Green Buildings: A Major Step Toward Energetic Sustainability and Beyond

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Introduction

Nowadays, we live, learn and work inside buildings; in short, we spend most of our days inside buildings. However, we may not have realized that 1/3 of world's greenhouse emissions comes from buildings and they use more than 40% of the global energy (RAMBOLL, 2019). By 2030, 60% of the global population will live in cities and will account for 70% of global energy consumption. While cities only occupy 3% of the total land surface, they account for 50% of all global waste and 75% of natural resources (Kindrat, 2014).

In particular, Asia is among the regions where population growth and economic growth are expected in the coming few years. Because of this inevitable motion of population to the cities, huge challenges on water supplies, sewage, the living environment and public health will be felt all around the world.

These statistics point out the threats that buildings and cities pose to the environment in terms of energy consumption and pollution. On the other side, they provide us with a great opportunity to transit from highly inefficient and pollutant constructions to green buildings. Green buildings use less energy because they work with thermodynamics in a more natural way. They reconnect us with nature; they bring nature back in our lives.

As green development becomes the world's new agenda to ensure that the human standard of living can be sustained (Elias, 2015), this report intends to investigate the characteristics of green buildings and its promise to enable us to achieve environmental sustainability.

1. Definition, characteristics, and design particularities of green buildings

1.1 Definition

Several terms such as sustainable building, sustainable construction and high performance building are often used interchangeably to refer to green buildings (Mao, 2009). According to the World Green Building Council, a 'green' building is "a building that, in its design, construction, or operation, reduces or eliminates negative impacts, and can create positive impacts on our climate and natural environment" (Shen, 2018). The U.S. Green Building Council defines the green buildings as "a type of structure that utilizes and demonstrates environmental stewardship and resource conservation throughout its entire lifespan, from construction, operations, maintenance, and renovation to demolition". Furthermore, a green building ideally would use very little energy, and renewable energy would be the source of most of the energy needed to heat, cool, and ventilate it. Today's green buildings include a wide range of innovations that are starting to change the energy profile of typical buildings. (Kibert, 2016)

1.2 Characteristics/ Key features

In line with the ideals of sustainable development (development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Mao, 2009)), green buildings are designed to reduce the overall impact of the built environment on its surroundings. They mostly are focus on increasing the efficiency of resource use (energy, water, and materials). Green residences operate by using sustainable resources that simply can be found around us such as wood (trees harvested and replanted), solar energy, hydroelectric power and wind power. Consequently, the green buildings have an important function in achieving the objectives of sustainable development - energy efficiencies and renewable energy, conservation and reuse of materials and resources, improvement of human health and indoor environmental quality (Elias, 2015).

Green building projects largely rely on green technical capabilities to provide open space and connect humans back to nature. Picture 1 and Picture 2 show some particularities green buildings.

Picture 1. Net-Zero energy building techniques in California, USA. these homes, as they have shown inherent benefits, are expected to prevent the release of approximately 78,000 tons of CO_2 annually (CREEDLA, 2017).

Picture 2. Key features of green buildings (open green space that generates oxygen for us to breathe) (Kindrat, 2014)

1.3 Design particularities

It makes sense to ask ourselves how the overall design process of a green building is handled. While it exists various techniques and theories about this topic, Randy Croxton, one of the pioneers of contemporary ecological design, introduces *passive design* and describes it as one that allows a building to "default to nature" (Kibert, 2016). Due to the complexity of designing the energy systems for a high-performance green building, the starting point must be full consideration of *passive solar design*, or *passive design*. Passive design is the design of the building's heating, cooling, lighting, and ventilation systems, relying on sunlight, wind, vegetation, and other naturally occurring resources on the building site. Passive design includes the use of all possible measures to reduce energy consumption prior to the consideration of any external energy source other than the sun and wind.

Thus, passive design ensures that the building get a certain amount of energy for its functioning prior to the consideration of active or powered systems such as boilers, air handlers, pumps, and other powered equipment. In sum, a building that has been well designed in a passive sense could be disconnected from its active energy sources and still be reasonably functional because daylighting, adequate passive heating and cooling, and ventilation are provided by the chimney effect, cross-ventilation, operable windows, and prevailing winds. A successful passive design creates a truly climate responsive, energy-conserving building with a wide range of benefits (Kibert, 2016).

