# Green Building

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ABSTRACT  The process of designing, constructing, and inhabiting the buildings has a profound influence on a community’s economy, environment, and quality of life. Building contributes almost 40% of CO\textsubscript{2} emissions and is a major contributor to the greenhouse gas (GHG) emissions. It is therefore necessary to harmonize the relationships between the buildings, the environment, and the inhabiting communities through sustainable or green buildings. This chapter discusses history and concepts of green buildings, impacts of buildings on the environment with embodied energy, and CO\textsubscript{2} emission from common construction materials. Major focus is given on green or sustainable design practices for buildings. It is proposed that both architectural and structural designers should first analyze the building scenario based on available “green” design strategies and then collate their outcomes with various design dimensions, with the help of Building Information Modeling, to finally decide on a building-specific model. The practice of green building is growing around the world. A number of examples of green buildings from both developed and developing countries, with their key features, are discussed. The rating criteria for assessing the green buildings, along with certified body to assess the energy performance, are discussed in details. It is observed that green buildings offer a wide range of benefits, including reduced use of materials and energy, as well as low carbon dioxide emission. On the other hand, main barriers seem to be the initial increased investment. It is expected that the readers will gain valuable knowledge on green building, involving architectural, structural, and passive designs for reduction of energy use and waste, leading to an affordable life in the future.

19.1 Introduction

Buildings are one of the vital components of the built environment; they provide the setting for human activity in this modern world. They include the place at which we work, live, and do other things. Internal air quality is therefore important for human health and well-being, which depend on the materials used in construction and on the manner (i.e., the process through which) they are used. Buildings result in loss of farmland and consume naturally occurring construction materials, a part of which becomes waste. They are major energy-consumption sector of many countries and are the cause of huge carbon dioxide emissions. According to the U.S. Environmental Protection Agency (EPA),
buildings in the United States generate 160 million tons of construction and demolition (C&D) waste every year and consume 13% of water and 40% of total energy [1]. The latter is attributed as the principal reason of climate change, since consumption of energy is the major contributor to carbon dioxide emissions [2]. Moreover, unsustainable building practices such as urban sprawl, brownfields’ redevelopment, access to healthy food, loss of open space, and health impacts due to decreased physical activity can lead to unintended social and economic consequences [1].

Therefore, the process of designing, constructing, and inhabiting the buildings has a profound influence on a community’s economy, environment, and quality of life. It is therefore necessary to harmonize the relationships between the buildings, the environment, and the inhabiting communities through sustainable or green buildings. Many construction firms (51%) are shifting their business toward green building [3]. Nevertheless, many attempt to achieve this by ensuring the design and construction requirements of different established sustainability assessment methodologies. Our attempt is to achieve the same through the practice of sustainable design practices. The aim is to integrate the buildings with the local ecology, while simultaneously attempting to lessen their impacts on natural resources, minimize energy consumption and carbon dioxide emissions, use environmentally friendly products, and improve operation and maintenance practices [1].

The previous chapters have highlighted the integrated management of water with optimization of water and energy use in processing industries. This chapter focuses on the sustainable design principles for green buildings. However, we first discuss the concept of green building, highlight some impacts of buildings on environment, and summarize benefits of green buildings. Sustainable design is then discussed at length, and some examples of successful green buildings from around the world are provided. The chapter then concludes with the assessment and economics of green buildings.

19.2 History and Concept of Green Building

“Green building” is also known as “sustainable building,” “sustainable construction,” or “green construction.” While there are many definitions for it, green building refers to both a structure (i.e., the constructed facility) and the processes responsible for constructing that structure, to be environmentally accountable and resource-efficient, throughout a building’s life cycle. Therefore, relevant activities span from conceptualizing, planning, designing, and constructing through to operation, maintenance, renovation, and demolition. These are carried out with a focused consideration of a few core issues of energy use (and thereby carbon dioxide emissions), building’s effect on the adjacent ecology, selection of construction materials, and indoor environmental quality [2].

The concept of green building appears to have emerged in 1960s, when many cities saw further, and rapid, urbanization as a result of constructing high-rise-tower buildings, for example, as happened in Chicago and New York for providing our dwelling homes, work places, and other public buildings. Such physical infrastructures reflect the economic strength or growth of a nation and also validate the success and progress of human society [4]. However, they (i.e., the buildings) not only consumed high volume of concrete (thereby creating demand on naturally occurring construction materials, e.g., boulders for aggregates, limestones for cement, and woods) but also led to the clearance of forest cover and replacement of communities. Moreover, they created huge demand of large amounts of energy for running and maintaining the ventilation and other services of those buildings, heating during the winter,
Sustainable Utilization of Natural Resources

and air conditioning in the hot summer. As a result, architects, civil engineers, and property developers began to rethink about their crucial roles as planners, designers, and developers of the buildings, the most cherished environment of where we live and work.

Green building started to emerge as reality from its research and development phase to overcome the energy crisis of the 1970s. Developers and designers focused on reducing the energy uses derived from fossil fuel to reduce reliance on fossil fuels, additional expenses from relevant higher costs, and carbon dioxide emissions. Solar panels were introduced as an alternate, and renewable energy was used to lessen the dependence on conventional fossil fuels and to make more environmentally friendly homes. However, the uses of solar panels were very limited owing to their high initial costs. Therefore, emphases were given on manufacturing solar panels that were more efficient and less expensive, making solar energy more of a reality. Designers, developers, individual users, and companies also focused on reducing energy bills through various types of design, such as “passive solar” buildings made of non-toxic and low-impact materials. These are designed with good insulation, adequate ventilation, wider use of natural light through integrated design, greening of surrounding areas, and optimum use of water through various water-saving devices [2].

The growing “green movement,” particularly during 1990s, responded with sustainable and wise use of natural resources for the reduction of greenhouse gas (GHG) emission, which is responsible for global warming and climate change [5]. The green building then received increased popularity. The American Institute of Architects (AIA) formed the Committee on the Environment in 1989, and it led to one of the pioneering steps toward green movement in the United States. Also, the Environmental Protection Agency (EPA) and the Department of Energy launched the Energy Star program in 1992. Austin, Texas, was the first U.S. city to introduce a local green-housing program. The following year, that is, 1993, saw many more advancements in the green revolution, and the U.S. Green Building Council (USGBC) was founded. A large number of people were motivated by USGBC initiatives, and they made changes in their homes by having appliances with energy star ratings. In 1998, the USGBC launched their Leadership in Energy and Environmental Design (LEED) program and promoted the practice and benefits of having green building [2].

