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Innovative Sustainable Infrastructure Solutions

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ABSTRACT: Several factors, which are interactive in nature, are affecting as well as threatening the existence of our planet Earth. They include overpopulation and urbanization (which have multitude of effects), transportation in cities, energy use and global warming, excessive waste generation and subsequent pollution of air, water and soil, and limited supply of resources. A brief discussion about these challenges is provided and some solutions are given. The building industry consumes about 40 percent of the extracted materials and is responsible for 35 percent of CO2 emissions. Green and smart buildings will substantially impact the energy consumption and volume of emissions.

INTRODUCTION

This paper describes the following various innovative solutions to the sustainable infrastructure development.

A number of solutions have been suggested and some have been successfully implemented in the past in several countries to produce clean energy and to maintain sustainability. These solutions include: geothermal power, solar energy, and wind power, modern forms of bio-energy, solar photovoltaic, advanced biomass gasification, bio refinery technologies, solar thermal power stations and ocean energy.

Development of alternative fuels such as biodiesel, bio alcohol (ethanol and butanol), chemically stored electricity (batteries and fuel cells), hydrogen, non-fossil methane, non-fossil natural gas, vegetable oil and other biomass sources have also been attempted. Each one has its advantages and drawbacks.

INNOVATIVE SUSTAINABLE INFRASTRUCTURE SOLUTIONS

Solar chimney

Though a number of alternative proposals have been given for meeting the growing energy demands of the world, the renewable energy power plant proposed by Prof. Schlaich is more appealing. The solar chimney proposed by him consists of three essential elements -glass roof collector, chimney and wind turbine, Figure 1.Air is heated in a very large circular structure similar to a greenhouse, and the resulting convection causes the air to rise and escape through a tall tower. The moving air drives turbines, which produce electricity. This type of power plant provides enormous amount of energy with no ecological breakdown at minimal cost (most poor countries cannot afford environmental protection), and without safety hazards (unlike nuclear power plants). Above all, there is no depletion of natural resources at the expense of future generations (many countries are lavishly provided with solar radiation in their deserts!).Net energy payback is estimated to be 2-3 years. If sufficient concrete aggregate materials are available in the area and the anticipated seismic acceleration is less than g/3, then reinforced concrete chimneys are found to be the most suitable. Detailed research has shown that it is appropriate to stiffen the chimney at about four levels with cables arranged like spokes within the chimney so that thinner walls can be used. Feasibility studies have shown that it is possible to build such tall concrete chimneys in India and construction of the same would be particularly reasonable in terms of cost.

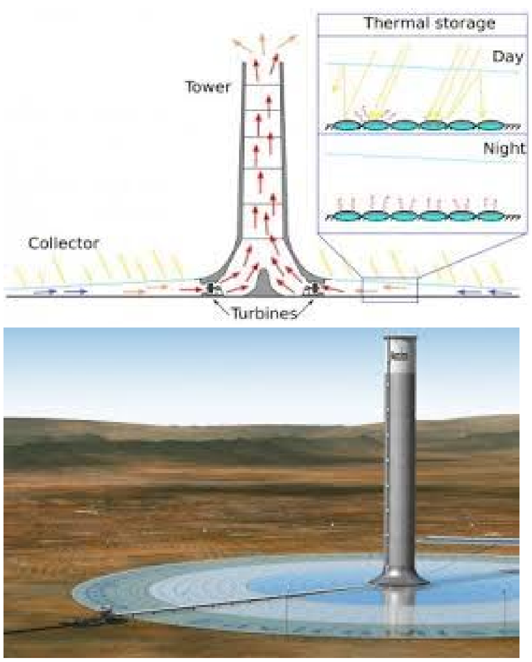

Figure.1.Principle and Prototype of Solar Chimney

Green buildings

A green/ sustainable building design is one that achieves high performance over the full life cycle, in the followingareas11:

1. Minimizing natural resource consumption through more efficient utilization of nonrenewable natural resources, land, water and construction materials apart from utilization of renewable energy resources to achieve net zero energy consumption.
2. Minimizing emissions that negatively impact the indoor environment and outdoor environment, especially those related to indoor air quality, greenhouse gases, global warming, particulates and acid rain.
3. Minimizing discharge of solid waste and liquid effluents, including demolition and occupant waste, sewer and storm water apart from creating the required infrastructure to accommodate removal of wastes.
4. Minimal negative impact on site ecosystem.
5. Maximum quality of indoor environment, including air quality, thermal regime, illumination, acoustics/noise and visual aspects so as to provide comfortable and satisfactory physiological and psychological perceptions.

