Environmental and sustainable aspects of green building: A review

F Çiner¹ and N Doğan-Sağlamtimur¹

¹Department of Environmental Engineering, Niğde Ömer Halisdemir University, Niğde, 51240, Turkey
E-mail: neslihandogansaglamtimur@gmail.com

Abstract. Public and scientific focus of interest on climate changes, population increase, rapid urbanization is rising day by day. Thus, increased demand for green buildings that reduces negative impacts, and can create positive impacts on climate, natural environment and sustainable development is a new topic. Green buildings must be not only eco-friendly (efficiently use energy, water, and other resources, use renewable energy, reduce pollution and waste, enable reuse and recycling, have good indoor environmental quality, use of materials that are non-toxic, ethical and sustainable) but also function as the key part to provide a comfortable working/living environment for human activities and improve quality of life. It is realised that green buildings as a worldwide response to raise awareness of the role of human activity in global climate changes, with maximum expression in Leadership in Energy and Environmental Design (LEED) Certification and its five basic requirements: Sustainable Space (SS), Materials and Resources (MR), Energy and Atmosphere (EA), Environmental Quality (EQ), and Water Efficiency (WE). The aim of this study is to review the environmental and sustainable aspects of green buildings. For this goal, environmental and sustainable aspects of green building including its origin, concept, eco-friendly properties, benefits, tools, rating systems, certifications are given and discussed in detail in this study.

1. Introduction
A building as the shelter is designed to provide an indoor environmental quality (IEQ) that is comfortable and attractive/appealing to its users. Having the understanding of the relationship between the IEQ performance in buildings and the overall satisfaction derivable from the environment by the building occupants are necessary variables that will enhance the formulation of the requirements for architectural and building systems design and control. Nowadays, the assessment and advancement of the IEQ in buildings is arousing attention due to its contributions to green buildings and sustainable environment [1-6]. It is therefore relevant to state that providing an excellent indoor environment in a building will contribute substantially to its rating as a green building [3].

The increase in the world population pertains to higher demand for water, energy and natural resources which, in turn, overloads ecosystems and increasingly damages the environment [7]. Sustainable cities necessitate sustainable/green buildings[8]. A green building (a green construction or a sustainable building) refers to a structure that uses an environmentally responsible and resource-efficient process throughout a building's lifecycle: from sitting to design, construction, maintenance, operation, destruction and renovation [9]. A green building has many different definitions, but it is generally considered to be the planning, design, construction and operation of buildings with utmost
Among other manufacturing and production sectors, the construction sector is one of the sectors that should include sustainability and has been the main driving force of sustainable construction and green building movements. There is a consensus in the literature that green buildings perform better than traditional (non-green) buildings in a number of performance/application areas [7]. Green building designs are applicable for various real estate projects such as: (i) Residential (Housing and Development), (ii) Industrial (Plants, Factories, Industrial Parks, etc.), (iii) Corporate (Office, Research Centres) and (iv) Commercial (Retail: Hotels, Shops, Malls, Showrooms, etc.) [12]. Conceptual drawings of a green building are shown in Figure 1 [13, 14].

![Conceptual drawings of a green building](image)

**Figure 1.** Conceptual drawings of a green building, indicating features (top) [13] and components (bottom) [14].
The aim of this study is to review the environmental and sustainable aspects of green buildings. It also addresses the issues on its origin, concept, eco-friendly properties, benefits and focuses its tools, rating systems and certifications.

2. Green Building Issues: Its Origin, Concept, Eco-Friendly Properties and Benefits

The history of green buildings dates back to ancient times. Even the cave dwellers utilized environmentally friendly materials and resided in their homes in compliance with the landscape. Throughout the eras, human interference with the environmental balance causes problems. This was the beginning of the sustainability and green movements. Even though the green building movement has been accelerated throughout the past 10 years; its origins can be detected at as early as the end of the nineteenth century [15]. Green building philosophy is derived from the term “Arcology” which stands for a combination of architecture and ecology [16,17]. Green buildings point out an application in the construction sector that prioritize environmentally responsible and efficient resource allocation in the whole life-cycle of a building [18].