2. Green buildings, sustainability projections, and climate change

Not many of house owners know that their houses degrade and produce CO_2, roughly 10 to 30 tons annually. This means that our houses are one of the causes of the global warming and environmental pollution. Therefore, the green building concept is an alternative effort to decrease the effects of CO_2. About 1.8 billion tons of CO_2 emitted or more can be prevented by using the improvements green buildings provide (Elias, 2015).

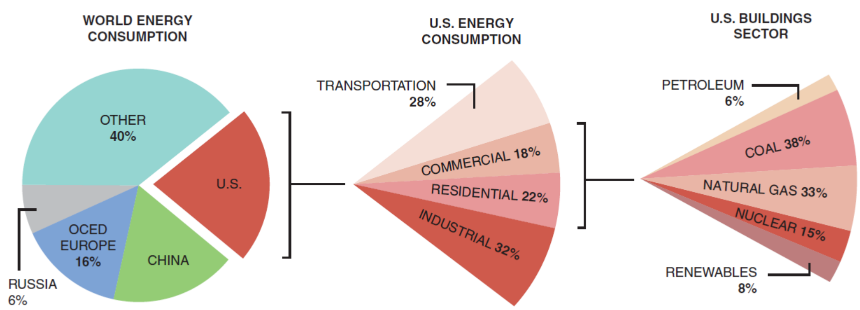
A House Electric Consumption	%	A House Electric Consumption	%
Cooling – Air Conditioning	45	Cooking	5
Refrigerator & Freezer	22	Entertainment	4
Heating - Iron, Kettle, etc.	11	Washing Machine & Dryer	2
Lighting	7	Others	4

Picture 3. Repartition of the electricity consumption of a typical house in developing countries (Malaysia in this case) (Elias, 2015).

In addition, conventional homeowners use large number of power sources. The environmental impacts of extracting and consuming nonrenewable energy resources, such as fossil and nuclear fuels, are profound. The major contribution to climate change—land impacts from coal and uranium mining, acid rain, nitrous oxides, particulates, radiation, ash disposal problems, and long-term storage of nuclear waste—are just some of the consequences of energy consumption (Picture 3) by the built environment (Kibert, 2016).

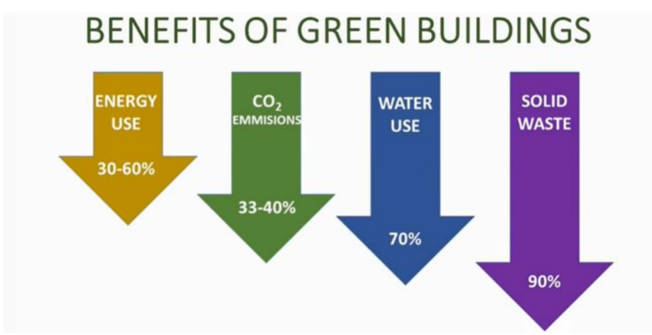
The phenomenon of climate change, which, as aforementioned, has impacts on nature, such as floods, hurricanes, ice liquidity in the north and south, rising sea levels and temperatures, and the destruction of flora and fauna (Elias, 2015), makes the agenda to consider innovative green technology in every aspect of life essential. Thus, applying green technology that can be incorporated in the construction of a building is necessary to reduce greenhouses gases, achieve energy and cost savings while creating a more environmentally friendly lifestyle.

The United States, with 5% of the world's population, accounts for 20% of the world's total primary energy consumption. Buildings there consume 40% of the total energy or about 8% of global primary energy (Picture 4). Although at first glance transportation and industrial energy appear to be unrelated to building energy, they are, in fact, coupled together. It has been demonstrated that the relationships of buildings and the distances between them are a major contributor to transportation energy (Kibert, 2016).