As mentioned above, the history of green-building movement evolved owing to demand for more energy-competent and environmentally less-damaging construction practices. As it is practiced now, the approach includes an array of design strategies that focus on the selection of a suitable location and also of construction materials. Buildings consume almost 40% of energy in most countries [6]. This may be more in many mega-cities such as Beijing, Shanghai, Mumbai, Jakarta, Dhaka, and Mexico City, where construction is also booming, implying that those will consume more energy. The concept of sustainable construction (or green building) takes into consideration the environmental, socioeconomic and cultural issues. It also addresses the issues such as design, construction and management of buildings, performance of buildings, and energy and resource consumption. This is now regarded as the guideline for the building industry to move toward achieving sustainable development [7–8].

Green building or sustainable building is the process of having a constructed facility that encompasses ultimate energy efficiency, forward-thinking resources management, and general sustainable construction [9]. Larsson [10] explained how integrated design process (IDP) assists in applying green-building practices and ensures the prospect of introducing environmentally friendly and resource-efficient buildings. According to Sorrel [11], the barriers to and complexity of developing green building arising from building services, structural and architectural features, and related costs can be overcome through an integrated team having a wide range of different specialists. While Section 5 of this chapter

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Green Building explains five examples (or case study with visuals) of green buildings from around the world, we summarize below the salient features of green buildings:

- Resource conservation, including energy efficiency, renewable energy, and water-saving features
- Consideration of environmental impacts and waste minimization
- Reduction of operation and maintenance costs and use of environment friendly construction materials through life cycle assessment during the planning and development process [12]
- Creation of a healthy and comfortable environment, leading to overall quality of life [12]

19.3 Impacts of Building on the Environment

Climate of a region significantly influences the nature of a building and its energy demands. For instance, the demand for heating energy is the highest in colder climates. Intertek Report [13] observed that 68.4% of all energy consumption in dwellings is attributed to space heating. On the other hand, hotter regions require more attention to cooling. On the whole, in either case, more use of energy means more emission of carbon dioxide, which is the leading cause of climate change [2]. Thus, the nature of the buildings creates counter-influence onto the environment.

The higher demand of energy plays a significant role in the design of building. For example, buildings in colder climates give more focus on better air tightness and insulation. Humidity, rainfall, and temperature are crucial factors that should be taken into consideration during the building design. However, it is impossible to come with a single technical solution to energy efficiency that will work in all cities and countries when all those meteorological parameters need to be considered. As such, American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) assesses energy-related design conditions through a combination of factors, including the numbers of heating and cooling days.

Moreover, despite the remarkable benefits of green buildings, the activities for constructing them can be a major source of environmental damage through depletion of the natural resource base, degradation of fragile eco zones, chemical pollution, and the use of building materials harmful to human health [14].

As seen above, the design, construction, and maintenance of buildings have a remarkable impact on the environment and natural resources. Impacts of buildings can be analyzed from multiple perspectives, such as the type of buildings (private and commercial, office, dwellings, civic centers, schools, and hospitals), life cycle phases (design, construction, operation, and refurbishment), and type of environmental impacts (soil, energy, CO₂ emissions, material, water, and waste). Nevertheless, residential and commercial buildings consume approximately 60% of the world’s electricity [15]. On the other hand, Augenbroe et al. [16] summarize that, globally, buildings account for:

- One-sixth (17%) of the world’s freshwater withdrawals
- One-quarter (25%) of world’s wood harvest
• Two-fifths (40%) of world’s material and energy flows
• Nearly one-quarter (25%) of all ozone-depleting chlorofluorocarbons (CFCs) emissions generated from building air conditioners and the processes used to manufacture building materials

Indiscriminate use of building material, without giving a thought to the environment, possesses a challenge to the effort of reducing GHG contributed from buildings. A report from the Worldwatch Institute stated that building construction uses 55% of non-fuel wood [17], 40% of global resources, and 40% of global energy [15]. Moreover, resources, such as ground cover, water, and tillable lands, are depleted to accommodate space required for buildings. The energy consumption in both residential and commercial buildings is likely to remarkably increase in the next 30 years, particularly in the developing countries. On the other hand, energy consumption of developed countries will increase very steadily, in general. This steady increase in developed countries indicates their use of sustainable technologies and various energy-efficient construction materials in the built environment. This is frequently measured in terms of “embodied energy,” a term to express “the total energy required for the extraction, processing, manufacture and delivery of building materials to the building site.” It is imperative to use materials with less embodied energy in buildings, in an attempt to reduce overall GHG emission. As such, the embodied energy and CO\textsubscript{2} emission of common construction materials [18,19] are shown in Table 19.1, as ready reference.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Embodied Energy (MJ/kg)</th>
<th>CO\textsubscript{2} Emission (kg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel and sand</td>
<td>0.5</td>
<td>0.0018</td>
</tr>
<tr>
<td>Timber</td>
<td>3</td>
<td>0.003</td>
</tr>
<tr>
<td>Concrete</td>
<td>1.3</td>
<td>0.1311</td>
</tr>
<tr>
<td>Aggregate</td>
<td>0.1</td>
<td>0.16</td>
</tr>
<tr>
<td>Brick</td>
<td>2.5</td>
<td>0.189</td>
</tr>
<tr>
<td>Ceramics</td>
<td>5</td>
<td>0.349</td>
</tr>
<tr>
<td>Glass</td>
<td>30.3</td>
<td>0.748</td>
</tr>
<tr>
<td>Cement</td>
<td>5.8</td>
<td>0.9638</td>
</tr>
<tr>
<td>Lime</td>
<td>6</td>
<td>1.352</td>
</tr>
<tr>
<td>Plastics</td>
<td>61</td>
<td>2.2</td>
</tr>
<tr>
<td>Paint</td>
<td>93.3</td>
<td>2.42</td>
</tr>
<tr>
<td>PVC</td>
<td>70</td>
<td>2.6904</td>
</tr>
<tr>
<td>Steel</td>
<td>32</td>
<td>2.95</td>
</tr>
<tr>
<td>Plywood</td>
<td>10.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Aluminum</td>
<td>227</td>
<td>9.964</td>
</tr>
</tbody>
</table>