Green building concept has a worldwide popularity. The negative influence of construction on the environment crucially stimulates the emergence of the green building concept. This concept is a final reaction in addressing environmental and health problems which arise from buildings and minimizing the effects of the construction sector on the natural habitat as well as on individuals [5,19,20]. The concept of green building considers ecology and social conservation in business planning and performance processes, including energy-saving [21].

To eliminate the adverse impacts of buildings on the environment; green buildings, which could create better IEQ for residents with less consumption of natural resources, have begun to develop [11]. Sustainable construction and green buildings are two interchangeable terms that arise from the concept of sustainable development. A green building stands for the reaction of the construction industry towards the sustainability requirements, and thus, besides health and the environment, energy and water efficiency, the reduction of natural resource consumption as the main features of a green building [7,22]. Because of having these properties, green buildings are generally termed as environmentally friendly [23] (eco-friendly) buildings.

Saved energy (30-40%) and water (20-30%), improved indoor air quality, enhanced health and productivity, increased property value, enhanced day light and ventilation, among others, are frequently mentioned efficacies/benefits related to green building [7,12,22,24]. The environmental efficacies of the environmentally friendly building are evident, but there are other stringent grounds for practicing green building tasks that may not be instantly conceivable. Examples are as follows: (i) Healthier and happier employees working in green buildings, reporting improvements in asthma and allergy symptoms and fewer headaches, (ii) Lowered energy costs, (iii) Ability to hold and retain senior talent, (iv) The possibility of selling a green building for more money than a standard building, (v) Additional business opportunities that appeal to the ever-growing conscious consumer pool [25].

3. Green Building Tools, Rating Systems and Certifications

Two main strategies would be utilized to render buildings more sustainable or greener. The first involves the construction of new (green) buildings that corresponds to a key policy in urban sustainability by altering the constructed environment [26]. The second strategy is the sustainable renovation of existing buildings as an alternative to the new structure due to the high investment costs of new buildings [27]. Over the last decade, attention has been paid to the construction of green buildings and to renewing existing buildings with green technologies. The main results of this attention are the introduction of green building councils and the introduction of certification systems to assess the environmental performance of buildings and to document best practices [5].

Since globally recognized performance goals for the green building have not yet been determined, some countries in the world have developed their own tools and systems to assess the performance of green buildings. According to these vehicles and systems known as building environmental assessment methods (BEAM), a building is rated green if it achieves a set of performance targets.
specified by the accepted green rating system. Since the mid-90s, construction green labels and certificates have emerged in order to meet the demands of the community for sustainable buildings, non-governmental organizations and private companies[7].

The green building provided tremendous development and thousands of buildings were labeled as “green” all over the world. Meanwhile, a number of rating systems or tools have been developed in the world to facilitate the development of green buildings in many countries, such as Leadership in Energy and Environmental Design (LEED) in the United States (US) of America, The Building Research Establishment Environmental Assessment Method (BREEAM) in the United Kingdom, Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) in Germany, Green Globes in Canada, Green Building Council of Australia Green Star (GS) in Australia, BCA Green MarkScheme in Singapore, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan,Green Rating for Integrated Habitat Assessment (GRIHA) in India and Building Environmental Assessment Method (BEAM) in Hong Kong and Assessment Standard for Green Building (ASGB) in China [1,2,11, 28].

The American LEED and the British BREEAM can be cited as widely accepted and used green rating systems for green buildings [7]. The US Green Building Council (USGBC) classifies and labels green buildings, the so-called green building rating system, which approves a construction area of 1.85 million square meters in more than 150 countries worldwide with LEED, the most widely used green building rating system worldwide[23], as well as the most perfect, effective evaluation system among all green building assessment systems in the world [23,29,30]. The LEED certification enables independent verification of the green properties of a building or environment and ensures the design, construction, operation and maintenance of resource-efficient, high-performance, healthy, cost-effective buildings. LEED does not specify the phase to be evaluated. As a result, most buildings focus on the design phase rather than the operational phase [11]. The LEED Certification and its five fundamental requirements point to a global response to the green building to maximize awareness of the role of human activity in global climate change: the Sustainable Area (SS); Materials and Sources (MR); Energy and Atmosphere (EA), Environmental Quality (EQ) and Water Efficiency (WE)[8,22].

