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SUSTAINABILITY - CHALLENGES AND SOLUTIONS

ABSTRACT

Several factors, which are interactive in nature, are affecting as well as threatening the existence of our planet Earth. They include over population and urbanization (which have a whole host of effects), transportation in cities, energy use and global warming, excessive waste generation and consequent pollution of air, water and soil and a limited supply of resources. Some of these challenges are briefly discussed and a few solutions are provided. The building industry consumes about 40 % of the extracted materials and is responsible for 35% of CO_2 emissions. Green and smart buildings will substantially impact the energy consumption and volume of emissions. A life-cycle analysis of building materials and life-cycle management of products are necessary in order to select the materials for high performance green buildings. Concrete with cementitious materials such as fly ash, silica fume and slag can be used to build sustainable constructions.

Key words*: global warming, green buildings, high performance concrete, intelligent buildings, LEED Certification, life-cycle management, life-cycle cost, solar chimney, sustainability, urbanization, waste management.*

INTRODUCTION

Though several definitions for sustainability are available, the definition suggested by the then Prime minister of Norway, Gro Bruntland, in 1987 - *meeting the needs of the present without compromising the ability of future generations to meet their needs*- is considered as simple and effective[1]. Sustainable development or simply sustainability is thus a realization that today's population is merely borrowing resources and environmental conditions from future generations.

Several factors which are interactive in nature are affecting as well as threatening the existence of our planet Earth. They include over population and urbanization (which have a whole host of effects), transportation in cities, energy use and global warming, excessive waste generation and consequent pollution of air, water, soil and a limited supply of resources. Though it is difficult to discuss all these challenges in a short paper of this nature, these challenges are briefly discussed and a few solutions for the same are provided. It has been found that reinforced concrete coupled with the use of cementitious materials greatly aids sustainability.

ENVIRONMENTAL THREATS

The greatest threats to sustainable development on earth are: population growth and urbanization, energy use and global warming, excessive waste generation and the consequent pollution of soil, air, water, transportation in cities, and limited supply of resources. Many of them are inter-related. Let us now briefly discuss these threats.

Population Growth

The world population in 2007 was estimated at 6.7 billion with an annual growth rate of about 1.2 %. To put the recent growth in perspective, the world population in the year 1900 was only 1.6 billion and in 1960 it was 3.0 billion. According to the UN, the world population in 2050 will be between 7.9 billion and 10.3 billion (see Figure No.1).

Currently, 80 million people are being added every year in the less developed countries, compared with about 1.6 million in the more developed countries (see Figure No. 2). Thus population is growing more rapidly at places which cannot afford such an alarming growth.

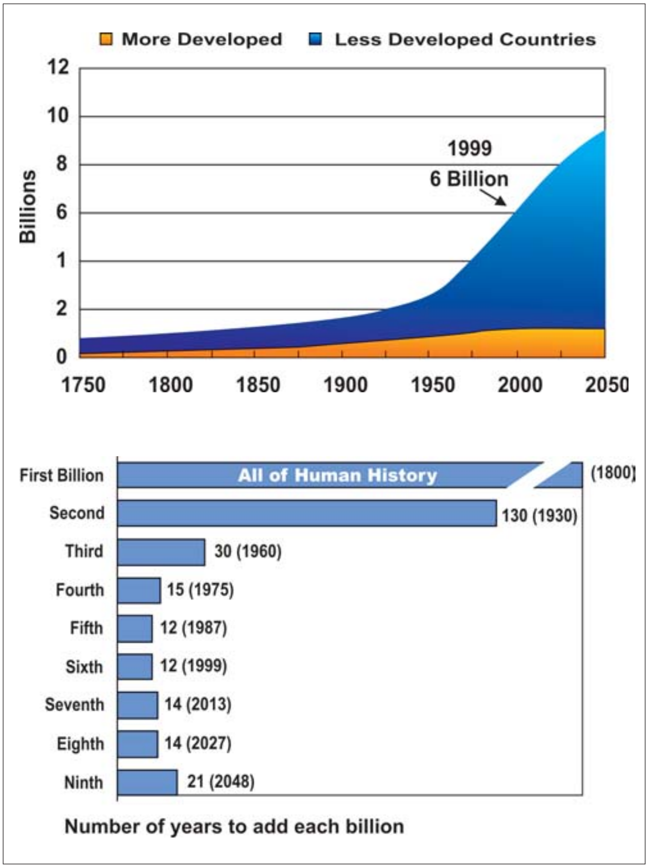

Figure No. 1 Population Trend from 1750-2050 *(source: www.sustainablescale.org)*