**Lower to Higher Emission**

19.4 Benefits, Drawbacks, and User Satisfaction of Green Building

Benefits of green buildings are manifold. Lallanilla [20] summarized eight interdependent benefits of green buildings: (1) lower costs of green buildings in terms of return from initial additional investment in sustainable design; (2) healthy occupants in green buildings owing to the use of non-toxic construction materials and improved ventilation; (3) improved quality of life of the occupants, perceived to be the outcome of healthy lifestyle; (4) improved productivity of occupants; (5) improved sales from and reduced electricity costs of the retail stores constructed by applying green-building principles; (6) reduced utility bills; (7) green buildings retain higher resale market value compared with conventional buildings; and (8) tax benefits for green buildings. Many authors/organizations also reported the benefits in greater detail and grouped them as economic, environmental, and social or health and community benefits, for example, USGBC [21], Lennox [22], and The City of Bloomington [23]. A cross section of those benefits is shown in Figure 19.1. It can be argued that some specific items of benefits can be arranged under a different category, for example, waste reduction, since it saves money. However, our primary aim is to show the divergence of the benefits, while also loosely categorizing them.

<table>
<thead>
<tr>
<th>Benefits of green buildings</th>
<th>Environmental benefits:</th>
<th>Economic benefits:</th>
<th>Social benefits:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Emissions reduction</td>
<td></td>
<td>Improved health</td>
</tr>
<tr>
<td></td>
<td>Water conservation</td>
<td></td>
<td>Improved schools</td>
</tr>
<tr>
<td></td>
<td>Stormwater management</td>
<td></td>
<td>Healthier lifestyles and recreation</td>
</tr>
<tr>
<td></td>
<td>Temperature moderation</td>
<td></td>
<td>Improved employee satisfaction</td>
</tr>
<tr>
<td></td>
<td>Waste reduction</td>
<td></td>
<td>Improve air, thermal, and acoustic environments</td>
</tr>
<tr>
<td></td>
<td>Improved air and water quality</td>
<td></td>
<td>Enhance occupant comfort and health</td>
</tr>
<tr>
<td></td>
<td>Reduced solid waste</td>
<td></td>
<td>Possibly limiting growth of mold and other airborne contaminants that can affect workers’ productivity and/or health</td>
</tr>
<tr>
<td></td>
<td>Conserve natural resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enhance and protect ecosystems and biodiversity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 19.1**
From environmental perspective, green buildings help improve the urban biodiversity and protect the ecosystem through sustainable use of land [24–25]. Green buildings generally provide higher performance than conventional buildings owing to efficient use of energy and water and higher reduction in carbon dioxide emission owing to the use of materials with low embodied energy [26–27]. Furthermore, Turner and Frankel [28] observed that the LEED-certified buildings could achieve more than 28% of energy savings compared with the national average level.

Contrary to the benefits summarized above, green buildings have a number of drawbacks or disadvantages too, including high initial costs, unavailability of sustainable construction materials, problems in getting loan, and lack of suitable builders of green buildings [29–32]. However, the core drawback seems to be the cost—that sustainable buildings cost more than conventional buildings. In fact, sustainable buildings cost 2%–7% more, in general, if compared with conventional buildings [29], although the homes are peaceful and quiet and dwellers/occupants are more comfortable inside, irrespective of the outside weather. Moreover, decision makers rarely take into account the savings from reduced operating costs and utility bills of the sustainable buildings, as their estimates are hardly based on whole-life costs [33]. In this regard, many authors reported that the initial higher expenses are recovered from the incredible savings in utility bills. Al-Yami and Price [29] urged decision makers to focus on value, instead of cost, and on long-term perspectives, instead of short-term perspectives. However, Lallanilla [20] argues, “... green buildings save money, starting (from) the very first day of construction. This is true for green homes as well as sustainable office buildings, factories, churches, schools and other structures.” He gave an example citing the 2003 case study conducted by the California Sustainable Building Task Force that: “... an initial green design investment of just two percent ... (which may be) ... $40,000 ... in a $2 million project will be repaid in just two years. Over 20 years, the savings will amount to $400,000.” In other words the savings will be 10 times higher over 20 years.

For any new concept or product, the satisfaction level or acceptability of the users plays a considerable role. As such, opinion of the users/occupants will greatly impact the future of green buildings. Foregoing paragraphs show that benefits of green buildings grossly outweigh the relevant drawbacks. Along the same line, studies have shown that occupants are more comfortable in green buildings, in general, compared with conventional buildings [34–35]. Moreover, occupants of green buildings are usually energy-conscious, so they highly appreciate natural lighting, cooling/heating, and ventilation systems, as well as the relevant building control system [36]. Such occupants are ready to change their lifestyle and sacrifice their comfort levels to conserve energy. Nevertheless, the building control system could be significantly different for non-energy-conscious occupants. Therefore, the designers have to appreciate the energy-conservation behavior of different types of occupants.

