Architecture
Image Studies
AIS Scientific Journal

Vol.6 , Issue 1, Territories, 2025

Sustainable Design of Eco-Friendly Skyscraper for the Modern Society

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Abstract

The industrial revolution and technological advancement started in the 18th century have a lot to boast for its success in many aspects of human life like reduction in infant mortality rate, human life expectancy, education, health, global food production etc. But the development and gains have many flip sides also. It is not sustainable in long run. It is undermining the ability of the environment and ecosystem, disturbing the fine balance of nature on the planet which is threatening the lives of many species on earth. The main cause of Environmental problems is excessive emission of Green House Gases (GHG) like CO_2, NO_2, SO_2, CO etc. due to the burning of fossil fuels to meet the energy demand of human beings and reduction in forest cover. This project proposes the design of a sustainable and eco-friendly skyscraper that incorporates cutting-edge green technologies and innovative design strategies to minimize its environmental footprint. The design aims to reduce energy consumption by 50% through renewable energy sources, harvest and reuse rainwater and greywater to reduce water consumption by 75%, and incorporate green spaces and vertical gardens to improve air quality. The study reveals that the presence of the green building Movement is far better in the South and Western part and lesser in the Northern and further lesser in the Eastern part of the country. It is an indicator of adaptability and awareness in the regions. The adoption of the Green Building Concept is significantly influenced by economic growth, the existence of international and multinational corporations, and incentives from regional urban authorities.

Keywords

Skyscrapers, Awareness, Environmental, Research, Awareness, Eco-friendly, Green house.

Figure 1. Sustainable Architecture

1. Introduction

The Indian society was practising a form of sustainability from the very beginning. Every natural element, like mountain, river, water, trees etc. were revered and protected. The Earth was revered as 'Mother' which produced everything for human beings and other species on the earth. Each generation had a responsibility to think and ensure the survival of the next generation (Al-Kodmany, 2016). However, at the Rio Earth summit, the concept of sustainability was recognized as an international effort, based on the interdependence of each nation on each other. The greater participation of government, international institutions, regional institutions, non-government organizations and peoples were the key in this process and its implementation. Agenda 21 was a dynamic programme. The plan, policies

and strategies were to be adopted by various nations according to the situations capabilities, priorities of the countries and regions based on all the principles contained in the Rio declaration on development and environment (Allabergenov et al. 2024). The globe was facing many environmental challenges like ozone layer depletion, the rise of the globe's environmental temperature, glacier melting, change of rainfall pattern, reduction in forest cover, etc (Alraouf and Clarke, 2014). Of these environmental problems, many problems are interrelated and interdependent (Metwally, 2019). The main causes of the problems were excessive emission of Green House Gases (GHG) like CO_2, NO_2, SO_2, CO, etc. due to burning of fossil fuels to meet the energy demand of the human beings and reduction in forest cover which acts as carbon sink on one hand and habitat for millions of species on the other hand. The origin of sustainability can be traced back to the 1960s with the beginning of the modern environmental movement. The greater participation of government, international institutions, regional institutions, non-government organizations and peoples were the key in this process and its implementation. Agenda 21 was a dynamic programme. The plan, policies and strategies were to be adopted by various nations according to the situations capabilities, priorities of the countries and regions based on all the principles contained in the Rio declaration on development and environment (Farajizadeh and Bakhsh, 2015). Sustainable Architecture shown in figure 1.

This research was focused on sustainability issues in the construction sector. Therefore, the energy demand and CO_2 emissions from the construction sector have been discussed and deliberated. Industrialization and urbanization are two important elements of development and are interrelated and interdependent.

2. Review of Literature

Policymakers and decision-makers' interest in vertical urbanism is growing as cities try to stop urban expansion and deal with the fast urban population development. According to UN estimates, the urban population would grow by around 2.5 billion people by 2050, which is equivalent to 80 million residents annually, 1.5 million new residents every week, or 220,000 people per day. Additionally, it projects that the current urban population of 4.5 billion people will double to around 9 billion people by the year 2100. Thus, we need to address the vertical dimension of cities in order to handle the urban population growth while minimizing urban sprawl (Al-Kodmany, 2014).