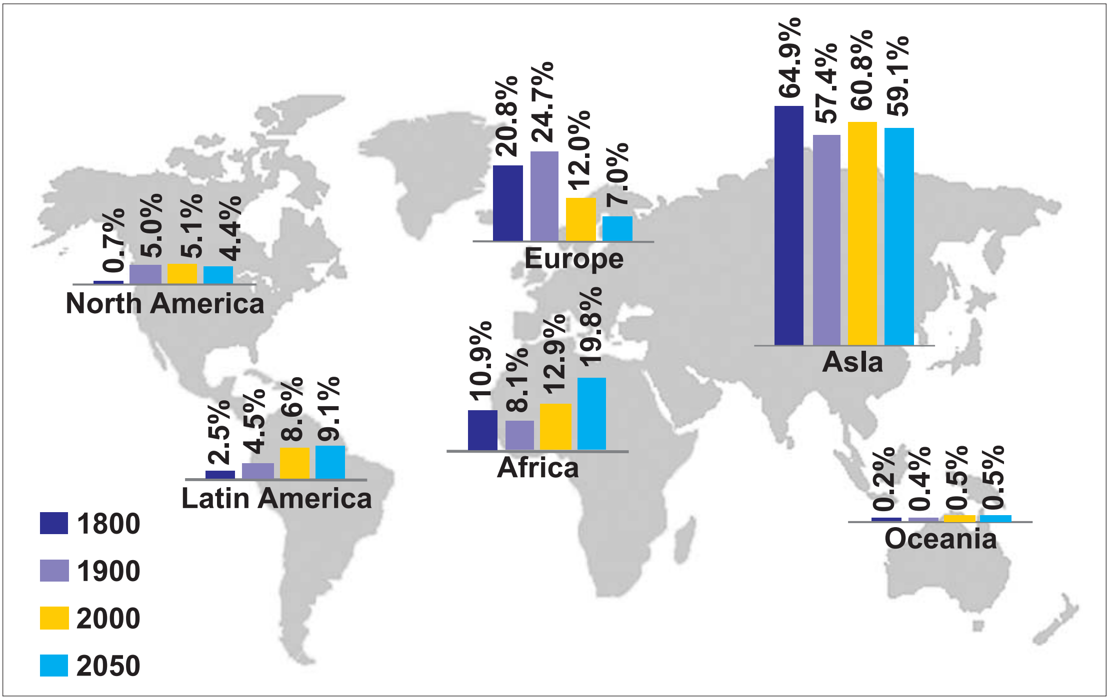

Figure No. 2 Distribution of World Population *(source: www.geographyalltheway.com)*

The Ecological Footprint Analysis is now widely used around the globe as an indicator of environmental sustainability[2]. Ecological Footprint Analysis compares human demand on nature with the biosphere's ability to regenerate resources and provide services. This approach can also be applied to an activity such as the manufacturing of a product or driving of a car. This resource accounting is similar to life-cycle analysis, wherein the consumption of energy, bio-mass (food, fiber), building material, water and other resources are converted into a normalized measure of land area called 'global hectares' (*gha*).

The amount of bio-productive land and sea available to supply human needs is limited. It is estimated that only one - eighth of the surface of the Earth is suitable for humans to live on — three-quarters is covered by oceans and half of the land area is desert (14%), high mountains (27%) or other less suitable terrain.

Currently, the approximately 11.2 billion hectares of productive earth, divided by the 6.3 billion people who depend on it for their well being, results in an average of approximately 1.8 hectares per person. At present we are collectively using approximately 2.2 gha per person or over 20% more than is produced annually, which means that the population has already exceeded the sustainable limit[2].

Urbanization

In 1950, New York was the only city in the world with a population of more than 10 million. The number of cities with a population of more than 10 million increased to 5 in 1975 and 17 in 2001 and is expected to increase to 21 cities by the year 2015. The world's urban population reached 2.9 billion in 2000 and is expected to increase by 2.1 billion by 2030. Currently, about half of the world's population lives in urban areas. By 2030, urban dwellers will make up roughly 60% of the world's population. The percentage of urban population in India increased from 18.0 in 1961 to 27.8 in 2001. It is projected that Asia and Africa will have more urban dwellers than any other continent of the world and Asia will comprise 54% of the world's urban population by 2030.

Population growth coupled with urbanization results in significant impacts on the environment and other problems, which include:

(1) increased ambient temperature

(2) decreased air quality

(3) increased water run-off

(4) decreased quality of run-off water

(5) altered weather patterns

(6) loss of aesthetic beauty/character of the community

(7) reduction in farm lands and subsequent food shortage

(8) deforestation

(Deforestation is occurring at a rapid rate, with 0.8 hectares of rain forest disappearing every second. Deforestation is closely linked with negative environmental consequences such as bio-diversity loss, global warming, soil erosion and desertification). Also urbanization results in the migration of rural population to towns thus creating the development of slums, increased pollution and waste, the need to develop infrastructure for housing the masses, educational facilities, roads and highways, health care, civil supplies, etc. Congestion of living space, inadequate lung space, and traffic etc., result in a proliferation of diseases.