Internationally, green buildings are certified through an independent body, the US Green Building Council (USGBC), through its LEED (Leadership in Energy and Environmental Design) certification programme.

From 1994 to 2006, LEED grew from one standard for new construction to a comprehensive system of six interrelated standards covering all aspects of the development and construction process2. LEED – NC 2.2, issued in 2005, is structured with seven prerequisites and a maximum of 69 points divided into the following 6 major categories: energy and atmosphere (17 maximum points), indoor environmental quality (15 maximum points), sustainable sites (14 maximum points), materials and resources (13 maximum points), water efficiency (5 maximum points), and innovation and design process (5 maximum points). A building is LEED certified if it obtains at least 26 points. Silver, gold and platinum levels are awarded for at least 33, 39 and 52 points, respectively. Note that different versions of the rating system are available for specific project types. Similar assessment systems are available in other countries also (e.g. BREEAM of United Kingdom and Green Star of Australia). It is expected that LEED - NC 3.0 will include a requirement for a carbon footprint (carbon building **46 The Indian Concrete Journal** DECEMBER 2007print) and a significant reduction of GHG (greenhouse gases) beyond a baseline level2.

Figure 2(a) shows the 41-storey, 62,245 m2 reinforced concrete office tower located in the heart of midtown Atlanta, USA, completed in February, 2006 and designed by Pickard Chilton Architects. It was the first high rise office building in the world to be pre-certified for silver status in the LEED core and shell development and the second to be awarded LEED - CS Gold status, satisfying more than 30 green and high performance requirements.

Figure 2(b) shows CII – Sohrabji Godrej Green Business Centre, Hyderabad, India, which was the first structure in India to receive the prestigious `platinum' rating from the USGBC. The Wipro Technologies Development Centre (WTDC) in Gurgaon is the largest platinum rated green building in Asia that has been felicitated by USGBC. Vangeem and Marceau have shown that by using concrete, one can earn up to 18 points (out of the 26required) towards a LEED certified building12.Green buildings adopt various strategies for water management like using low flow or ultra-low flow plumbing fixtures, electronic controls and fixtures, alternative water sources (rainwater, reclaimed water and grey water) for potable water, rainwater harvesting, xeriscaping, and use of other technologies and approaches that result in reduction of potable waterconsumption2.

a. The 41 storey reinforced concrete

b.CII Sohrabji Godrej Green Business center office tower in Atlanta USA Hyderabad

Figure.2.LEED certified concrete buildings

Intelligent buildings

An intelligent or smart building is one that uses technology and systems to create a space that is not only safer and more productive for its occupants but also more operationally efficient for its owners. In such a building, networks of electronic devices monitors and control the mechanical and lighting systems to reduce energy and maintenance costs. Lighting is controlled with a system based on sensors which can detect the presence of occupants and the relative darkness, and modulate lights accordingly. Air-handling units mix outside air to regulate temperatures in various parts of the building. Sensors are placed in rooms and air-ducts to monitor temperature. Such buildings have hot water systems to supply heat to the building's air-handling units and chilled water systems to cool its air and equipment, with sensors maintaining temperatures at optimum level. Intelligent buildings also have alarm capabilities. Whilst fire and smoke alarms are common, other types of alarms for reporting critical faults in the mechanical and electrical systems are also increasingly coming into use. Among the earliest intelligent buildings in India is the India Habitat Centre in New Delhi. The Engineering Design and Research Centre (EDRC) of Larsen &Toubro's Engineering, Construction and Contract division in Chennai is another such building. It has fully automated energy management, life-safety and telecommunication systems and is possibly the first building in India without any light switch. All cabins are equipped with infra-red detectors to detect occupancy. Entry is only through smart cards with built-in antennas.

The economic benefits in using green and intelligent technology require deeper study. Financial considerations are important as builders and project promoters look for low initial costs while the occupants are concerned about recurring costs. Such smart buildings have to demonstrate their strengths on both these counts for their large-scale acceptability.

SUSTAINABLE DESIGN AND LIFE CYCLE MANAGEMENT

More than any other human endeavor the built environment has direct, complex, and long lasting impact on the biosphere. Around one-tenth of global economy is devoted to construction and about one half of world's major resources are consumed by construction and related industries. It is estimated that in the US, the building industry involves the extraction and movement of 6 billion tonnes of basic materials annually (this represents 8 percent of USA's GDP and 40 percent of extracted material). Residential and commercial buildings together use

Figure.3.Three Spheres of sustainability

One-third of all energy and two thirds of all electricity is consumed in one country (USA).They also account for 47 per cent of sulphur dioxide emissions, 22 per cent of nitrogen oxide emissions, and10 per cent of particulate emissions, all of which damage air quality. Further, buildings produce 35 per cent of the country's carbon dioxide emissions - the chief pollutant blamed for climate change. Indoor air quality is inadequate in 30 percent of the buildings around the world. Construction waste is generated at the rate of about 0.5 tonnes per person each year in the US. Of the approximately 145 million tonnes of construction and demolition waste generated in the US, about 90 percent is demolition waste.