Santin [37] observed that less-energy-conscious occupants conserve more energy with systems that do not require active involvement, and on the other hand, energy-conscious occupants conserve more energy with systems that require active involvement. Azizi [36] observed that occupants in green buildings are less likely to adjust temperature and use personal heaters/fans when feeling hot or cold, as compared with conventional-building occupants, even though they have higher access to building control systems. Whether hot and cold, they tend to cope more with discomfort in comparison with occupants in conventional buildings, because they consider that the green buildings are designed to be energy-efficient, and therefore, the building operation should support energy-saving features.
19.5 Green or Sustainable Design

Achieving zero carbon or green building is a concept inspired to bring minimum impact on the natural environment on which development was brought. The concept mainly covers two broad intentions: (i) increasing the efficiency in the way buildings use energy, materials, and water; and (ii) reducing the impact of building on both the environment and human health, thereby ensuring comfort of occupants. A great deal of these are arguably achieved through design. Moreover, initiatives targeting sustainability improvement are more effective if they are considered in the design. As such, it is now becoming almost a truism that design must consider sustainable construction principles crafted in design strategies by all concerned professionals, that is, sustainable or green design. Sustainable design is mostly concerned with energy conservation features, use of renewable energy, water conservation features, use of low-GHG-emitting and recycled materials, reduced construction waste, and less environmentally destructive site development. We present here sustainable design strategies in three groups: (i) as in architectural practice; (ii) for structural engineers; and (iii) those that follow natural phenomenon, that is, passive design. Some argue that the latter should not be considered a separate stream rather all “designers” should consider it along with any practice-specific (i.e., architectural or structural) design strategy. However, we then provide a brief overview of how Building Information Modeling (BIM) can help use the above design strategies in building design, in general, and in green-building design, in particular, and lead to the development of structure-specific green-building model. This model can then be used for the entire life of the green building, namely in construction, operation, maintenance, renovation, and demolition.

19.5.1 Sustainable Design in Architecture

As shown in Figure 19.2, the University of Michigan proposed a framework for sustainable design in architecture, with different levels of principles, strategies, and methods [38]. The three principles are aligned with those of sustainability in architecture, which are economy of resources, life cycle design, and humane design. Economy of resources is concerned with the reduction, reuse, and recycling of the natural resources that are used in buildings, focusing on the conservation of energy water and building materials. Life cycle design (LCD), the second principle, offers a methodology for analyzing the building process and relevant impact of buildings on the environment. Humane design, the third principle, focuses on the interactions between the natural world and humans. These principles are applied in design by using a number of methods, which are summarized below.

19.5.1.1 Strategies and Methods under Principle One—Economy of Resources

There are three strategies under this principle, in order to focus on the conservation of energy, water, and building materials. Relevant methods to focus on energy conservation, which is strategy one, are energy-conscious urban and site planning, alternative sources of energy, avoidance of heat gain/heat loss, use of materials with low-embodied energy, use of energy-efficient appliances with timing devices, and passive heating and cooling.

Strategy two focuses on water conservation through the methods of reduction and reuse. Reduction deals with indigenous landscaping, vacuum-assist toilets or smaller toilet tanks, and low-flow showerheads. On the other hand, reuse method deals with
collection and use of rainwater and gray water from domestic uses. Strategy three deals with the conservation of building materials, which are channeled through the methods of material-conserving design and construction, rehabilitation of existing structures, use of reclaimed/recycled materials and components, proper sizing of building systems, and use of nonconventional building materials.

### 19.5.1.2 Strategies and Methods under Principle 2—Life Cycle Design

The three strategies under this principle are aligned with the stages of the building, namely preconstruction stage, construction stage, and postconstruction stage. Preconstruction stage is concerned with the methods of minimizing energy needed to distribute/supply the materials and using the materials that are recycled, recyclable, made of renewable resources, long-lasting, harvested/extracted without ecological damage, and require low maintenance. The methods applied during construction stage include scheduling of construction activities to minimize site impact, provision for waste-separation facilities, specification of regular maintenance with nontoxic cleaners, and use of nontoxic materials to protect construction workers and end users. Strategy three of postconstruction stage is approached through the methods of adapting existing structures to new users and programs, recycling building materials and components, reusing building materials and components, and reusing the existing infrastructure and land.
19.5.1.3 Strategies and Methods under Principle Three—Humane Design

Among the three strategies under this principle, strategy one deals with the preservation of natural conditions; it is addressed through the methods of understanding the impact of design on nature, preserving the existing flora and fauna, respecting topographical contours, and not disturbing the water table. Strategy two is concerned with urban design site planning, which is appreciated through the methods of avoiding pollution contribution, providing for human-powered transportation, promoting mixed-use development, integrating design with public transportation, and creating pedestrian pockets. Strategy three is design for human comfort. Relevant methods are to provide clean and fresh air; thermal, visual, and acoustic comfort; operable windows; and visual connection to exterior, as well as accommodate persons with differing physical abilities.

19.5.2 Sustainable Structural Design

One of the goals for structural engineers in sustainable design is to minimize the impact of the project/building on the environment and natural resources, irrespective of whether designing high/low-rise buildings, long/short-span bridges or any structure in between. Danatzko and Sezen [39] compiled five methods that structural engineers can apply when designing a system or any structural element, as discussed below. Also, Figure 19.3 shows how the outcomes from the analysis of the five methods, jointly with the other factors

FIGURE 19.3
Green-building design process following sustainable design strategies.
affecting the decision makers’ choice, lead to the eventual structure-specific design of the green building.

19.5.2.1 Minimizing Material Use

The objective of this method is reduction of the amount of materials in the use of the building/structure, aiming to reduce project’s impact on environment. This is achieved either by optimization of a structural model, employing a single material type, or by combinations of various material types to form more efficient structural members and systems. Positive attributes of this method are to reduce requirement of raw materials and lower the impact on natural environment, which can lead to innovative designs and practices. Negative attributes are longer design and analysis time, possible greater structural system complexity, requirement of more drawings and details, and possible longer approvals process.

19.5.2.2 Minimizing Material Production Energy

The objective of this method is to reduce the production energy cost through reducing the amount of natural resources and energy required for the production of building materials. Positive attributes of this method are reduction of by-product and conservation of natural resources, which can lead to simultaneous assessment of strength and sustainability properties of materials and allow innovative designs. Negative attributes are lack of input from building industry, limitations to sustainability from material choice, and that the eventual design may not be “most” sustainable.

19.5.2.3 Minimizing Embodied Energy

The objective is to minimizing embodied energy by assessing the energy cost of construction and operational phase of the building. The core is to design long-life, durable, and adaptable buildings to reduce the impact of embodied energy. Positive attributes are considerations of both sustainable form and function, focus on operating energy use, and attention to service core. Negative attributes are that this method is highly sensitive to location or region, it can result in less-efficient structural system, its surrounding built environment can limit methodology, and its design is limited to most effective use of ambient energy (i.e., naturally occurring).