In addition, population growth and urbanization pose significant challenges for water resources management throughout the world. Urban populations consume much more food, energy and durable goods than rural populations. The urbanization of the world's populations will increase aggregate energy use. Not only do urban areas generate more rain, they reduce the infiltration of water and lower the water tables. This means that run-off occurs more quickly with greater peak flows. Flood volumes increase, as do floods and water pollution downstream.

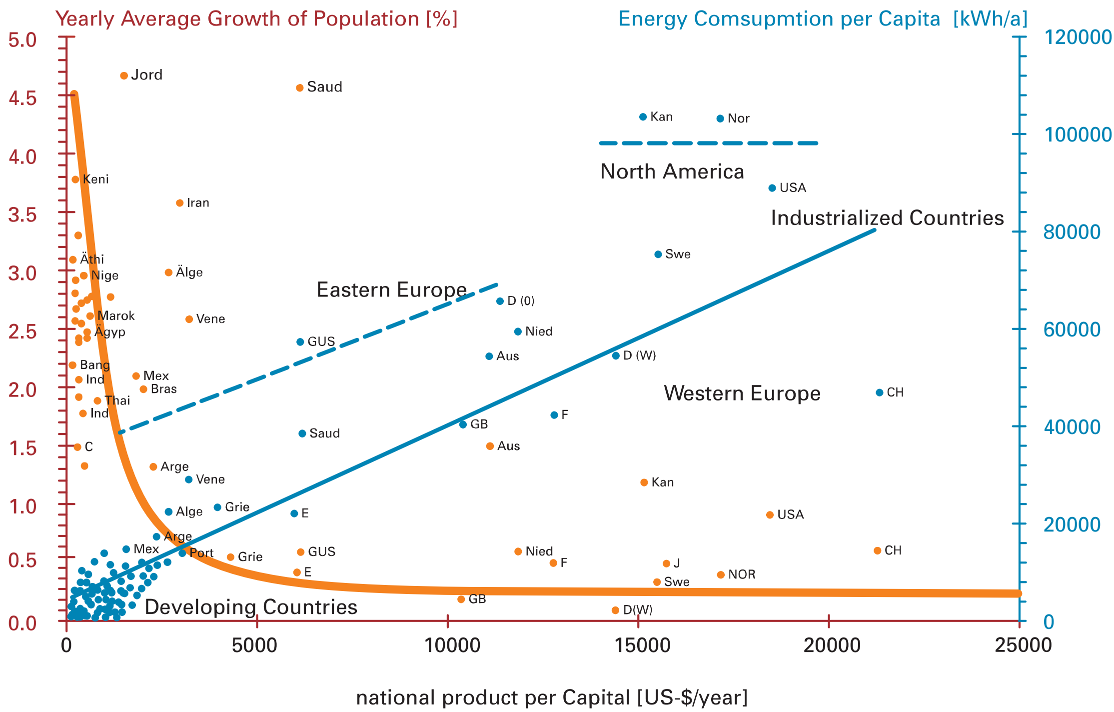

Figure No. 3 Correlation between per capita Energy consumption, per capita GNP and population
(source: http://www.sbp.de/de/html/projects/solar/aufwind/index.htm)

Energy use and Global warming[3-6]

In 2004, the average total worldwide power consumption of the human race was 15 TW (= 15 x 10^{12} W) with 86.5% from burning fossil fuels (oil, coal and natural gas). Figure No. 3 shows that there is a broad relation between wealth and energy consumption. Figure No. 4 shows the contribution of various sources to this worldwide power consumption. The energy consumption in India increased threefold, from 4.16 to 12.8 quadrillion Btu between 1980 and 2001, putting India next only to the US, Germany, Japan and China in total energy consumption. According to the International Energy Outlook, projections for 2030 of the US Department of Energy, China and India account

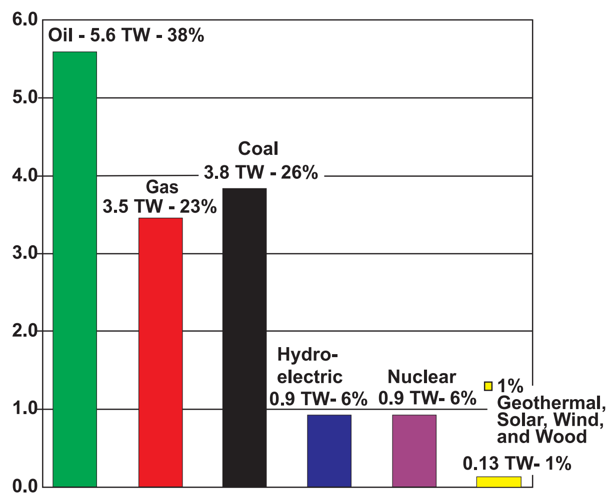

Figure No. 4 Worldwide energy supply in TW
(source: Energy Information Administration, U.S. Department of Energy)

for nearly one-half of the total increase in residential energy use in non-OECD countries.