This waste has to be transported, thus consuming more energy and causing more pollution (transportation consumes about 40 percent of primary energy consumption in the US). While the situation is not so acute in India at present, increasing urbanization may push us in that direction. These statistics underline the importance of changing the construction practices.
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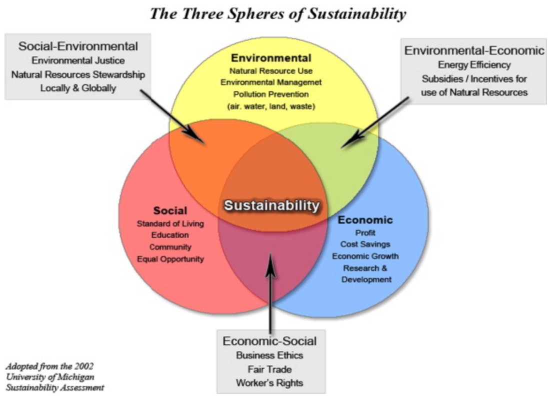
To address these challenges, there is a need to develop effective approaches for life cycle design and management of constructions that will ensure their sustainability in terms of improved physical performance, cost effectiveness, and environmental compatibility. These optimized designs and management systems should provide the owners with the solutions that achieve an optimal balance between three relevant and competing criteria, namely,(i) engineering performance (e.g. safety, serviceability and durability), (ii) economic performance(minimum life cycle costs and minimum user costs) and(iii) environmental performance (minimum greenhouse gas emissions, reduced materials consumption, energy efficiency, etc.).The first two criteria are not new to design professionals but the last criterion changes the entire thinking of design. Life cycle thinking expands the traditional focus on manufacturing processes to incorporate various aspects associated with a product over its entire life cycle. The producer becomes responsible for the products from 'cradle to grave' and has, for instance, to develop products with improved performance in all phases of the product life cycle. Sustainable design has to consider three major aspects of sustainability, namely, social, economic and environmental, Figure 3.



The following are the design considerations for a sustainable building design:

1. Resources should be used only at the speed at which they naturally regenerate and discarded only at the speed at which local ecosystems can absorb them.
2. Site planning should incorporate resources naturally available on the site such as solar and Wind energy, natural shading and drainage.
3. Resource efficient materials should be used in the construction of buildings and in furnishings to lessen local and global impact.
4. Energy and material waste should be minimized throughout the building's life cycle through reuse.
5. The building shell should be designed for energy efficiency considering factors such as day lighting, passive ventilation, building envelope, internal load, local climate, etc.
6. Material and design strategies should produce excellent indoor environmental quality
7. The design should maximize occupant health and productivity.
8. Operation and maintenance systems should support waste reduction and recycling.
9. Water should be managed as a limited resource.
10. Location and systems should optimize employee commuting and customer transportation options and minimize the use of single-occupancy vehicles. These include using alternative work modes such as telecommuting and teleconferencing.

The above design considerations show that there should be effective interaction among all the persons involved in the project (client, architect structural engineer, electrical and mechanical engineer, landscape architect, and others) at all the stages of the project.

SUSTAINABILITY ASSESEMENT RATING SYSTEMS

Over the past decade, various green building rating systems or certification schemes were promoted across the globe. However, there are three most commonly used sustainability rating systems in the global coverage; they are LEED, BREEAM and GREEN STAR. LEED is the most recognized rating system mainly used in USA and Canada, and now extended to include Mexico, India, Brazil, Emirates, etc. BREEAM is the BRE Environmental Assessment Method that mainly operated in UK and part of Europe including Netherlands, France, Spain, Germany, Sweden, Poland, Norway, Russia, etc. GREEN STAR is the environmental rating system to evaluate the environmental design and construction of buildings and communities that operated in Australia and New Zealand. When comparing BREEAM, LEED and Green Star, there are similarities that sustainability issues are broken down into a number of categories and assigned weights, such as management, energy, transport, health and wellbeing, water, materials, land use and ecology, pollution, and sustainable sites, etc. The success of the LEED rating systems in USA lead to the rise of similar green building councils in many other countries such as, Singapore, Hong Kong, India, Canada, etc, which in turn created their own rating systems (Talwar, 2013). In Asia, the sustainability rating systems are more diversified and most of the countries have established their own rating systems, including:

CASBEE is the Comprehensive Assessment System for Building Environmental Efficiency owned and operated in Japan by the Japan Sustainable Building Consortium,

BEAM Plus is the environmental assessment scheme for new buildings and existing Buildings, which is owned by BEAM Society Limited, recognized by the Hong Kong Green Building Council and operated in Hong Kong.