Indeed, there are other ways to boost urban density than using high-rise buildings. However, cities are embracing the tall building typology for additional reasons, including land prices, demographic change, globalization, urban regeneration, agglomeration, land preservation, infrastructure, transportation, international finance, and air right, among others (Al-Kodmany, 2016). Notably, we have seen in the last 20 years, or so an unprecedented, accelerated pace in constructing significant high-rises. Over the past 20 years, the world has added 12,979 tall buildings (100+ meters) to the 7,804 that were already constructed. In addition, "cities have constructed more than 1,361 towers that are more than 200 meters high, whereas they previously constructed only 284." In addition, cities built 150 supertalls (more than 300 meters), compared to just 24 in the past. Additionally, three megatalls (600+ m) were recently finished by cities, which clearly had never built one before (Almusaed and Almssad, 2022; Karthikeyan and Venkatesh Kumar, 2015).

A new sustainable design that tackles major issues including severe storms, earthquakes, and flooding is required by climate change. Recently, urban planners have created new models, such as the "sponge city," which promotes the design of infrastructure and buildings to safely withstand expected high levels of flooding (Jha, 2024). The Green Infrastructure (GI) model, which strives to strengthen water management systems and increase the ecological welfare of urban ecosystems, is the foundation of the "sponge city" paradigm (Ravshanova et al. 2024). Rainwater absorption will undoubtedly be aided by the incorporation of green features into buildings and their surroundings. To further lessen the chance of floods, creative engineering and architectural solutions are also used to collect and reuse rainfall (Aduwo et al. 2024).

3. Methodology

In the bustling landscapes of our cities, a new architectural trend is soaring to new heights - the rise of eco-friendly skyscrapers. As the world grapples with environmental challenges, the construction industry is stepping up to the plate, introducing innovative solutions that marry urban living with sustainable practices. In this article, we discuss the genesis of green skyscrapers, the effects they have on the environment, and the promising possibilities they hold for our cities of the future (Arya, 2023).

- The Emergency of Green Architecture
- The exponentially growing urbanization and its cost on the environment.
- The call to decrease carbon footprints in the building sector.
- The contribution of architecture to climate change.

With concrete jungles proliferating by the day, the environmental cost of urbanization cannot be overlooked. The energy-sapping designs and material-intensive constructions of traditional skyscrapers do much to increase carbon emissions. With the call for action against climate change, sustainable architecture has emerged into the limelight, and green skyscrapers take center stage.

- Innovations in Design and Materials
- The use of renewable energy sources as a part of skyscraper design.
- Eco-friendly material and construction practices.
- Integration of green spaces in the building complex.

Green skyscrapers are not only an idea but a reality, with creative designs and materials. Solar panels, wind turbines, and rainwater harvesting systems are built into the building without any obtrusiveness, making these tall buildings self-sustaining systems. Architects are also incorporating eco-friendly materials and construction methods, minimizing the environmental impact of these giant buildings. The use of green spaces, such as vertical gardens and rooftop parks, not only provides a visual treat but also helps to enhance air quality and increase biodiversity (Metwally, 2019).

- The Economic Feasibility of Sustainability
- Energy efficiency in terms of long-term cost savings.
- Drawing environmentally friendly investors and occupants.
- Government incentives and regulations favoring sustainable building.

Contrary to the general perception of sustainability being costly, green skyscrapers are proving to be economically viable in the long run. These structures are attractive investments because the integration of efficient technologies means huge cost savings in the long run. Additionally, environmental awareness increases, so investors and occupants are looking for green spaces more than ever, and this demand stimulates the market. Governments, aware of sustainable development, are providing incentives and mandating laws that further stimulate the construction of green skyscrapers.

Community Engagement and Well-Being

- Encouraging community spirit through the shared green spaces.
- Placing natural light and ventilation at the forefront of occupant well-being.
- Encouraging an urban healthier lifestyle.