BREEAM is the world’s first building assessment method since its founding in 1990 [16]. BREEAM sets the standard of best practice in sustainable building design, construction and operation and has become one of the most comprehensive and widely accepted measures of environmental performance of a building. BREEAM is widely used in Europe and throughout the world. As the first green building assessment system, it has a profound impact on other green building assessment systems and facilitates the development of green buildings[11].

DGNB is one of the newest and the first in Germany (the most industrial European country and the most active in the construction and development of sustainable cities) [29]. It provides an objective definition and assessment of the sustainability of buildings and city areas. Quality is assessed comprehensively throughout the entire life cycle of the building. The DGNB Certification System can be applied internationally. Because of its flexibility, it can be fully adapted to the various uses of a building and can even meet country-specific requirements. Ecology, economy, socio-cultural aspects, technology, process workflows and quality departments of the field have been certified to fulfill a maximum of 50 sustainability criteria. The system is based on better use of concepts that are common or usual today [25].

Green Globes (GG) is an online green building rating and certification tool used primarily in Canada and the USA. It is interactive, flexible and affordable, and provides market recognition of a building’s environmental attributes through third-party assessment. There are many studies that show that GG is similar in terms of criteria with some exceptions (e.g. materials), and is competitive in terms of usability and cost[31].

The Australian Green Building Council (GBCA) launched the green building rating system as “Green Star (GS)”. The GS is Australia's only national, voluntary assessment system for buildings and communities. Australia is the largest contributor to greenhouse gases and accounts for 40% of waste; While the GS increases environmental efficiency in buildings, it also aims to increase productivity,
create jobs and improve the health and well-being of communities. Initially, the GBCA had green legacy vehicles and by the end of 2015, all these vehicles were replaced by a new set of green building rating tools. These tools include four green building assessment tools for Design, Interiors, Communities, and Performances, and also evaluate the sustainability of projects at all stages of the life cycle. The GS performance tool evaluates green buildings during its operation stage [17, 23].

BCA Green Mark (GM) Scheme was initiated in January 2005 as an attempt to steer Singapore's construction industry towards more environmentally friendly (eco-friendly) buildings. It is aimed to stimulate sustainability in the constructed environment and to promote environmental awareness among developers, designers and builders as they began to conceptualize projects and designing as well as the construction process. It is a benchmarking scheme that includes internationally recognized best practices of environmental design and performance. The BCA GM certification is in favor of the movement of green buildings by encouraging sustainable buildings in the constructed environment in Singapore [32].

CASBEE is an abbreviation that stands for the method for assessing and evaluating the environmental performance of buildings and the constructed environment. It was developed in 2001 by a research committee established by the cooperation of academia, industry and national and local governments, which established the Japan Sustainable Building Consortium (JSBC) under the auspices of the Ministry of Land, Infrastructure, Transport and Tourism. The CASBEE was designed to improve people's quality of life and also to reduce life cycle resource utilization and environmental burdens pertaining to the constructed environment, from a single home to a whole city [33].

GRIHA is own rating systems of India. It is a green building design evaluation system where buildings are rated in a three-tier process. The process initiates with the online submission of documents as per the prescribed criteria followed by on site visit and evaluation of the building by a team of professionals and experts from GRIHA Secretariat. GRIHA rating system consists of 34 criteria categorised in four different sections. Some of them are site selection and site planning, conservation and efficient utilization of resources, building operation and maintenance, and innovation[34].