Picture 4. Energy consumption patterns worldwide, in the US, and for US buildings (Kibert, 2016)

Moreover, the vast majority of energy consumption is via fossil fuel combustion, which has human health impacts. Finally, greater energy production generally means higher greenhouse gas production, contributing even more to climate change. (Kibert, 2016)
In this section, we have seen various ways buildings in general might harm the environment and impact climate change. Green buildings, however, present viable alternatives that can help us decrease the pollution, accelerate sustainable development and decisively hamper the course of climate change. The benefits we can gain by building more responsibly are realistic and appealing.



Picture 5. Benefits of green buildings in terms of reduction of energy use, greenhouses emission, water use and solid waste (Kindrat, 2014)

3. The evaluation indicators used worldwide

In order to classify a given building into green building or not, it seems evident that we need to set a unit of measure against which to perform comparisons. Thus, a series of sustainable/green building assessment tools have been developed by some national or international research organizations. The following six mainstream green building assessment tools, including LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), SBTool, CASBEE (Comprehensive Assessment System for Building Environment Efficiency), BCA-GM (Building and Construction Authority Green Mark, Singapore) and ESGB (Evaluation Standard for Green Building), are the most used ones worldwide (Mao, 2009).

These assessment tools play a major role. They assess the performance of the outcomes of the sustainable construction, guide the entire process of the construction to reach the three pillars of sustainability (economic growth, ecological balance, social progress and equity), and they accelerate the evolution and transformation of the traditional construction industry.

a) LEED

This rating system, established by the United States Green Building Council (USGBC), is the primarily green building organization in the US, and serves to evaluate the environment performance of a building over almost the entire life cycle. LEED is considered as one of the most successful green building rating system in the world especially for its strong market penetration (in terms of amount of certified projects and certified construction square feet). LEED Platinum Certification the highest LEED achievement (Shen, 2018), (Mao, 2009).

LEED certification levels

LEVEL	REQUIRED POINTS
LEED certified	40 to 49
Silver	50 to 59
Gold	60 to 79
Platinum	80 and above

Picture 6. Factors taken into account in the LEED assessment and the requirements for each level (Lane, 2012), (Against LEED: Does LEED matter anymore?, n.d.)

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b) BREEAM

The BREEAM was developed in 1990 by the Building Research Establishment (BRE) in the UK. It is the first really meaningful green building assessment tool in the world, and it is also the widely used environmental assessment method for buildings. It sets the standard for best practice in sustainable design and has become the de facto measure used to describe a building’s environmental performance (Mao, 2009).

c) SBTool

SBTool, formerly called GBTool, is designed to assess the environmental and sustainable performance of buildings. SBTool is the predominant outcome of the Green Building Challenge (GBC). The former version of SBTool is GBTool, which is designed to allow users to reflect the different priorities, technologies, building traditions, and cultural value that exist in various regions and countries in the assessment process. The GBTool includes of a Microsoft Excel workbook that is configured to suit almost any local condition or build type (Mao, 2009).

In the structure of the assessment systems, all rating tools are focused on the life cycle assessment, which covers the stages of programming, design, construction, and operation. In the content of these guidelines, all of them include the issues of water & energy efficiency, materials & resources, and indoor environmental quality (IEQ) (Mao, 2009). This reflects that most of the relevant countries have been aware of the problems of water, energy, materials & resources, and IEQ.

However, in the developed countries, the rating tools have all been established by non-profit third party and designed according to the market acceptance while, in the developing countries, the assessment tools are largely dominated by governments and thus have low market acceptance concerning.