Green skyscrapers are more than just bricks and mortar, with an emphasis placed on building communities within the concrete horizons of the city. Shared green spaces become hubs for social interaction, fostering a sense of connection among residents. The emphasis on natural light and ventilation not only reduces energy consumption but also enhances the well-being of occupants. By promoting a healthier lifestyle in urban environments, these eco-friendly high-rises are redefining the concept of urban living.

4. Sustainable Materials Revolutionizing Skyscraper Construction

Key components including concrete, steel, and glass are frequently used extensively in skyscraper construction. Sustainable alternatives are necessary since the extraction and production of these minerals can have serious negative effects on the environment (Al-Kodmany, 2015). The transition to greener practices in the industry is underway with the adoption of the following green innovations.

4.1. Self-Healing Concrete

The lifespan of structures is increased by self-healing

concrete, which uses bacterial agents or microcapsules to automatically patch cracks. For example, several aqueducts built using this innovation since ancient Roman times are still functioning today. This material represents a groundbreaking innovation in sustainable skyscraper construction because it enhances the structure's durability and reduces maintenance requirements.

Reduced demand for new cement manufacturing, which contributes to up to 8% of global carbon dioxide (CO_2) emissions, results from the longer life cycle. Shifting to self-healing concrete also reduces construction waste and air pollution, and thus it is a very sought-after practice for sustainable urbanization.

4.2. Recycled Steel

Skyscrapers are infamous for their sky-high vanity — focusing more on aesthetics than functionality and sustainability. Consider the world's tallest building, for instance. For aesthetic purposes alone, the Burj Khalifa employs 4,000 tons of structural steel. Its beauty is undeniable, but the environmental cost is high.

7% to 9% of the global anthropogenic greenhouse gas emissions are due to the production of steel. Habitat destruction, soil erosion, and water pollution can also be caused by ore mining.

Conversely, recycled steel greatly decreases these environmental effects. These products employ scrap metal rather than virgin ore, saving natural resources as well as reducing landfill waste. Recycled steel is also very strong structurally and resistant to wear, and therefore ideal for a variety of applications in construction, such as high-rises and other urban structures.

4.3. Cross-Laminated Timber (CLT)

Wood has been a primary building material for millennia. But traditional agriculture often involves the clear-cutting of forests, causing habitat loss, biodiversity depletion and rising carbon emissions from forest destruction. The conventional logging operations also lead to soil erosion and water pollution, further damaging the ecosystems.

CLT offers a sustainable, highly feasible alternative. The production of this material entails bonding small fragments of solid wood from smaller, low-value trees to produce stable and strong composite lumber that can be used for many building purposes. CLT plays a crucial role in the development of timber skyscrapers such as the Justine, an 18-story wooden building which consists of a 72-room hotel, residential and office space.

4.4. Green Roofs

A waterproof membrane is topped with a layer of vegetation to form a green roof. Such systems effectively counteract the heat island effect and lower building temperatures by 30 to 40 degrees Fahrenheit, among other ecological advantages. This cooling aspect renders them a very promising answer to sustainable urban planning.

They also provide more effective stormwater management than roofs that are covered with conventional materials such as wood and asphalt. They minimize runoff and filter pollutants before entering the drainage system through their ability to absorb rain more effectively.

Although green roofs have numerous advantages, more durable roofing materials are a reasonable alternative. Materials such as slate and clay tiles have a lifespan of 100 years or more, with lower replacement costs and upkeep — attractive traits in sustainable high-rise building rooftops.

4.5. Recycled Plastic

The ecological effect of plastic waste is well established. Redirecting these products from landfills and recycling them for use in construction work is a sustainability game-changer. Recycling plastic also decreases the need for virgin plastic manufacturing, a highly energy-consuming process with significant carbon emissions.

Recycled plastic converts waste into useful materials for use in numerous building purposes. For instance, it can be molded into exterior panelling and cladding, offering a lightweight, watertight substitute for conventional materials.

This adaptability enables developers and architects to design novel structures while encouraging environmentally friendly building practices and driving the industry towards a circular economy. A competition in 2023 organized by eVolo Magazine showcased the

potential of a raised plastic skyscraper as a viable option for managing plastic waste in Africa. Although a long way from realization, the idea is clearly very promising both economically and environmentally.