BEAM is Hong Kong rating tools for green buildings, it is a voluntary private sector initiative and has developed into an internationally recognised suite of rating tools for green buildings that include new buildings, existing buildings and interiors for shops, offices and retail. BEAM Plus rating tool is sub divided into six categories as (i) site aspects, (ii) materials aspects, (iii) energy use, (iv) water use, indoor environmental quality and innovation [35].

The concept of green building was first coined in China in the 1990s, and then the assessment standard was improved. By June 2006, the Ministry of Construction published “the green building assessment criteria” as the first national standard for assessing green buildings in China [11]. The ASGB constitutes the basis for environmental rating systems in China, the largest construction market in the world. The ASGB is an assessment instrument for ASGB residence certificate, suitable for all civilian buildings [17].

Green building certification has become a recognition of sustainable, high performance and energy efficient buildings. The agencies that are responsible for the development and administration of green building ratings operate globally and regionally. These agencies facilitate the certification through green building rating schemes, which are voluntary. There are several variants of green building rating schemes such as new construction, core and shell, existing buildings and major refurbishment. Green building rating schemes are used in industry practice as a practical tool for sustainable development[28].

The indicators that have been assigned highest priority in each green building scheme are given in Table 1 along with the relative weight. Green building rating schemes are noticed to differ considerably with respect to the set goals and achievable points. The indicators set forth to measure the “energy performance” and classified under the “energy” category are given the highest priority in 8 out of the 10 green building schemes. However, discrepancies are observed in the share of the total score (or weighted score) allotted to energy indicators. In the DGNB system, highest weight has been
assigned to the indicators “lifecycle cost” and “flexibility and adaptability” (9.6% each), which is higher than any other indicator defined in this system including “energy”. High priority is provided for indicators “thermal comfort” under the section “environmental quality” and “efficiency in building services” under the section “environmental load” in the CASBEE scheme[28].

Table 1. Indicators with highest priority in green building schemes [17, 28].

| Scheme   | Indicator with highest priority                                                                 | Weight | Category                        |
|----------|-------------------------------------------------------------------------------------------------|--------|---------------------------------|
| LEED     | Optimize energy performance                                                                    | 16.4%  | Energy                          |
| BREEAM   | Reduction of energy use and carbon emissions                                                   | 10%    | Energy                          |
| DGNB     | Lifecycle cost                                                                                 | 9.6%   | Cost                            |
|          | Flexibility and adaptability                                                                    | 9.6%   | Economic development            |
| GG       | Energy performance                                                                             | 15%    | Energy                          |
| GS       | Efficiency in building services                                                                | 20%    | Energy                          |
|          | Greenhouse gases emissions                                                                     | 16%    |                                  |
| GM       | Building energy                                                                                | 9.2%   | Energy                          |
| CASBEE   | Thermal comfort                                                                                | 14%    | Indoor environment              |
| GRIHA    | Energy efficiency                                                                              | 13%    | Energy                          |
| BEAM Plus| Reduction of CO₂ emissions                                                                     | 10.9%  | Energy                          |
| ASGB     | Renewable energy utilization                                                                   | 28%    | Energy                          |

4. Conclusions
Green building development is an integral part of the active participation of stakeholders, including government, developers, technology producers and consumers. Social, economic and ecological behaviors of stakeholders can be the key factor in guiding the sustainable development of green buildings. It was stated [36] that green building development can provide promising efficacies, including improvement of ecological environment, ensuring sustainable land use, conservation of ecological systems, facilitating recycling and reuse of materials, improving energy efficiency and minimizing solid waste and CO₂ emissions.

A total of 73 councils in five continents [37] have so far certified many green buildings. According to USGBC and BREEAM sources, the LEED -the most widely used green building rating system in the world- carried out the certification process of numerous green building projects in more than 167 countries. Correspondingly, the BREEAM, the second most widely accepted rating system in the world, certified many green buildings in 77 countries. Studies have indicated that “green” rated buildings perform better than traditional buildings in terms of their sustainability features with IEQ and energy use.

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