19.5.2.4 Life Cycle Analysis/Inventory/Assessment

The objective of this method is to justify/qualify the economic impact or net-cost-to-benefit ratio of a design decision. Positive attributes are greater inclusion of representative project parties, consideration on sustainability over project life, and that it encourages cross-discipline interaction. Negative attributes are risk and uncertainty included in analyses, potential model accuracy, and other sustainable issues that can detract from most sustainable structural design.

19.5.2.5 Maximizing Structural System Reuse

The objective of this method is to generate designs and layouts that generate minimum solid waste at end of life or to allow for the greatest amount of whole or partial system and/or structural component reuse. Positive attributes are financial incentives, extended
service life, design to suit surrounding built environment, and potential innovation in stand-
ardized designs. Negative attributes are adverse effects from minimal design changes, possibility for reduced primary-use functionality, and the requirement of inspection for structural element reuse.

19.5.3 Passive Design

Buildings are highly sensitive to climate, and therefore, adequate attention should be given during their design to allow maximum natural ventilation and day lightings to minimize the cost of energy use. A study carried out by Azizi [37] found that people staying in green buildings are more used to personal and psychological adjustments and less concerned with environmental adjustments, when compared with people living in conventional buildings. It is therefore necessary for designers to understand the level on interaction of the occupants with the building control system, in order to design buildings that encourage occupants to practice energy-saving behavior. These are addressed through a number of “passive design” strategies, which considers two major aspects: (i) the use of the building’s location and site to reduce the building’s energy profile; and (ii) the design of the building itself, that is, its aspect ratio, orientation, ventilation paths, massing, fenestration, and other measures. The target is to optimize the design to remarkably reduce the energy costs of heating, cooling, ventilation, and lighting. Its success is highly dependent on factors such as local climate, site conditions, building aspect ratio, and building orientation. These are briefly discussed in the following subsections.

19.5.3.1 Incorporation of Nature

There should be shading in terms of vegetation and trees. The plants directly absorb the sunlight and carbon dioxide as well as produce oxygen, which contributes to natural ventilation.

19.5.3.2 Orientation

Building should be located on the long side on a true east-west axis to minimize solar loads on the east and west surfaces.

19.5.3.3 Aspect Ratio

The aspect ratio is the ratio of a building’s length to its width, which is an indicator of the general shape of a building. For hot and humid climate, it is recommended to increase a building’s aspect ratio, with the building becoming longer and narrower. This minimizes the east and west surfaces that experience the greatest sun load. It is further minimized by installing smaller windows [5]. However, under cold and dry climate, buildings require a decrease in their aspect ratio, with the building becoming shorter and wider and requiring installment of large windows.

19.5.3.4 Roofing

The roof has the highest heat gain within the building structure, with approximately 70% of total heat gain [40]. Thickness and reflective texture, along with types of color used for slanting roof used with tiles, can be effective in reducing heat transmission. Apart from the
thickness, texture, and color of roof, green building focuses on development of eco-roof or green roof, which can reduce indoor temperature significantly. An eco-roof is made of plants, root barrier, soil mix, filter fabric, water-retention layer, drainage layer, waterproof layer, or insulation layer [41–42], allowing it to blend with surrounding environment to reduce heat island effect and assist in climate stabilization; it is particularly beneficial in wet climate [43].

19.5.3.5 Thermal Comfort

Thermal comfort comprising complex dynamics of temperature and humidity [44–46] is one of the key features that building users look for. Green buildings, which are mostly mechanically and naturally ventilated buildings, adopt the ASHRAE 552010 [47] and ISO7730 [48] guidelines, which suggest a thermal comfort temperature between 20°C and 24°C.

19.5.3.6 External Painting and Coloring

Various color surfaces can reflect invisible solar ray; for example, light-colored surface reflects 80%, dark-colored surface reflects 40%, and a normal dark-colored surface reflects 20% of incoming sunlight [42].

19.5.3.7 Flooring

Wood is rather preferred as flooring within the house, because it is a good conductor of heat in the context of buildings in cold climate. It is also convenient and cheaper to maintain in the long haul than carpet application. However, ceramic tiles/mosaics are more preferred for floors in hot climate to keep the interior cool.

19.5.3.8 Passive Cooling

Building should have minimal mass for storing energy and should generally be lightweight and well-insulated. Moujalled et al. [49] discovered that occupants prefer more naturally ventilated buildings as compared with air-conditioned buildings.

19.5.3.9 Daylighting

Based on scientific research, it was shown that using natural lighting provides great physical and psychological benefits to the building occupants. This, in return, generate an increase in productivity. The use of shading devices is vital for facades with large, glazed portions for providing adequate daylight in buildings. Highly glazed facades are widely used in new buildings to provide natural light and external view. There are different shading device types used to improve building energy performance, such as overhangs [50], external roller shades [51], venetian blinds [52], and internal shading. The field measurements and simulations showed that movable solar shading devices had crucial effect on energy performance and indoor thermal and visual comfort [53].

19.5.4 BIM and Green-Building Design

Autodesk, [54] one of the leading software developers and suppliers to construction industry, defines Building Information Modeling (BIM) as “an intelligent 3D model-based process that equips architecture, engineering, and construction professionals with the insight
and tools to more efficiently plan, design, construct, and manage buildings and infrastructure.” Although the BIM process is largely generic, even building information model is project- or structure-specific. A brief overview of the development of BIM and relevant conceptualization is given in the following paragraph.

The invention of AutoCAD allowed designers to visualize their designs (or projects) in 3D form (i.e., x, y, and z axes). However, 3D in construction goes beyond the design’s geometric dimensions and replicates visual attributes such as color and texture. Time sequencing of such 3D geometric model in visual environments is commonly referred to as 4D modeling [55]. 4D modeling allows demonstration of the building construction process before any real construction activity takes place. It helps identify any possible mistakes and conflicts at early project stages and enables prediction of construction methods and schedule [56]. This concept can be extended to further integrate “n” number of design dimensions in a holistic model to portray and visually project the building design over whole project life cycle [57]. This is based on the concept that a computer model database will contain all the information of building design, which will also contain information about the building’s construction, management, operations, and maintenance [57–58] and both graphical (i.e., drawings) and non-graphical (e.g., specifications and schedule) data, in a logical structure, forming a highly coordinated repository. Changes in each item are made at only one place, and all project participants see the same information.