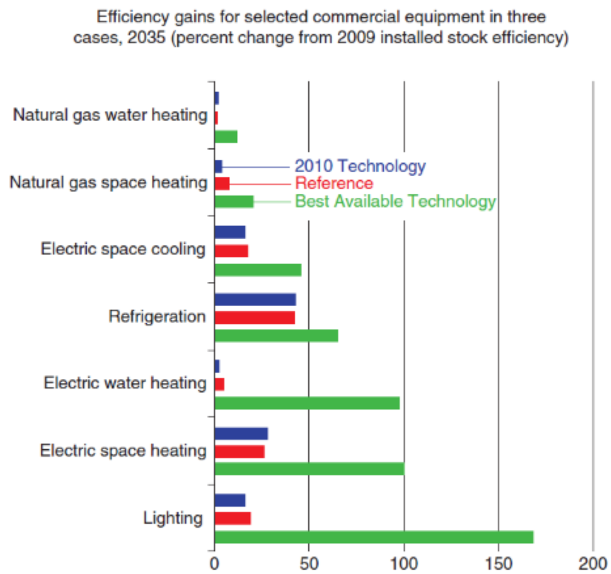
In addition to these mainstream green buildings indicator tools, the United States Environmental Protection Agency (EPA) has developed *Energy Star Target Finder*, an online tool helping to set goals for building energy performance. It provides a percentile score that predicts performance compared to the same type of buildings in the same location. The advantage of this approach is that the target is based on actual buildings, and the designed building is compared to like structures in the immediate area. The drawback of *Target Finder* is that the database lists a limited range of building types. *Target Finder* does have the capability of taking mixed-use buildings into account; for example, a building combining office and residential space can be analyzed to determine the appropriate target. (Kibert, 2016). To earn an Energy Star certification, a building must meet the 75 percent target, meaning that the building has to be in the top 25 percent of buildings of that type, in the specific area, as contained in the *Target Finder* database.

4. Green buildings and energy efficiency, water efficiency, material efficiency.

4.1 Energy efficiency

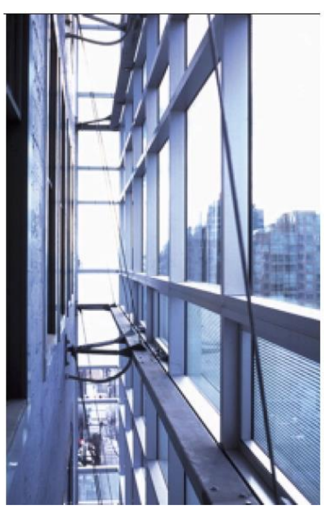
There is a large variety of methods that are used in green buildings to ensure the efficiency of energy. They go from using continuous thermal insulation, eliminating metal studs in outside walls, or ensuring thermal break structure (Picture 8) to completely novel techniques.

Innovative application of energy-efficient measures such as the use of solar thermal technologies, low-emissivity glass, triple glazing, LED lighting, thermal mass with high ventilation, and reflective coating windows can be effective ways to help buildings reduce their energy consumption. Technology advancement is a fundamental driver to green building development and it is manifested through the integration of the use of renewable energy sources with compatible designs (Shen, 2018).



Picture 7. Building energy consumption (especially in lighting, heating, cooling and refrigeration) can be significantly lowered by employing the best available technology for the major energy-consuming systems in buildings (Kibert, 2016).

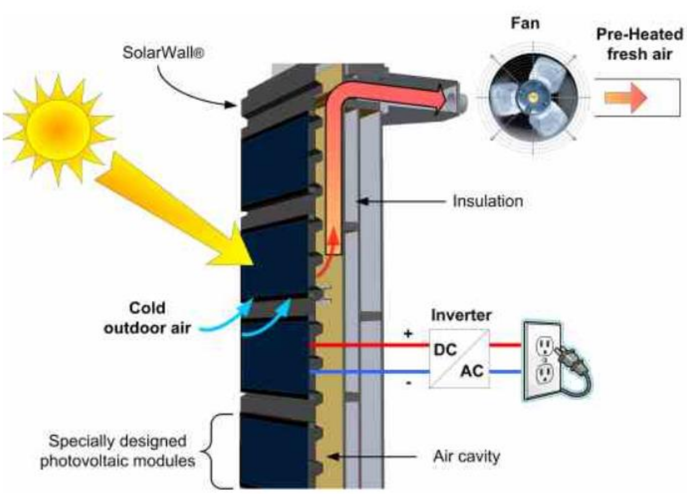
The use of green roofs and walls is related to the utilization of renewable energy, especially solar power. Solar water heater/solar PV can be parts of roofs, and optimized building structures combining with thermal insulation materials can enable solar radiation heat and daylight to be efficiently received. In addition, some alternate energy sources such as solar water pre-heating, wind power, geothermal heat exchange, and fuel cells can be explored to reduce the proportion of less clean sources (Woolliams, 2001).