Though Greenhouse Effect occurs naturally (providing a habitable climate), atmospheric concentrations of some of the gases that produce the Greenhouse Effect are increasing due to human activity causing global warming. Over one-third of human-induced greenhouse gases is caused by the burning of fossil fuel to generate electricity. All fossil fuels are made up of hydrocarbons and release carbon dioxide when burned.

The principal greenhouse gases that enter the atmosphere because of human activities are:

- **Carbon Dioxide (CO_2)**: Carbon dioxide enters the atmosphere through the burning of fossil fuels (oil, natural gas, and coal), solid waste, trees and wood products, and also as a result of other chemical reactions (e.g., manufacture of cement). Carbon dioxide is also removed from the atmosphere (or "sequestered") when it is absorbed by plants as part of the biological carbon cycle.

- **Methane (CH_4)**: Methane is emitted during the production and transport of coal, natural gas and oil. Methane emissions also result from livestock and other agricultural practices and due to decay of organic waste in municipal solid waste landfills.

- **Nitrous Oxide (N_2O)**: Nitrous oxide is emitted during agricultural and industrial activities as well as during combustion of fossil fuels and solid waste.

- **Fluorinated Gases**: Hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride are synthetic, powerful greenhouse gases that are emitted on account of a variety of industrial processes. These gases are typically emitted in smaller quantities, but because they are potent greenhouse gases, they are sometimes referred to as High Global Warming Potential gases ("High GWP gases").

In addition to the above gases, volatile organic compounds, radon, asbestos, carbon monoxide, nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and combustion particulates may affect indoor air-quality. These are introduced into the indoor environment by painting, glues, solvents, wood preservatives, installation of carpets or through cleaning products. It has to be noted that asbestos products are not yet banned in India.

Though Nuclear power plants do not emit greenhouse gases, no solution has been found till now to dispose Plutonium and other wastes from nuclear power plants, which are highly radio-active. It may be noted that plutonium takes approximately 25,000 years to decay to half of its original potency! (For example, in the past 50 years, the U.S. has accumulated about 30,000 metric tonnes of spent fuel rods from power reactors and another 380,000 cubic meters of high-level radioactive waste, a by-product of producing plutonium for nuclear weapons. None of these materials have found anything more than interim accommodation).

The Inter-governmental Panel on Climate Change (IPCC) of the United Nations predicts that, based on a range of scenarios, by the end of the 21st century, climate change will result in:

- A probable temperature rise between 1.8°C and 4°C, with a possible temperature rise between 1.1°C and 6.4°C.
- A sea level rise most likely to be 28-43cm.
- Arctic summer sea ice disappearing in the second half of the century.
- An increase in heat-waves being very likely.
- A likely increase in tropical storm intensity.

It is interesting to note that the IPCC and Albert Arnold (Al) Gore Jr. were awarded the Nobel Peace Prize for the year 2007 in commemoration of their efforts to build up and disseminate greater knowledge about man-made climate changes and for laying the foundations for measures that are needed to counteract such change. It has been reported that globally the cost of climate related disasters has doubled every decade from $ 50 billion in 1960s (16 disasters) to $400 billion in the 1990s (70 disasters).

According to new NASA satellite data, the Arctic Ocean could be nearly ice-free at the end of summer by 2012, much faster than previous predictions. Faster melting there means eventual sea level rise and more immediate changes in winter weather because of less sea ice. White sea ice reflects about 80% of the sun's heat off Earth. When there is no sea ice, about 90% of the heat goes into the ocean which then warms everything else up. Warmer oceans ultimately lead to more melting.

The objective of Kyoto Protocol, which came into force in February 2005, is to reduce the emissions of carbon dioxide and five other greenhouse gases (5% below their 1990 level), or engage in emissions trading if they maintain or increase emissions of these gases. As of November 2007, 174 parties have ratified the Protocol, except the US and Kazakhstan. Representatives of more than 180 nations gathered on the Indonesian island of Bali in Dec. 07 to commit themselves towards working out a new agreement on emission cuts to extend or replace the Kyoto Protocol, which expires in 2012. It is expected that they will agree to reduce emissions by 20-40% below their 1990 level, by 2020 (though this move is opposed by the US, Canada and Japan).

Though there may be some difference of opinion in the development of global warming, there are no two opinions about the fact that there is a depletion of resources, such as metals, fossil fuels and non-renewable energy sources. Hence it is of paramount importance to seriously consider replacing these resources in construction, in order to use existing reserves over a long period of time.

Water Scarcity [7-9]

According to a United Nations Report, one person in six does not get safe drinking water and double that number, about 2.4 billion lack adequate sanitation facilities. This is because of all the Earth's water, only about 2.5% is fresh water, and of that, three quarters is locked up in glaciers and permanent snow cover. Only 0.3% of water is surface water found in rivers and lakes and thus readily accessible. Throughout the world both ground and surface water is being used at a faster rate than it is being replenished. A country is considered water-scarce when its' annual supply of renewable fresh water is less than 1,000 m^3 per capita.

