers emphasized the positive effects of GBs on people, which was based on the period of time people spend inside buildings. Numerous studies have indicated that GBs are capable of achieving greater levels of IEQ than traditional buildings, which benefits occupants' efficiency and health. The amount of building users' satisfaction is raised as a consequence [160]. Another research concluded that users of GBs are more pleased with thermal and visual comforts than those in traditional buildings, but there was no difference in sound satisfaction between these two kinds of buildings [161].

- **SDG17 partnership for the goals**

Governmental institutions all over the world have established numerous plans to achieve the SDGs; however, GBs play a significant role in this concern. Developers, designers, and governmental institutions are required to be better aware of the merits of investing in GBs to maximize their contribution to the achievement of the SDGs. The lack of data and awareness about GBs is still a challenge toward achieving SDG17.

5. Barriers

Although GBs has been shown to have positive effects on the environment, society, and economy, most nations only use them on a small percentage of all construction projects, and their results aren't always satisfying. Due to the high risk of delays associated with GBs initiatives, improvements to their timetable performance have been suggested [162].

Additionally, the environmental sustainability of GBs during their active stage is significantly below their intended values [163].

Numerous researchers have discovered and compiled difficulties, important elements, and obstacles influencing GBs in various ways. Based on a field survey with numerous Singapore-based construction firms, a number of potential hazards in green commercial building schemes in Singapore were assessed in order to quantify their potential criticalities to those in conventional counterparts and to recommend prevention strategies that can address these risk factors [164]. According to survey findings, the top 5 major risk factors for green commercial construction projects are: inflation, currency and interest rate instability made more serious by the purchase of green products, longevity of green resources, damages brought on by human mistake, and a lack of green goods. The findings also indicated that while adopting green concepts, supplies, and techniques had increased risks for green commercial building objectives, they were still less serious than those associated with their conventional counterparts in terms of layout modifications and poor constructing quality. Seven commonly used risk reduction strategies were also suggested in this research.

Risk variables that had an impact on the key GB criteria were divided into 4 categories (financial, social, ecological, and managerial sustainability) [165]. Although numerous investigations have looked at project managers' abilities, not many have done so in the field of GB. The difficulties encountered by project managers who carry out GB projects have been recognized and decided, and the key knowledge and skills that must be managed to address these difficulties have also been recognized [166]. In order to build a knowledge foundation for project managers to compete and successfully carry out sustainable projects, numerous surveys and interviews with project managers were also performed [167].

The findings of a questionnaire survey that included 6 crucial variables revealed a number of obstacles preventing the growth of GBs in China's urban region. The influence of the key variables' relative importance over company intentions to reduce carbon emissions was further demonstrated using structural equation modeling. The findings demonstrated that each of these crucial variables has a substantial effect on low-carbon building, with return on investment taking precedence over low-carbon desire. Six suggestions were made in response, with the intention of serving as a guide for the successful creation of metropolitan low-carbon buildings [168].

To emphasize the significance of economic goals, incentives against threats to GB growth were thoroughly examined in Malaysia [169]. The majority of the information came from answers to surveys that construction stakeholders engaged in GB advancements filled out. The results of the survey have undergone a comprehensive analysis employing the Analytical Hierarchy Process technique in order to identify the top significance of the financial incentive factors and risks found for GB growth. As an outcome, the two main variables that had the greatest primary significance and affected the majority of the decision-making for GB growth in Malaysia were a shortage of government incentives and expensive capital costs, both of which were categorized as GB risks. The findings demonstrated that government support and assistance have contributed to the growth of GBs and that more instances of greater profit yields have increased developers' inclinations for GB growth.

To determine the different frameworks of GBs evolution study, advances and constraints, similarities, and methods to improve these theories [170], a thorough analysis was conducted. Project delivery characteristics, vital success variables, challenges, motivations, risks, and rewards were some of the GB theories that were found. However, obstacles still persist in GBs all over the globe, such as poor GB quality and errors in GB distribution and green remodeling for current buildings [171-174].