Picture 8. (Leftmost) Building in which daylight and occupancy sensors are used to reduce artificial lighting. (Right) The third skin of this building creates an air gap which keeps heat in during the winter and provides shade in the summer (Woolliams, 2001).

It is also possible to ensure that all occupied spaces inside the buildings have direct access to outdoor views and to daylight (Picture 8); smaller footprint and narrower building depth allows light to penetrate better throughout the building. One further step might be to reduce unwanted heat gain by using sun shading, interior/exterior window treatments or light shelves. This can be done by selecting glazing with appropriate ratio of visible light transmittance to solar heat gain coefficient and by using trees or plantings to allow light through in the winter and block unwanted lighting the summer.

Additional possibilities include the usage of active solar technologies like photovoltaic panels and passive solar technologies like solar walls. Solar walls passively heat a building. They combine exterior construction with interior devices to use solar energy to heat and ventilate indoor spaces. The solar walls are constructed first by placing metal solar cladding on the exterior wall of a building (Picture 9). This cladding is perforated and built in front of an already present building wall. In the Northern hemisphere, this wall faces south. Furthermore, solar walls can even keep a building warmer in the winter as the added solar wall shields the actual exterior wall of the building from cold air. As well, these walls are fairly inexpensive because of their simplistic construction, and are equal in cost to the installation of a brick wall (Calgary, n.d.).



Picture 9. (Left) Solar wall technology takes cool outdoor air and warms it using heat-absorbing panels. (Right) Solar wall technology added to the Greater Toronto Airport (Siegle, 2010).

Besides the previously mentioned measures, one can decide to directly reduce the lighting load as well by installing high-efficacy lamps and fixtures (e.g.: compact fluorescents and T-8 lamps) (Woolliams, 2001). In this way, one might see a 40% savings on energy bill and can even benefit from really cool light, which incandescent lighting cannot provide. Finally, buildings with access to clean air and a quiet outdoor environment may benefit from the use of natural ventilation systems at least in swing seasons. They are, thus, able to capture the wind and fresh air available on site and reduce the need to mechanically heat, cool, and move air. In the long run, such a choice may constitute a tremendous source of energy saving.

To successfully erect an energy-efficient building, a proper energy design should be considered. Energy design should encompass strategies taken in building orientation and configuration, structure, envelope, ventilation, water, lighting and mechanical design since it is crucial to set a well-coordinated design in order to achieve significant energy savings (Woolliams, 2001).

In *Sustainable Construction: Green Building Design and Delivery*, Kibert J. (Kibert, 2016) lists the following 10 steps which he considers to be critical in designing energy systems with low-energy and low-carbon footprints:

1. Use building energy simulation tools throughout the design process (The goal is to investigate energy and cost savings resulting from the synergies between the various building systems and their components. This process will generally lead to the selection of a smaller mechanical system than would normally be the case.)
2. Optimize the passive solar design of the building.
3. Maximize the thermal performance of the building envelope.
4. Minimize internal building loads.
5. Maximize daylighting and integrate with a high-efficiency lighting system.
6. Design a hyper efficient heating, ventilation, and air conditioning (HVAC) system that minimizes energy use.
7. Select high-efficiency appliances and motors.
8. Maximize the use of renewable energy systems.
9. Harvest and use waste energy.
10. Incorporate innovative emerging strategies, such as ground coupling and radiant cooling.