In India the water scarcity is very much experienced due to the frequent occurrences of droughts and floods. Due to global warming, Himalayan glaciers may shrink from 500,000 sq. km. to 100,000 sq. km. in 2030 and per capita availability may shrink from 1,800 cubic m. to 1000 cubic m. Many states wrangle over sharing of river waters. It is estimated that 80% of domestic needs in rural areas and 50% in urban areas are met by ground water. Agriculture is the cause of serious water supply problems as it consumes over 80% of ground water consumption[6]. About 40% of water in large cities is lost due to leaky systems. In addition, even the class I cities, (the largest Indian cities) are treating only a small part of their effluents, while the smaller towns practically do not have any treatment facilities.

Globally, water scarcity is resulting in a host of crises such as food shortages, regional water conflicts, limited economic development, and environmental degradation. The values of implementing water reclamation and reuse are recognized by many in the context of sustainable water resources management because municipal wastewater is produced at the doorstep of the metropolis where water is needed the most and priced the highest.

Though fresh water can be extracted from sea water, it is very expensive (for example, Israel is now desalinizing water at a cost of 53 cents per cubic meter).

Around 1,500 desalination plants exist in the world and the two leading methods are Reverse Osmosis (47.2% of installed capacity world-wide) and Multi-stage Flash (36.5%). Saudi Arabia's desalination plants account for about 24% of total world capacity.

Waste Management

Waste management is the collection, transport, processing, recycling or disposal of waste materials. The term usually relates to materials produced by human activity, and is generally undertaken to reduce their effect on health,

Figure No. *5 Waste management can involve solid, liquid or gaseous substances*

aesthetics or amenities. Waste management is also carried out to reduce the materials' effect on the environment and to recover resources from them. Waste management can involve solid, liquid or gaseous substances with different methods and fields of expertise for each (see Figure No.5).

Various methods are used for waste management, which include disposal (landfill and incineration), recycling (physical and biological processing), energy recovery, avoidance and reduction.

The Central Pollution Control Board estimates the current quantum of municipal solid waste generation in India to the tune of 48 million tonnes per annum, out of which the waste from construction industry accounts for about 12 to 14.7 million tonnes. Per capita waste generation in major Indian cities ranges from 0.2 to 0.6 kg. In addition, the hazardous waste generation is around 4.4 million tonnes. In future every country has to accord importance to energy and waste management in order to have sustainability.

SUSTAINABILITY- SOME SOLUTIONS

A number of solutions have been suggested and some successfully implemented in the past in several countries to produce clean energy and maintain sustainability. These solutions include: Building more nuclear power plants, geothermal power and heat, solar heating and cooling, wind power, modern forms of bio-energy, solar photovoltaics, advanced bio-mass gasification, bio-refinery technologies, solar thermal power stations, hot-dry-rock geothermal power and ocean energy. Development of alternative fuels such as bio-diesel, bio-alcohol (ethanol, butanol), chemically stored electricity (batteries and fuel cells), hydrogen, non-fossil methane, non-fossil natural gas, vegetable oil and other bio-mass sources have also been attempted. Each one has its advantages and drawbacks- http://en.wikipedia.org/wiki/Sustainable_energy.

In the following we shall discuss only a few of these suggestions while confining ourselves to sustainable construction and the role of concrete.

Solar Chimney[10]

Though a number of alternative proposals have been forwarded 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 (see Figure No.6). Air is heated in a very large circular greenhouse-like structure 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

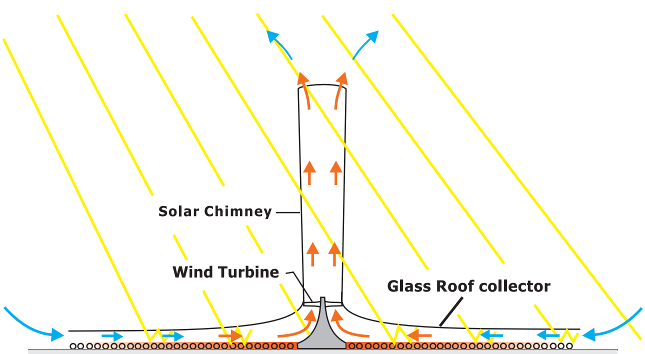

Figure No. 6 Principle and Prototype of the 195 m high solar chimney (50kW power plant) at Manzanares, Spain, which was in operation between 1982 and 1989.

power plant provides an enormous amount of energy without any ecological breakdown (note that poor countries cannot afford environmental protection), without safety hazards (unlike nuclear power plants) and without a rapid 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.

In case of sufficient availability of concrete aggregate materials in the area and if 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 whose construction would be particularly reasonable in terms of costs.

Green buildings

A green/ sustainable building design is one that achieves high performance over the full life-cycle, in the following areas[11]:

1 Minimizing natural resource consumption through more efficient utilization of non-renewable natural resources, land, water and construction materials, including utilization of renewable energy resources to achieve net zero energy consumption.