BIM can significantly help in implementing sustainable construction, in general, and in delivering green buildings, in particular. As shown in Figure 19.4, BIM can consider all sustainable design strategies and various design dimensions relating to client and project, as well as those relating to sustainability and environment, and can lead to the development of a structure-specific green-building model. This model can be used through all the phases of the building, namely construction, operation, maintenance, and demolition. A few specific examples of the help or support that BIM can offer are as follows:

- Full-scale analysis of passive design issues, for example, relating to geography, climate, place, surrounding systems, and resources [5], [59]
- To efficiently consider various aspects of energy use, emission of GHG or CO₂, waste generation, life cycle cost, and facilities management, thereby improving sustainability rating [5]
- To reduce planning time and insurance cost and improve project quality, risk management, and life cycle performance [60]
- To consider innovative ideas and adopt best practices in construction, for example, lean construction and prefabrication [61]

19.6 Case Study from Developed and Developing Countries

19.6.1 The San Francisco Federal Building, California, United States

The 18-story building having an area of 600,000 square feet and located on a 3-acre site was completed in 2007. It takes into account the benefits of natural ventilation by utilizing the breeze coming from the sea through adjustable front windows fixed with glass. Concrete is one of the major construction materials to integrate modernization with
tradition. The front windows are operated using remote controls in order to admit cooler air by expelling warmer air and to create a comfortable environment by reducing temperature inside the building. The building comprises a shear wall built from concrete, with a dimension of 60 ft, to overcome the effect of potential shocks resulting from earthquakes, as shown in Figure 19.5. Besides, cast-in-place fluted surfaces and floor system provide natural air circulation and thus save energy used for cooling. The floor also increases reflectivity through the mixture of Portland cement with slag cement and reduces the cost of indoor lightings. USGBC awarded LEED® Silver Certification to the San Francisco Federal Building, and it was awarded The International Outstanding Building of the Year (TOBY) owing to its various green features such as sustainability and materials and energy conservation.

19.6.1.1 Key Features

- Incorporates energy-efficient technologies through roof-mounted 96-panel photovoltaic solar panels to reduce energy use by 30% annually.
- Energy-efficient office lighting equipped with daylight/occupancy sensors and electronic dimming ballasts provides adjustable levels of light to match the prevailing conditions; this reduces electric lighting loads by more than 50%.
Green roof design decreases storm-water runoff by 75%, reduces the urban heat island effect, and provides a safe haven for bird, butterfly, and insect populations.

- Water-efficient plumbing fixtures and a drip irrigation system provide for 30% indoor water reduction and 50% outdoor water reduction.
- 98% of the existing walls, floors, and roof, as well as 52% of the building’s interior, nonstructural elements, were reused.
- Building’s unique “D” shape with central courtyard ensures that workspaces are within 6 m of daylight.
- Mixed-mode ventilation system relies on operable windows for thermal conditioning and ventilation for perimeter spaces, and 100% outside air units for interior spaces.

19.6.1.2 Awards
- 2008 Design Award from the AIA San Francisco
- 2012 EPA Designed to Earn Energy Star Challenge
- 2014 GSA Public Buildings Service Commissioner Award
- 2014 GSA Design Excellence Award

19.6.2 K2 Housing Project, Melbourne, Australia
Design Inc Melbourne designed the K2 buildings for housing; they have 96 units with balconies and communal garden [63]. K2 housing project is Australia’s first ecologically and environmentally sustainable public housing, as shown in Figure 19.6. The housing complex made partially of recycled timber generates and consumes only renewable energy on site through solar water heating and photovoltaic panels and uses half water of the average water used by other buildings by practicing rainwater harvesting and gray water reuse.
19.6.2.1 Key Features

According to the Victorian State Government’s Office of Housing, it has following key features:

- The building has a life span of 200 years.
- Annual reduction in energy consumption by 55% or 716 tons of CO$_2$ in comparison with a standard building.
- Saving of 46% due to the solar hot-water system.
- Water-efficient fittings, rainwater harvesting, and recycling of wastewater contributed to 54% saving of water.
- Special consideration given with selection of materials such as biodegradable linoleum used for kitchen floor and recycled polymer used for carpet tiles.

19.6.3 Clinton Presidential Library, Little Rock, Arkansas, United States

Clinton Presidential Library integrates various key features of green building, which include floors made of recycled rubber tire, rooftop garden for reducing emission and rainwater runoff, regulation of temperature with solar panels as part of its renewable energy use, and supply of power-charging station for electric cars. As a result, USGBC awarded LEED Silver Certification in 2004 and Platinum Certification in 2007 [64], as shown in Figure 19.7.

19.6.3.1 Key Features

- The library uses 24% less energy, because of 306 roof-mounted solar panels than comparable code-compliant buildings [64].
Green Building

- Recycles 100% of goods.
- Reduces water use by 90% for maintenance of natural green space in the park attached to the library.

19.6.3.2 Awards

- Applied Arts Awards Annual, Environmental Design
- Industrial Designers Society of America
- Gold Industrial Design Excellence Award

19.6.4 Khoo Teck Puat Hospital, Yishun Central, Singapore

Singapore has become a pioneer in evolving architectural, structural, and passive design in Asia, with particular focus on energy and material conservation, waste minimization, and maximum utilization of space. It is a small country with highly urbanized area, where utmost focus is given to improve energy efficiency for various types of buildings, which are assessed by Singapore Green Building Council. Khoo Teck Puat Hospital in Singapore [66] is an example of a green building that incorporates green vegetation to reduce surface runoff and indoor temperature and to maintain a comfortable and healing environment for its patients.

19.6.4.1 Key Features

- The hospital is 27% more energy-efficient due to solar heating system.
- Hot water required for the hospital is obtained by solar thermal system.
19.6.5 Turbo Energy Limited, Chennai, India

Turbo Energy Systems \[67\] in Chennai utilizes solar power for air conditioning. The building uses solar thermal energy for water heating and solar panel for generation of electricity.

**19.6.5.1 Key Features**

- Reduction of electrical load of 117 kW due to the 90-TR hot-water-fired vapour absorption machines system.
- Working turbine of 5 kW capacity.