4.6. Photovoltaic (PV) Glass

PV glass incorporates production of solar power into the building envelope, making it especially ideal for skyscrapers because they're so tall that they are able to catch the most sun and often feature designs that are glazing-dense.

Using PV glass instead of standard glass can help buildings contribute to a more sustainable urban environment, generate clean energy on-site and decrease dependence on non-renewable energy sources. According to simulation tests, using PV windows in high-rise buildings could eliminate up to 2 million kilograms of CO_2 emissions yearly in Denver. Moreover, PV glass can be designed to maintain aesthetic appeal while providing functional benefits, seamlessly integrating into modern architectural designs. This dual functionality reduces the need for additional roofing or cladding materials, further minimizing resource use.

4.7. Urbanization, Energy Demand and CO_2 Emissions

Rapid urbanization has created a huge demand for modern construction materials especially in the building sector. Modern building construction techniques use processed building materials like cement, steel, tiles, aluminium, glass, bricks etc. which are produced in the construction industry (Udomiaye et al. 2018). To produce these building materials, the construction industry burns mostly fossil fuels. As per estimates building and construction together consumes around 36% of global final energy as shown in Figure 2.

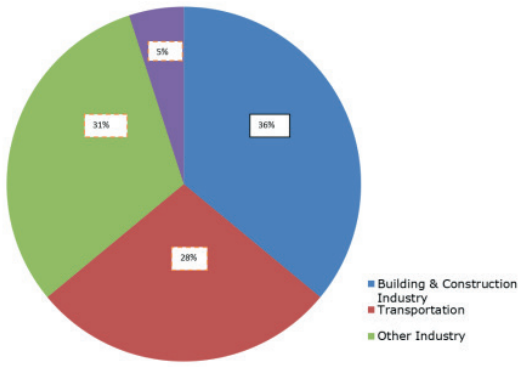

Figure 2. Global Estimates for Energy Consumption in the Building and Construction Sector

The building industry is expanding rapidly, with an estimated 230 billion m2 of new construction projected worldwide over the next 40 years. (UN Global Status Report 2017) adding to the existing 235 billion m2 in 2016. This growth will push energy demand to a very high level from the construction sector itself, globally. The primary source of meeting the energy demand has been the burning of fossil fuels disproportionately. As an estimate, 82% of final energy consumption in the building comes from the burning of fossil fuels (UN Global Status Report 2017).

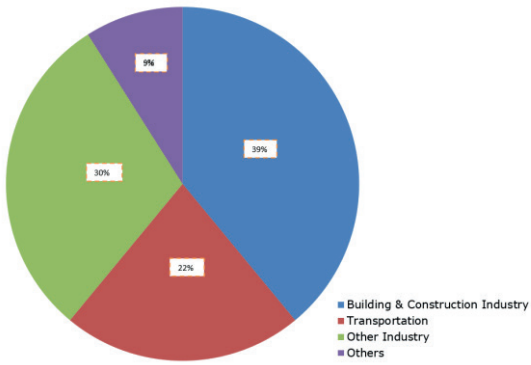

Figure 3. Global Estimates for CO_2 Emission from Different Sectors of Building and Construction

The building and construction industry account for about 40% of energy related CO2 emissions Figure 3. Buildings operation and construction emissions estimate for the year 2019 is 13512 MtCO2 (IEA 2020). In order to achieve the sustainability in building sector and tackle

the environmental challenges induced and generated by the building industry, the concept of green building was introduced by experts and scientists. Recently, UNEP prepared a vision of decarbonizing the building sector towards 2050 by using existing technologies and the urgent adoption of supporting policies and investments (UNEP 2020).