Green Mark is a benchmarking scheme for environmental design and performance, operated by Building and Construction Authority in Singapore.

EEWH is the green building certification system in Taiwan, stands for the evaluation of four categories -Ecology, Energy saving, Waste reduction, and Health

ESGB is the Evaluation Standard for Green Buildings in PRC China

Reed and Krajinovic-Bilos (2013) recognized that the individual characteristics of each country, such as the climate and type of building stock that lead to the development of an individual sustainability rating tool for each country.

Internationally, LEED is a globally recognized symbol of excellence in green buildings. The LEED rating systems generally have 100 base points plus six Innovation in Design points and four Regional Priority points, for a total of 110 points. Each credit is allocated points based on the environmental impacts and human benefits of the building-related impacts that it addresses. Projects achieve certification if they earn points according to the following levels:

Certified: 40–49 points
Silver: 50–59 points
Gold: 60–79 points
Platinum: 80+ points

However, some criticisms on LEED rating system is that its “Rating System Checklist” to evaluate a building’s water and energy efficiency, land use, choice of materials, and indoor environmental quality. Based on the checklist scoring results, it certifies buildings on a scale from simply “LEED certified” up through Silver, Gold and Platinum. Stein and Reiss (2004) pointed out that “*buildings that earn more LEED credits do not necessarily provide more environmental benefits than buildings that earn fewer credits*”, and Frangos (2005) recognized that “point mongering” is a common phenomenon under the LEED rating checklist scoring system. In addition, Leu (2012) pointed out that further potential problem is the scoring point system creates negative incentives to design around the checklist rather than to build the greenest building.

Holistic Approach

Since the first version of LEED released in 2000, The LEED system is gaining popularity in the International green building marketplace. Over the years, the rating systems became more stringent; with the recent Version 4 released in November 2013. As a result of this, at present there are better and more efficient buildings in the market. Lam et al. (2013) recognized that one of the key aspects on innovative design strategies allowed building performance to go beyond the checklist-based scoring systems.

The following is a case study analysis of an outstanding sustainable hotel project in Hong Kong using holistic approach to sustainability that achieved triple platinum awards from three different green assessment rating organizations.

Pilot Study: A Hotel Project in Hong Kong

The Holiday Inn Express Hong Kong SoHo hotel is situated in Sheung Wan, the heart of the commercial centre in Hong Kong. The project commenced in 2009 and opened in September 2013.The project site area is 612 square meters with a total Gross Floor Area of 9,496 square metres. It consists of 37 storeys and 274 guest rooms.

This hotel project sets out as an integrated green and sustainable building design participated by the developer, architect, engineers, special consultants and construction team. The hotel's design and construction is "Green" concerned and oriented on sustainability, carbon emission reduction, water &energy efficiency, atmosphere optimization, material and resources consideration, and indoor environmental quality performance with a number of innovative ideas on energy optimization solution and sustainable practices. The result is an overall energy saving of 58.5% over EMSD HK hotel energy consumption benchmark (EMSD, 2000). The key green features of the hotel project can be classified in a number of categories, including:

(A) Architecture

Building orientation: Guest rooms located at North-South directions and minimized Window area in the West direction.

5D Building Information Modelling is adopted during design development.

Provide podium garden, roof garden and Green wall from 2/F to 6/F, increased landscaping area to 47.5% of the site area.

Extensive use of standardized prefabricated elements up to 50% major building components

(B) Heating, Ventilation and Air-conditioning System

"Energy Optimization Solution" to Chiller Plant is adopted to optimize overall system energy efficiency and control performance. High CoP (5.48) Variable Speed Drive (VSD) water-cooled Chiller system

CO sensors installed to control air handling units.

Centralized control by Building Management System (BMS)

(C) Electrical System

Light-Emitting Diode (LED) lights and T5 light tubes installed.

Daylight sensors installed at the lift lobbies and Great Room.

Solar lawn lights installed to store solar energy in nickel cadmium batteries.

(D) Lift System

Lifts' motors driven under Variable Voltage Variable Frequency (VVVF)

(E) Plumbing and Hot Water Supply System

Heat pump to reclaim heat from HVAC system and solar energy from roof top solar hot water panel and solar reclaimed cladding.