19.7 Assessment of Green Buildings

Building sector has higher potential for cost-effective energy savings. For example, it can reduce 11% of total energy consumption in EU in 2020. As such, the European Commission has launched the Energy Performance of Buildings Directive (EPBD) (2002/91/EC and recast 2010/31/EU). This compilation applies to both EU residential and nonresidential buildings and aims to substantially augment investments in energy-efficiency measures taken for buildings. EPBD suggests all EU member states to undertake a methodology for energy performance of newly constructed buildings, focusing on, at least, thermal and characteristics, space and hot water heating, ventilation and air conditioning (HVAC) systems, lighting installations, orientation of the building, and indoor climatic conditions. Meanwhile, the United Kingdom consulted the relevant groups and introduced the Code for Sustainable (or Greener) Homes in 2007. The code is voluntary to adopt. It focuses on improving the overall sustainability of new homes through nine criteria: energy and CO\(_2\) emissions, pollution, water, health and well-being, materials, management, surface water runoff, ecology, and waste \[67\]. The code is set in a framework and is intended for the home building industry to design and construct homes of higher environmental standards. It also offers a tool for developers to differentiate themselves within the market. If used, the code gives new homebuyers better information about the environmental impact of their new home, along with potential running costs.

However, different countries use different rating systems, as shown in Table 19.2, and each country’s rating system follows different level of certification based on scoring range. LEED uses four levels of certification, such as Certified for 40–49 points, Silver for 50–59 points, Gold for 60–79 points, and Platinum for 80+ points.

19.7.1 Coding and Rating System

The Code for Greener Homes (CGH) of the United Kingdom assesses environmental performance of new homes by using objective criteria and verification in two stages: design and postconstruction phase. The outcomes of the evaluation are documented on a certificate assigned to the dwelling. The code especially focuses on energy, water, materials, waste, ecology, and health and well-being. Each of these criteria is given a weight, based on the relative importance of criteria over one another, as shown in Table 19.3. The weighting factors, in turn, are derived from extensive studies involving a wide range of stakeholders (e.g., design engineers, architects, city planners, policy
TABLE 19.2
Rating System of Various Countries of the World

<table>
<thead>
<tr>
<th>Countries</th>
<th>Green Rating System</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>BREEAM: Building Research Establishment Environmental Assessment Method</td>
<td>Launched in 1990 and is a widely used to review and improve the environmental performance of buildings.</td>
</tr>
<tr>
<td>United States</td>
<td>LEED: Leadership in Energy and Environmental Design</td>
<td>Inspires and instigates global adoption of sustainable green-building practices relative to performance, including sustainable site development, energy and atmosphere, water efficiency, indoor environmental quality, materials and resources, and innovation in design.</td>
</tr>
<tr>
<td>Australia</td>
<td>NABERS: National Australian Built Environment Rating System Also known as Green Star</td>
<td>National rating system that measures the energy efficiency, water usage, waste management, and indoor-environment quality of buildings, tenancies, and homes. It uses a scale of 1–6 stars for certification, where a 6-star rating demonstrates market-leading performance, while a 1-star rating means that the building or tenancy has considerable scope for improvement. For example, utility bills are converted into an easy-to-understand star rating scale from 1 to 6 stars.</td>
</tr>
<tr>
<td>Japan</td>
<td>CASBRE: Comprehensive Assessment System for Built Environment Efficiency</td>
<td>Introduced in 2004; the implementation is voluntary for both government and private sectors. The system is maintained by Japan Green Building Council.</td>
</tr>
<tr>
<td>China</td>
<td>CEPAS: Compressive Environmental Performance Assessment Scheme</td>
<td>The implementation is voluntary for both government and private sectors. It is maintained by building department.</td>
</tr>
<tr>
<td>Malaysia</td>
<td>GBI: Green Building Index</td>
<td>Launched in 2009 and comprises six key criteria for rating the green building in Malaysia. It is maintained by Malaysia Green Building Confederation.</td>
</tr>
<tr>
<td>Singapore</td>
<td>Green Mark</td>
<td>The implementation is enforced at minimum-level incentives for both government and private sectors. It is managed by the Building and Construction Authority of Singapore.</td>
</tr>
<tr>
<td>India</td>
<td>IGBC: Indian Green Building Council Also known as GRIHA</td>
<td>The Indian Green Building Council (IGBC), part of the Confederation of Indian Industry (CII), was formed in the year 2001 and offers a wide array of services, including development of new green-building rating programmes, certification services, and green-building training programmes. GRIHA assesses a building out of a total of 34 criteria and awards points on a scale of 100; a project must achieve at least 50 points to qualify for GRIHA certification.</td>
</tr>
</tbody>
</table>

(Continued)
### TABLE 19.2 (Continued)
Rating System of Various Countries of the World

<table>
<thead>
<tr>
<th>Countries</th>
<th>Green Rating System</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indonesia</td>
<td>Greenship</td>
<td>Launched in January 2010 and maintained by Green Building Council of Indonesia. The implementation is voluntary for both government and private sectors.</td>
</tr>
<tr>
<td>Thailand</td>
<td>TRES: Thai Rating of Energy and Environmental Sustainability</td>
<td>Launched in December 2012 and developed by Thai Green Building Institute, which was modified from USGBC’s LEED to fit Thailand’s environment. The system is categorized in seven basic areas.</td>
</tr>
</tbody>
</table>