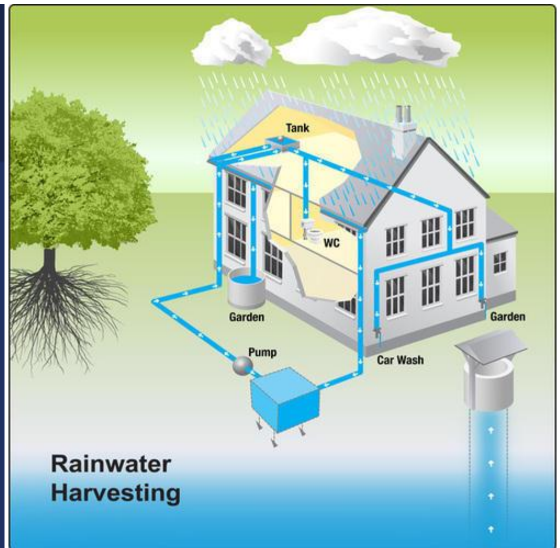
4.2 Water efficiency

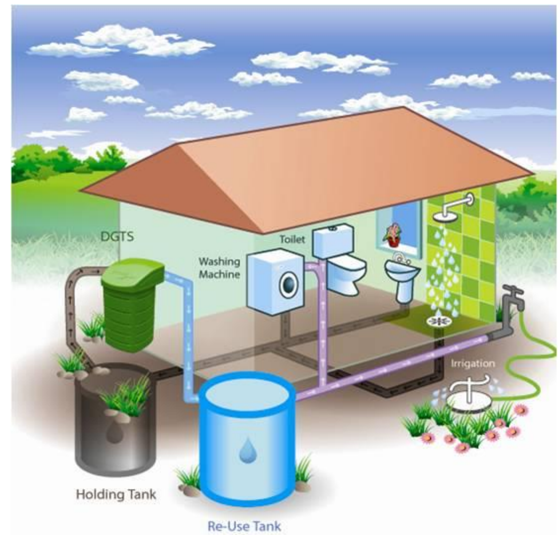
70 % of the earth is covered in water but only 2% of this quantity is fresh water. Even more alarming is the fact that out of the 2%, 1.6 % is confined to the glaciers and polar ice caps. Therefore, the world becomes thirsty for water management and the key to achieve it is with active water efficiency in the buildings we live and in our daily lifestyles (The concept of water efficiency in green buildings, 2018). Water Efficiency means responsible use of fresh water, reducing the overall usage of water and minimizing wastewater.

Water efficiency constitutes one of the major objectives set by green buildings. USGBC (U.S. Green Building Council) enumerates three key components of water efficiency: reduction of indoor potable water use, reduction of water consumption to save energy and improvement of environmental well-Being. The strategies and technologies involved in green buildings aim at reducing the amount of potable water consumed in buildings (The concept of water efficiency in green buildings, 2018).

Among the most used methods, we find rainwater harvesting which is the active collection and distribution of rainwater which rather than going to the sewage is put into use in daily life. Typically, rainwater is collected from the rooftops, deposited in a reservoir with filtration. Once the water is purified, it can be used for cultivation, gardening, and other domestic uses (Picture 10)

(The concept of water efficiency in green buildings, 2018). This system can be applied in the water landscape and general cleaning purposes. (Elias, 2015).





Picture 10. (Leftmost) Estimations vary, but every single person uses around 80-100 gallons of water each day. (Right) Illustration of the concept of rainwater harvesting (The concept of water efficiency in green buildings, 2018)

Moreover, one can select water efficient fixtures and install water meters to allow measurements of potable water consumption. It also exists ways to reduce water-related energy use by insulating water pipes, reducing pipe lengths, reclaiming heat from water, choosing efficient dishwashers and washing machines among others (Woolliams, 2001).

4.3 Material efficiency

Many materials used in buildings today create toxic emissions such as carcinogens, irritants, and odors (Shen, 2018). Using low-emitting materials can, therefore, largely prevent indoor air pollution. More generally, the use of green materials is related to pollution reduction and energy efficiency.

Applying environmentally friendly materials (e.g., recycled materials) to green buildings can effectively help reduce human activities' pressure on the natural environment and avoid damage to natural resources such as forests and minerals, thereby decreasing greenhouse gas emissions (Shen, 2018).

For instance, concrete is an amazing material in construction (it is strong, durable, adaptable) but the concrete industry is one of the two biggest producers of CO_2 and cement – the key ingredient in concrete – is responsible for around 8% of worldwide man-made emissions of greenhouse gas. If the cement industry were a country, it would be the third largest emitter of CO_2 in the world behind China and the US (Rodgers, 2018).

Even though some companies (for instance the Canadian firm Carbon Cure) are actually reusing the emitted CO_2 in the formation of concrete to make it harder and pollute less, we still need to prioritize the greener materials in the construction projects.