2 Minimizing emissions that negatively impact our indoor environment and the atmosphere of our planet, especially those related to indoor air quality, greenhouse gases, global warming, particulates or acid rain.

3 Minimizing discharge of solid waste and liquid effluents, including demolition and occupant waste, sewer and storm water and the associated infrastructure required to accommodate removal.

4 Minimal negative impact on site ecosystems.

5 Maximum quality of indoor environment, including air quality, thermal regime, illumination, acoustics/noise and visual aspects to provide comfortable human physiological and psychological perceptions.

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

From 1994 to 2006, LEED grew from one standard for new construction to a comprehensive system of six inter-related standards covering all aspects of the development and construction process[2]. LEED-NC 2.2, issued in 2005, is

Figure No. 7 Two LEED Certified concrete buildings: (a) The 41-store reinforced concrete office tower at Atlanta, (b) CII – Sohrabji Godrej Green Business Centre, Hyderabad, India

structured with seven pre-requisites and a maximum of 69 points divided into the following 6 major categories: energy and atmosphere (17 maximum points), indoor environmental quality (15 points), sustainable sites (14 points), materials and resources (13 points), water efficiency (5 points) and innovation and design process (5 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 print) and a significant reduction of GHG (green-house gases) beyond a baseline level[2].

Figure No. 7(a) displays the 41-storey, 62,245 sq. m. reinforced concrete office tower, located in the heart of midtown Atlanta, USA, (1180 Peachtree) 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 No. 7(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 26 required) towards a LEED Certified building[12].

Green buildings adopt various strategies for water management: using low flow or ultra-low flow plumbing fixtures, electronic controls and fixtures, substitution of alternative water sources (rainwater, reclaimed water and gray water) for potable water, rainwater harvesting, xeriscaping and use of other technologies and approaches that result in reduction of potable water consumption[2]. It is interesting to note that compulsory rainwater harvesting adopted in Chennai, a few years ago, resulted in increased water table.

Intelligent Buildings

An intelligent or smart building is one that uses technology and processes to create space that is safer and more productive for its occupants and more operationally efficient for its owners. In such a building, a network of electronic devices monitor 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 temperatures. 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 levels. Intelligent buildings also have alarm capabilities. While 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.

Amongst the earliest intelligent buildings in India is the India Habitat Centre in New Delhi. The Engineering Design and Research Centre (EDRC) of Larsen & Toubro Engineering Construction and Contracts 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.

Economic benefits of using green and intelligent technology requires a deeper study. Financial considerations are important: while builders and project promoters look for low initial costs, 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 endeavour, the built environment has direct, complex and long lasting impacts on the biosphere. Nearly one-tenth of the global economy is devoted to construction and about one half of the 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% of USA's GDP and 40% of extracted material); residential and commercial buildings together use one-third of all energy and two-thirds of all electricity consumed in the country. They also account for 47% of sulphur dioxide emissions, 22% of nitrogen oxide emissions, and 10% of particulate emissions, all of which damage air quality[13]. Further, buildings produce 35% of the country's carbon dioxide emissions - the chief pollutant blamed for climate change. Indoor air quality is inadequate in 30% 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% is demolition waste. This waste has to be transported, thus consuming more energy and pollution (Transportation consumes about 40% 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 construction practices.

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 solutions that achieve an optimal balance between three relevant and competing criteria, namely[14]:

(i) engineering performance (e.g. safety, serviceability and durability);
(ii) economic performance (minimum life cycle costs, minimum user costs);
(iii) environmental performance (minimum greenhouse gas emissions, reduced materials consumption, energy efficiency, etc.).

The first two criteria are not new to the 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[15]. Sustainable design has to consider three major aspects of sustainability: social, economic and environmental (see Figure No. 8)