### TABLE 19.3
Relative Importance of Each Criterion in the Coding Assessment

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>0.3</td>
<td>Energy is one of the most essential criteria, as prudent use of energy can reduce emissions. It is measured as how much conventional energy can be saved by alternative renewable sources, for example, solar, thermal, wind, and biomass energy.</td>
</tr>
<tr>
<td>Water</td>
<td>0.2</td>
<td>Clean and potable water is the prerequisite for a healthy environment. Good water quality as well as quantity can ensure health and well-being and protect ecosystem surrounding the built environment.</td>
</tr>
<tr>
<td>Waste</td>
<td>0.2</td>
<td>Proper and efficient solid waste management can reduce health hazards and promote well-being. Properly managed waste can be regarded as resources, for example, composting and recycling.</td>
</tr>
<tr>
<td>Materials</td>
<td>0.1</td>
<td>Materials that emit less embodied energy and CO during their life cycle should be selected. Use of locally available materials is encouraged, and emphasis has been given to the use of materials that can be recycled.</td>
</tr>
<tr>
<td>Ecology</td>
<td>0.1</td>
<td>Buildings often possess a threat to ecology as natural area is converted into built-up area, often causing serious damages to ecosystem. Greening of roof by using vegetation can substantially cool down (4°C–5°C) indoor air temperature and protect from heat flux [69–71].</td>
</tr>
<tr>
<td>Health and well-being</td>
<td>0.1</td>
<td>Health and well-being are directly correlated with water, waste disposal, and ecology. The building should ensure adequate natural sunlight and ventilation, as the both of them can improve mental health and work productivity [70].</td>
</tr>
</tbody>
</table>

makers, environmental specialist, doctors, and dwellers). They were asked to rank a range of environmental impacts in order of importance. The feedback from stakeholders was obtained through a questionnaire and recompiled to assess the relative importance of each criterion over one another. Therefore, the weighting factors may change based on the socioeconomic and cultural perspective of each country.

19.8 Economics of Green Building

It is estimated that the building sector contributes to 10% of global GDP (USD 7.5 trillion) and employs 111 million people [15]. As with all business decisions, the “build or not to build” decision depends on a cost-benefit analysis, that is, if perceived benefits outweigh costs, the green buildings will be constructed. However, there are important additional considerations that influence cost-benefit analysis of green buildings, that is, the price of going green and the value that it will impart. However, there is growing recognition that “green” should not be considered a discreet “add-on” feature grafted on to an otherwise-normal project and should be evaluated independently to assess its financial burdens and benefits. Rather, it is becoming ever clearer that sustainable building requires changes of both paradigm and process that, when embraced and applied to the entire building process, can make green building an attractive option, without being an expensive one.

As mentioned earlier, constructing a green building naturally costs more than a conventional building, since green buildings use premium materials, high-efficiency equipment, and additional layers of process workflow. The mindset that paying extra is beginning to give way to more holistic designs and a life cycle view of costs and relevant benefits. Recent studies show that green buildings cost a little or no more than conventional buildings, if undertaken through an integrated approach. A study conducted in 2003 found that 25 office buildings and 8 schools seeking certification through LEED had a small cost premium associated with completing the steps necessary for basic levels of certification and a single building seeking platinum status had a more substantial cost premium associated with completing the necessary steps of certification [72].

Although the clients pay higher premiums to designers and contractors for their efforts toward potential savings in energy, it is the occupants who actually enjoy the benefits from energy savings. However, recent studies show that green buildings are sold at higher price, indicating that clients are getting their extra-spent money back. McGraw Hill measured the price premium for the sale of Energy Star®-labeled buildings to be 12% [2]. Another study estimated the premium on LEED-certified buildings at 31% [73].

However, many of the international systems do not involve the economic evaluation of green buildings. For example, LEED, BREEAM, Evaluation Standard for Green Building, and Comprehensive Assessment System for Building Environment Efficiency do not contain such economic evaluation. Although the GBTool system proposes to evaluate cost benefits, it does not provide specific evaluation contents and methods. Moreover, current awareness of many people about green buildings is not sufficiently comprehensive and accurate. They do not develop or purchase green buildings, owing to their incompressive perceptions that green buildings require high investment and high cost. This has been the case that is hindering development of green buildings in China. Hence, it is very necessary to construct the theoretical method system of green building’s cost–benefit analysis from a technical and economic point of view, which has important theoretical value and practical significance for the healthy development of green buildings.
19.9 Summary and Concluding Observations

Construction industry is frequently blamed for degrading, or at least for not uplifting, sustainable development, mainly due to its vast use of natural resources and consumption of energy, thereby emitting greenhouse gas or carbon dioxide, which is the main reason for climate change. As the most important and most frequent product of construction industry, as well as the largest consumer of natural resources and energy, buildings are grossly held responsible for this blame. As such, efforts from around the globe are being made for the efficient use of naturally occurring resources (e.g., land, water, and construction materials) and fossil-fuel-based energy in buildings and, at the same time, optimal use of sunlight (both for light and heat) and renewable energy to reduce the demand of fossil fuel. The solution appears to be, what nowadays is widely known as, “green building.” The concept of green building refers to a constructed facility, as well as the processes involved in constructing that facility, to be environmentally responsible and resource-efficient, throughout a building’s life cycle, that is, in all the phases of its construction, operation, maintenance, renovation, and demolition. This is achieved through an IDP and at conceptual and design stage of a building, by crafting all suitable “green” features into the building. As such, this chapter focused on the practice of green or sustainable design practices for buildings. It is proposed that both architectural and structural designers should first analyze the building scenario on the basis of available “green” design strategies and then collate their outcomes with various design dimensions (i.e., both client- and project-related and environment-related design dimensions), with the help of BIM, to finally decide on a building-specific model. This model will be used throughout the entire life cycle of the building, that is, during construction, operations, maintenance, renovation, and the eventual demolition.

The practice of green building is growing around the world. A number of examples of green buildings from both developed and developing countries with their key features are discussed. The potential benefits leading to sustainable constructions resulting from green buildings are adequately addressed. It is observed that green buildings offer a wide range of benefits, including reduced use of materials, energy, and carbon dioxide emission. On the other hand, main barriers seem to be the initial increased investment. On the whole, the benefits seem to grossly outweigh the drawbacks. Current research also appears to delve on issues to justify the wider acceptability of green buildings. For example, the research agenda of USGBC spans from the delivery process of green buildings through to individual aspects of integrated building systems, building interactions with surrounding ecology, as well as indoor air quality and occupants’ satisfaction level. Other leading researches include effective utilization of IDP in delivering green buildings [10], occupants’ behavior to thermal discomfort in New Zealand [36], application of BIM and teamwork, suitability of building materials, and relevant cost analysis under various climatic conditions. All these grossly support wider adoption of green buildings; however, they have to be suited to local ecology and climatic condition. It appears that the practice of green building will continue to grow day by day.
Green Building

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