The following construction practices related to materials efficiency are typical of green buildings. Salvaged, recycled and efficient materials are integrated in the design as much as possible. Locally harvested or manufactured materials are prioritized to help reduce the environmental impacts of transportation. Materials with low environmental impact over their life are selected using software like BEES or ATHENA (Woolliams, 2001).

The concept of "design for reuse" (Woolliams, 2001) also helps in the achievement of the material efficiency objective. It is best practice to design structures that allow for changes in use over time. This may include modular building materials, or flexible floor plans, with column spacing and floor-to-floor heights that can be easily adapted to many uses, to ensure long structural life. Also selecting building systems that can be deconstructed at the end of the building's useful life may be added in all sustainable projects.

5. Green buildings and information technology.

The latest available technologies participate in enabling the homeowners to permanently have an eye on the sustainable parameters of their house, and therefore it becomes easier to achieve the highest possible efficiency. Besides the built-in mechanical and electrical advantages of the green houses, the homeowners dispose of practical technical tools to adjust some critical parameters as needed.

Through sensors and information technologies, individuals can directly adjust the operable windows and ventilation systems in order to control the airflow. Consequently, they have power over their energy consumption and their level of comfort. Additionally, carbon dioxide sensors can be installed to monitor ventilation rates and ensure indoor air quality. In many cases, they can also control the lighting: turn lights on/off automatically based on some given parameters or manually control it as one prefers.

As an example, the Japanese company *Denso* has unveiled the design of a smart green building that could be powered directly from an electric car (Picture 11). A personalized system controls the energy flowing in the home to achieve optimal energy efficiency and makes it possible to visualize and analyze the home's energy use. A control panel is installed inside the house that permits the owners to appropriately store the energy or dispatch it to the home appliances as needed. When people are in the rooms, lighting and temperature are automatically adjusted.

Picture 11. Smart green homes are in Japan's future. Home Energy Management Systems are among some of the hottest technologies being developed to make households energy efficient and eco-friendly. (Denso, 2013)

6. Barriers to green building implementation and the role of government

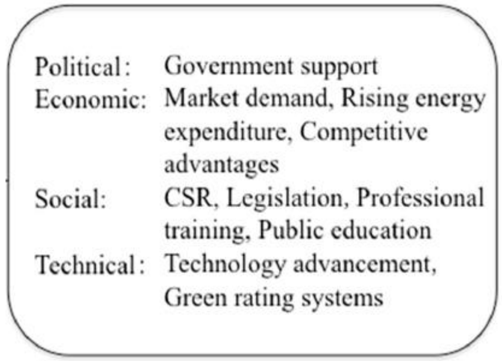
6.1 Barriers to the implementation of green buildings

Despite the ecological appeal of green buildings and the vast technologies that are available to promote its development, there are still many barriers and risks which lead to slow its implementation.

Due to perceived higher initial costs than conventional projects, green buildings' promotion in markets still faces challenges. High upfront costs reduce the green building's attraction to the public, and then affect the market demand, which is the fundamental driver for developing this industry. The financial pressure includes, namely, a "long payback period", "high initial cost", and "high expense of preparing documents for LEED certification" (Shen, 2018). Presently, the demand for green residences is very low because buyers hesitate to pay 30% more costs for a green residence than a conventional house (Elias, 2015).

In the developing countries, additional factors along with the financial pressure explain the slow implementation of green buildings. Shen et al. (Shen, 2018) enumerates these factors as lack of government support, lack of training and education in the industry (shortage of skilled workers), lack of green technologies (technical limitations), and lack of green products suppliers.

To propel green buildings to a mainstream market, the following strategies can be adopted: financial and further market-based incentives, availability of better information on cost and benefits of green buildings technologies, mandatory governmental policies and regulations, and development of green rating and labeling systems (Shen, 2018).



Picture 12. Strategies to promote green buildings (Shen, 2018)

6.2 Role of government

The government can play a supplementary role in promoting green buildings by promulgating laws and policies on issues such as favorable investment conditions, and sustainable building criteria related to energy efficiency, water efficiency, pollution prevention, built environment, research grants for academic research, professional training and public education (Shen, 2018).