Rainwater and AC condensation recycling tanks (total volume 10,000L) collected water from air-conditioning System and treated using carbon filter and ultraviolet lamp to remove suspended solids.

(F) Innovative Design and Techniques

Intelligent lift optimization counterweight reduced counterweight from 50% to 35% heavier than the lift car.

Intelligent fan coil unit (iFCU) used permanent magnet motor through magnetic forces to operate.

Peltier Headboard - personalized air-conditioner embedded into the headboard of the beds.

Pattern recognition technology, closed-circuit television (CCTV) cameras and motion sensors to observe the occupancy status of the corridors

It is the first high rise hotel project in the world that achieved triple platinum awards from three different green assessment rating organizations, including LEED-NC of USA (USGBC, 2013),BEAM Plus New Building of Hong Kong (HKGBC, 2013) and Green Mark's Provisional of Singapore (Building

Construction Authority, 2013). The score cards from these three green Assessment rating systems are listed in Table 1 to 3.

Table 1: LEED - New Construction Score Card for the Hotel Project

Category	Achieved Scores	Max Points	Percentage achieved
Sustainable Site	23	26	88.5%
Water Efficiency	13	14	92.9%
Energy and Atmosphere	28	35	80.0%
Material and Resources	1	14	7.1%
Indoor Environment Quality	13	15	86.7%
Innovation and Design Process	4	6	66.7%
OVERALL SCORE	82	110	74.5%

Table 2: BEAM Plus for New Building Score Card for the Hotel Project

Category	Achieved Credits	Applicable Credits	Achieved Percentage	Weighting Factor
Site Aspects	14	19	73.7%	25%
Material Aspects	6	20	30.0%	8%
Energy Use	31	37	83.8%	35%
Water Use	6	8	75.0%	12%
Indoor Environmental Quality	22	28	78.0%	20%
Innovations and Additions	5	1+5 Bonus	500.0%	100%
OVERALL RATING	84		11879.8	

Table 3: Green Mark Score Card for the Hotel Project

Category	Achieved Scores	Max Points	Percentage Achieved
Energy Efficiency	63.5	72	88.2%
Water Efficiency	9.93	14	70.9%
Environmental Protection	17.00	27	63.0%
Indoor Environmental Quality	4.00	4	100.0%
Other Green Features	1.50	7	21.4%
SCORE	95.93	124	77.4%

As indicated in the score cards of the three different green assessing rating systems, the top three categories of percentage achieved from each of the Platinum awarded rating system are very consistent, namely water efficiency, energy efficiency, and indoor environmental quality.

This hotel project adopted numerous innovative features and technologies in energy savings and environmental friendly features in its design, including automatic curtain system, photo sensors, energy efficient lighting, HVAC system optimization, counterweight optimization, Peltier headboard, etc. The building's entire life cycle has been thoroughly considered prior to construction in creating a Comfortable and sustainable building for guests and visitors (Mak et al., 2014). These innovative features and technologies are the excellent achievement of sustainability for the hotel project. For example, the Peltier Headboard is the first hotel to develop and patent the technology on headboards.

This smart technology ensure that when guests are sleeping cool air is only circulated to where it is needed rather than the entire guest room in order to save energy. However, LEED has only awarded one single point for this true innovation. On the whole, the category of innovative design and technologies only accounted for a very small proportion of the overall score, and a very small percentage achieved in the innovation category. For instance, percentage achieved for the innovation category in LEED is 4.8% (4/82), BEAM plus is 5.9% (5/84), and even lower in Green Mark is 1.6%(1.5/95.93). This indicated that the scored points in innovative category did not totally reflect the efforts input into the hotel project. The achievements of the hotel project are more than just the scored points at platinum level, it demonstrates a holistic approach that emphasis on the innovative design strategies to acquire the highest commitment to sustainability.

SUMMARY AND CONCLUSIONS

Our planet Earth is at peril due to a number of factors which include population explosion, urbanization, and excessive energy use and associated global warming, water scarcity and inefficient waste management. A number of solutions have been proposed for sustainability. A few sustainable solutions have been discussed. Construction industry consumes 40 percent of the total energy and about one half of world's major resources. Hence, it is imperative to regulate the use of materials and energy in this industry. Green and intelligent buildings and LEED certification have been evolved for sustainability of the construction industry. Life cycle costing and life cycle management of resources play an important role in the development of sustainable construction. However, unless means of making these green buildings affordable for the common man are not developed, we cannot attain full sustainability.

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