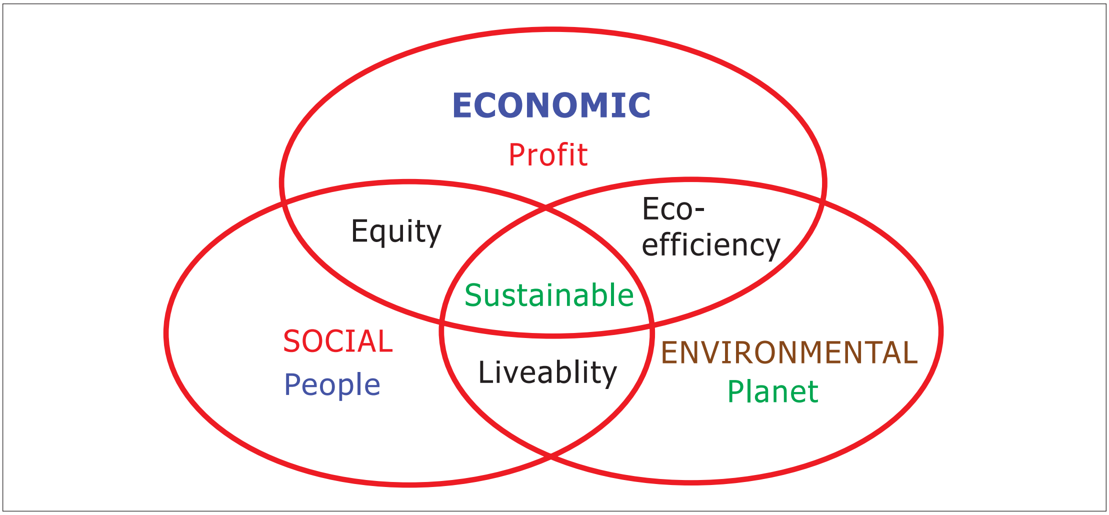

Figure No. 8 Three Pillars of Sustainability: Economic, Social and Environmental

The following are the design considerations for a sustainable building design[2]:

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 buildings life- cycle from design through re-use or demolition.

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 stages of the project.

Concrete- A sustainable material

The task of selecting building materials and products for a high performance green building is the most difficult and challenging task for any design team. Several tools are available for this process and one of the best tools is the life-cycle assessment (LCA). LCA provides information about the resources, emissions and other impacts resulting from the life-cycle of material use from extraction to disposal. Hence one must consider the impact of the material from extraction to disposal (Figure No.9). One such LCA program is BEES-**B**uilding for **E**nvironmental and **E**conomic **S**ustainability software[16]. Ideally the material cycle should be close-looped and waste-free. Thus the following rules apply while selecting the materials:

1 They should consume least energy to manufacture.

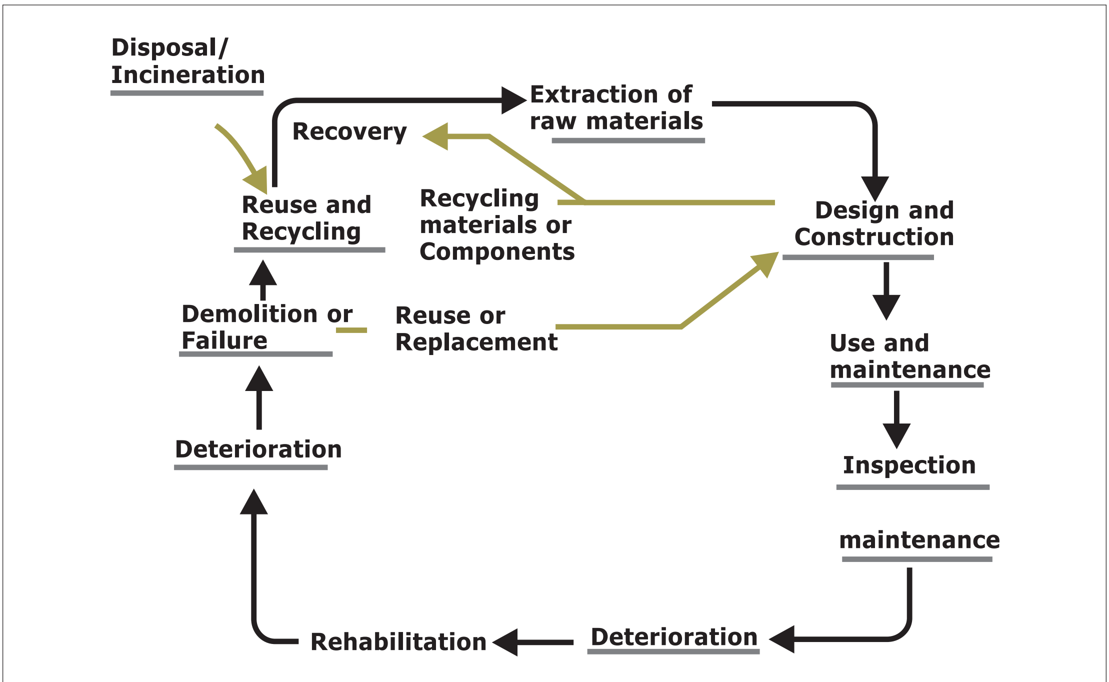

Figure No. 9 Life cycle assessment of building materials

2 They should not involve long distance transportation (for the raw materials as well as finished product).

3 The natural resources and raw materials used should not affect the environment.

4 They must be easy to re-cycle and safe to dispose in landfills.

5 Materials should be harmless in production and use.

6 Materials dissipated from re-cycling must be harmless.

7 They should have long life and durability.

8 Buildings must be deconstructible.

9 Building components must be easy to disassemble.

It may be difficult to identify a material that obeys all the above rules. Especially the last rule of disassembly has not been considered in traditional building materials, except pre-fabricated steel structures. Disassembly also discourages the use of composite materials[17].