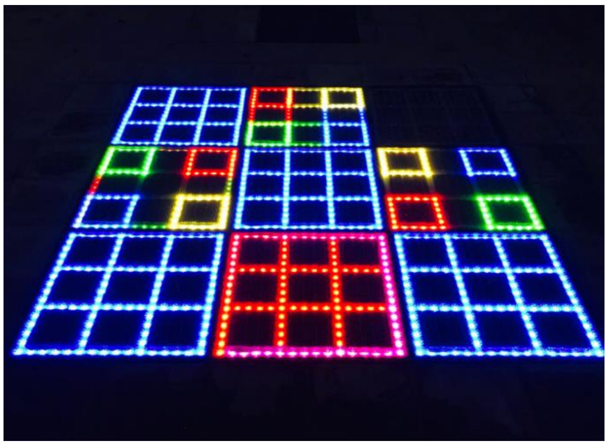
Practically, governments can require all public construction projects to meet certain green criteria such as LEED. Such decisions would raise awareness of sustainable design practices and showcase the benefits of green buildings, especially to the private sector builders. The second approach would be to provide tax credits to developers and consumers, and accelerate permits for developers. Finally, several major cities in the US such as Boston and Los Angeles have required all new construction projects over a certain square footage, both private and public, to meet certain green standards (Shen, 2018). Other large cities in the world could follow this trend to increase their sustainability.

7. Key future trends and new perspectives on the topic.

A high scale implementation of green buildings will significantly benefit populations and the environment; it will constitute, as well, a major step toward reaching the ambitious sustainable goals worldwide. As such, scientists and engineers continue to research methods and techniques that will enable us to reach even higher efficiency possibilities while keeping the operation costs bearable.

A wider utilization of renewable sources of energy to power homes is expected in the coming years. However, forward-looking companies such as *Energy Floors* seek to push the boundaries further.

They design smart and interactive floors that generate energy and make sustainability visible. *Energy Floors* aims to create awareness about renewable energy generation and environmental impact. They opened the world's first sustainable dance club in which partygoers dance on an energy-generating dance floor. The idea is, thus, to turn movements on given surfaces into electricity and to make everyone who steps on them realizes that they can really have an impact (About Energy Floors, n.d.). Such technologies, if massively used in green buildings, can contribute to reduce the amount of energy needed from external sources, and in consequence would lessen the pressure on the environment in extracting energy-related materials.



Picture 13. Interactive energy generating floors designed by *Energy Floors* (About Energy Floors, n.d.)

All the technological innovations that are to come will seek to fulfill the ultimate goal of green building design, that is to design *energy-neutral buildings* or even buildings that are net *exporters* of energy (energy-neutral buildings get half or more of their energy from the grid, and return the same amount over the course of a year. Buildings that produce a surplus of energy over the year may be called net exporters, (Zero-energy building, 2020)). Advancing the use of solar energy, ground coupling, radiant cooling, and other radical approaches may, in the near future, enable buildings to generate at least as much energy as they consume (Kibert, 2016).

In Songdo, a futuristic green city in South Korea, authorities and engineers take the concept of energy-neutral buildings seriously. Designers expect overall energy use to be 40% less by person compared to existing cities due to insulation, high performance glass, the latest generation enlightening and heating, and air control technology. Within a single panel, residents can control their overall usage of energy. They can also track their individual consumption of energy and compare that with their neighbors which increases efficiency. Buildings and streets bristle with sensors that monitor everything from energy use to traffic flow, all with an eye toward sustainability. Songdo has over 20 million square feet of LEED-certified space—the highest concentration of LEED-certified projects in the world (Poon, 2018).

While the technological future of green buildings seems promising, tremendous efforts remain necessary to boost the attractiveness of such buildings. Clearly, green buildings will become more and more mainstream in the future because of its irrefutable advantages such as reducing greenhouse gas emissions and energy efficiency. Therefore, future policies should focus on increasing market demand, encouraging green technology innovation, and reducing the cost of development and construction (Shen, 2018). In addition, both professional training and public education are essential to make the whole society realize the long-term economic, environmental, and social value of green buildings.

As we have seen throughout this report, green buildings are not only a technical/engineering issue but also a social, economic and political one. All its different aspects need to be addressed in order to enhance its feasibility.

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