The involvement of stakeholders is crucial for the growth of the GB sector, and numerous study investigations have been carried out in this field [175]. Each participant in a GB project should evaluate the risk sources, rate their own risks, and take action to reduce any potential risks' negative effects. Stakeholders and risk assessments are crucial for creating a thorough risk inventory and identifying the root causes of risks, as well as for GB project management's efficient decision-making and communication [176].

According to the discussions with contractors and designers about the security status of green and non-green buildings, a number of researchers examined the risks related to GBs with a focus on stakeholder accountability to determine whether there were variations in recordable incidents and lost time cases between the two project types [177]. The last ten years have seen a huge increase in the importance of the responsibilities of project stakeholders in GB implementing projects. Researchers divided project stakeholders into two groups: the group of exterior project stakeholders and the group heading the green effort, such as the government, contractor/builder, and expert [178, 179].

For green techniques, the importance of teamwork and project stakeholder involvement was highlighted. It was made clear that project stakeholders had a duty to promote and develop a local and international building industry and community that was more viable [180]. The building project's risks and stakeholder teams, including the customer, contractor, subcontractor, provider, end user, and competitors, were identified [181]. Other studies examined green strategies across numerous areas and risk analysis from the viewpoint of project stakeholders.

These studies primarily used case studies or questionnaire surveys to gather views from business professionals regarding the risks associated with green project development. Project team employees, including contractors, advisors, and developers/owners, made up the majority of the stakeholders [182].

On the other hand, many research articles addressed the motivators and obstacles in GBs, which were also associated with key elements of success, while a variety of investigations determined the essential characteristics of GBs from various viewpoints to achieve better GBs procedures [170, 173, 183]. The most significant variables that have an impact on GBs are determined to be upper management and sponsor aid, stakeholder standards, and end-user-imposed limitations [184]. Besides, five critical success factors for enhancing green renovations in China were provided: specific requirements and regulations, recognized governmental schemes, an organized plan, current building assessment and policies, and incentives or tax reductions [185]. In order to support place attachment and offer a variety of social, psychological, and ecological aids in GBs, several important green design strategies have been developed. These strategies include opportunities for connection to nature, visible environmentalism, opportunities for environmentally conscious actions, and indoor environmental quality which promotes physiological comfort [186].

Twenty specific research that were chosen yielded the identification of 40 essential variables for success in GB marketing. Following a meta-analysis that evaluated the importance of these variables, publishing biases, subgroup evaluation, and sensitivity assessments were carried out as additional analyses. The findings suggested that governments and parties play crucial roles in promoting GBs. GB applications depend on the dedication and collaboration of stakeholders, alongside sufficient rewards and legally mandated requirements. Additionally, compared to variations in other categories, the distinction in the building style subgroup is more substantial [12].

6. Conclusions and future perspectives

This study offered a display of the GBs' contribution to the SDGs. The relationships between the 17 SDGs and GBs vary remarkably such that not all of them are closely tied to GBs. The SDGs 1, 2, 4, and 5 are usually thought to be poorly tied to GBs, while SDG3, SDG6, SDG7, SDG8, SDG9, SDG11, SDG12, and SDG15 are widely thought to be strongly related. It is envisaged that this research will offer a new viewpoint and a greater understanding of the significance and influence of the SDGs in the GBs field. Discovering green resources will greatly reduce the cost as materials and personnel make up the majority of GB's expenses. Recycled and reused materials must be used in new building projects since the recycling rate must be above 90% in order to reduce the apparent environmental effects of construction and demolition debris. Reducing resource usage and increasing resource application effectiveness are two important aspects of sustainable building design. Reducing, recycling, and reusing waste from building and demolition projects is one of the most prevalent strategies.

While the current study has identified that not all SDGs are closely tied to GBs, there is a need for more research to understand the reasons behind this and explore how the relationship between SDGs and GBs can be strengthened. This may include the development of new strategies, promoting green resources, emphasizing reduced resource usage, and increasing resource application effectiveness.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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