4.8. Sustainable Construction / Green Building a Subset of Sustainability

The sustainability debate entered all sectors of development after the Rio Summit 1992. The building sector too was not left behind as it was the biggest culprit as far as CO_2 emission is a concern (Al-Kodmany, 2010). It is also the biggest consumer of primary energy. The experts and policymakers started a debate on how to reduce the energy demand and its adverse impact on the built environment without compromising its functionality. The industrialization, technological advancement and urbanization pushed the building sector beyond the boundary of basic need, and it entered the arena of aspirations where the human living standard and style have made the built environment one of the biggest consumers of primary energy produced globally and biggest consumer of extracted natural minerals. The experts started a discussion on methods and means of construction to reduce or eliminate adverse impacts on the environment and make the building sector more sustainable. This gave birth to the "Green Building Concept". In general, a "green building" is one that is designed and constructed with resource-efficient techniques and materials that won't negatively impact the environment or the health of its tenants, construction workers, or the general public.

The modern building uses a lot of materials that are processed and produced by modifying the natural resources. These processed material does not go well with the natural ecosystem. A mini-environment is created within the larger ecosystem when a building is built there. The constructed environment is the name given to this little ecology. Plants, soil, surface runoff, hydrology, and microclimate (Heat Island) are all impacted by the built environment. It is promised that this man-made area will be a safer place for people to live within the greater natural ecosystem. In order to minimize its negative effects and influence on the natural environment, the built environment should be carefully planned, developed, and erected. The behaviour and operation of the natural environment must be understood by planners, architects, and engineers. Our contemporary built environment and current building methods require a significant number of natural resources. The building experts and architects need to learn some remarkable features which the natural ecosystem exhibits:

- Renewable solar energy is a natural ecosystem's only source of power or energy.
- Localized production and consumption of concentrated hazardous elements occur inside the system.
- Productivity and deficiency are dynamically balanced with resilience.
- Cooperation and competition are intertwined and maintained in equilibrium within the ecosystem.

Instead of being linear, the majority of natural processes are cyclical. The changes are natural and foster cooperation, interdependability, and resilience. Compared to the natural ecosystem, the artificially constructed built environment has linear processes, wastes a lot of natural resources, uses fossil fuels (mostly nonrenewable), damages the environment, and disrupts the natural ecosystem's balance while also decreasing the ecosystem's capacity to support life. The modern technique of building construction and living styles coupled with the high population growth of humankind especially in urban areas have pushed the energy demand and extraction of natural resources globally to an unprecedented level. Huge amounts of raw materials, including steel, stone, and minerals, are needed for modern building procedures in order to produce cement and other components. These materials are further processed to convert them to a suitable and useful form. In this process, huge energy is required for the conversion and processing of materials. The source of energy for each activity is predominantly non-renewable fossil fuels.

The processed materials and modern techniques of building construction have given unlimited liberty and opportunity to the architects and planners to reflect their thoughts and creativity to any limit. A designer or architect may be revered and adorned for the masterpieces when seen with the spectacles of humans but may fail when to seem with the spectacles of nature. It is the parameter of evaluation that creates a difference. There are various levels of interaction between the natural environment and the constructed world. Individual structures may only have an effect on the local environment, but cities have an effect on the regional environment because they alter natural hydrological cycles, change the weather due to changes in Earth's albedo and degrade the air, water, and land through emissions from their energy systems and the actions of their residents. These factors compelled the planners, experts and architects to review and rethink about modern buildings methods and technology. The research and thinking started for techniques and methods which are more environmentally friendly and sustainable. After the Rio Earth Summit 1992, the sustainability deliberations in the developed countries like the USA, UK etc. brought the concept of Green Building and introduced Green Rating Building System (Zhang et al. 2019). The thought process started whether there are alternates available or can be developed which can save energy and save precious natural resources without compromising functionality or even better ambience. In this concept, every aspect of the building construction is tested on the scale of sustainability from site selection, placing of the building, orientation, technique, fittings, fixtures material selection to final built space.

5. Analysis PF Results

For multi-dwelling unit projects and non-residential projects of size 20,000 sqm., the additional cost is Rs. 4 Lacs plus Travelling Expenses. It is not a big burden. It can be afforded easily by the developer's hand by the Public Authority in the case of public buildings. For example, in a multi-dwelling project of 20,000 sqm., around 130 dwelling units can be constructed with a built-up area of 150 sqm. The cost of certification will be around Rs. 4.5 Lacs and it will be distributed to 130 units, hence for an individual, it will cost around Rs. 34,00/- which is not much. And more importantly, it can be absorbed by the developers themselves and get some incentives from ULB. The most important segment is public buildings. There is no valid reason for not adopting the green building concept for public buildings. It can be made mandatory for all public buildings under sustainable development goals. It will have a profound effect on society by raising awareness, educating the populace, and developing a pool of professionals in green building. The public buildings are spread throughout the country from big to small cities/towns.

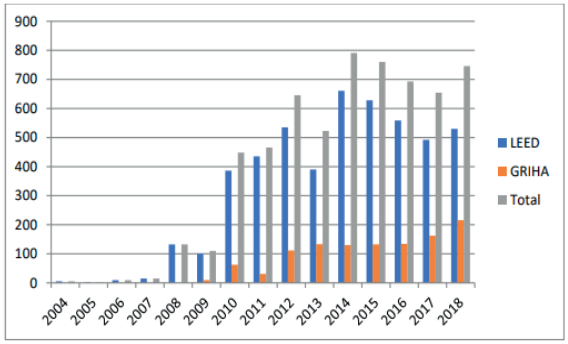

Figure 4. Green Building Registered Projects

Figure 4 and Figure 5 illustrate the yearly and cumulative growth of Green Building projects in the nation, respectively, using the combined data of buildings registered under LEED INDIA and GRIHA.

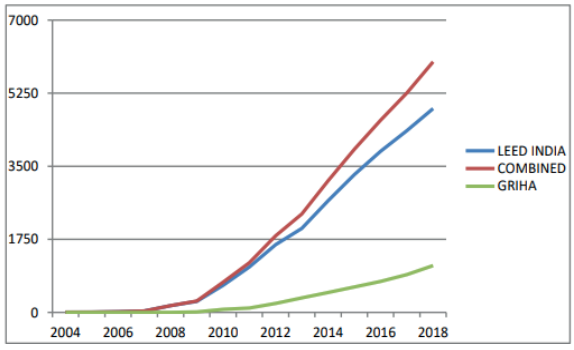

Figure 5. Cumulative Growth of Green Building Projects

The presence of Green Rated Projects which is far better in the South and Western part and lesser in Northern and further lesser in Eastern part of the country is an indicator of adaptability and awareness in the regions. The economic development, presence of multinational companies / transnational companies and incentives from local urban bodies play a key role in the adoptability of the green building concept. The preference of MNC's and foreign investors, better paying capacity are the other reasons for the better adaptability of the green building concept in the Western and Southern parts. Bengaluru is the IT hub and has very good exposure to the external world, is another factor to encourage the green building concept. For example, WIPRO corporate building located in Bangaluru has been contributing a lot to the green building concept. Some of the fast-growing cities like Pune, Noida, Greater Noida have shown affinity to Green Building Concept due to incentives and encouragement by urban local government. The Greater Hyderabad Municipal Corporation explored the use of green buildings as a way to solve its energy shortage and encourage the use of alternate energy sources.

6. Conclusion

Urbanization is taking place throughout the world. The people are migrating to urban areas for better health, better income, better opportunity and overall better quality of life. This phenomenon of urbanization is taking place in India too at a very healthy rate. The urbanization coupled with modern techniques of building construction has brought many challenges for the governments, society and Earth's life-supporting ecosystem. Indian cities are already facing challenges like the freshwater crisis, air pollution, crippling civic amenities and many climatic changes. The present level of urbanization in India is 33% which is likely to cross the 50% level in 2050. The urban population presently is 417 million which is likely to become 875 million in 2050. There will be an unprecedented increase in the demand for electricity and demand for natural resources like fresh water and other natural resources/minerals. There is a need to strike the balance by conserving the natural resources, efficiently utilizing the resources, reducing the electricity demand, recycling and reusing the natural resources, recycling and reusing the wastewater and a host of other measures. The green building concept is a very structured, scientifically designed program to address these issues in a systematic and organised way. The green building certification programs need to be propagated in all parts of the country from metropolitan to small urban towns.

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