Several materials are used in the construction of modern day buildings. We shall limit our discussion only to concrete. Concrete is the primary construction material in the world and its use is expected to double in the next thirty years. Concrete is used only second to water on a volume consumption basis. Two tonnes of concrete are used globally, per person, per year. Cement is the main component of concrete. The world cement production was evaluated at 2 billion tonnes annually in 2004 and it has been estimated that it would reach 7.5 billion tonnes annually by the year 2050. Concrete has many positive qualities: high strength, thermal mass, high reflectance, locally made, can be used with interior/or exterior finishes, does not affect interior air quality, readily cleanable, impervious to insect damage, fire resistant, fairly durable and cost-effective. In addition, concrete provides heat storage capacity and chemical inertness. Concrete can also be designed to be pervious and hence can be used as a paving material, allowing rain water to percolate into the ground.

The largest environmental impact of the concrete industry comes from the cement manufacturing process that leads to relatively considerable greenhouse gas emissions, which in turn are the main factors responsible for climate change. Approximately 0.7 to 0.95 tonnes of CO_2 are produced for every tonne of cement manufactured, depending on plant efficiency. The world's yearly cement production of 1.6 billion tonnes accounts for about 7% of the world CO_2 emissions into the atmosphere. However, during the life-cycle of concrete, it re-absorbs about 20% of the CO_2, thus partially mitigating the effect during manufacturing. Producing 1 tonne of cement requires about 4 GJ of energy[18].

Remarkable improvements have been made in cement plants, reducing the head energy required for cement production (about 50% between 1960 -1989) and replacing part of coal used in the burning process with other wastes such as used tyres, sewage pellets, refuse-derived fuels, etc. Dust emission during cement production has also been substantially reduced over the years.

In addition, cement production requires mining large quantities of raw materials such as limestone and clay, fuels such as coal resulting in deforestation and loss of top-soil. Concrete industry also uses large amounts of potable water for washing aggregates, mixing and for curing. Typical concrete mixes contain 12-15% cement and 75-80% aggregates by mass. Globally, sand, gravel or crushed rock is used at the rate of 10-11 billion tonnes every year. Admixture ingredients in concrete generally comprise only a tiny percentage of concrete weight. These admixtures are mildly poisonous in their dosage stage and become harmless once bound into hydration products. Production of one tonne of concrete requires about 0.4 GJ of energy.

Minimizing the quantity of cement in a concrete mix has many potential benefits. Thus the use of industrial by-products such as fly ash, blast furnace slag and silica fume as cementitious materials in concrete structures can lead to significant reductions in the amount of cement needed to make concrete and hence reduce emissions of CO_2 and consumption of energy and raw materials as well as reduced landfill/disposal burdens (India produces over 270 million tonnes of fly ash per year, which is harmful and difficult to dispose). Fly ash can be readily substituted for over 30% of cement volume; blast furnace slag for more than 35%. High volume fly ash (HVFA) concretes with 50-70% of cementitious content have been studied extensively and found to be feasible in certain situations[19]. Fly ash and blast furnace slag can also be blended with cement in the cement manufacturing process, resulting in reduced CO_2 emissions, reduced energy consumption, and expanded production capacity. Use of these products is generally accomplished with beneficial improvements in the properties of both fresh and hardened concrete. In India, the proportion of blended cement to total cement produced increased from 32.58% in 1999 to about 56% in 2005 and is likely to increase further. However while using concretes with cementitious materials, prime importance has to be given to curing, as these concretes require more curing time to develop the required strength.

Increasing the service life of concrete structures from the present 50 years to 100-150 years and enhancing the long-term durability is one of the best solutions to improve sustainability[18]. Use of Ready Mixed Concrete can also help in obtaining quality concrete which will increase the durability and life of concrete structures. Modern concretes such as fibrous concrete, geo-polymer concrete, high-performance concrete, reactive powder concrete, self-compacting concrete, self-curing concrete, etc. not only enhance the properties of concrete but also increase the life of structures constructed, using them.

The re-cycling properties of concrete are generally satisfactory. Crushed concrete waste has been successfully used as sub-base for roads, side walks and parking lots. It has been found that up to 30% re-cycled coarse aggregates can be used in concretes having strength up to 30 MPa, without any modification in the mix design and with performance similar to natural aggregate concrete[20-22]. In many European countries, as well in the USA, methods have been developed to improve quality control of re-cycled aggregates to suit individual circumstances[23]. In the Netherlands and Belgium about 80-90% of aggregates used in concrete are from re-cycled waste. Re-cycling concrete not only conserves resources but also saves land fill space. Use of manufactured sand, dredged sand and mining wastes in place of river sand is also environment friendly options. Several other by-products have also been successfully used with concrete. These include: used foundry sand and cupola slag from metal-casting industries, post consumer glass, wood ash from pulp mills, saw mills and wood product manufacturing industries, sludge from primary clarifiers at paper mills and de-inking solids from paper-recycling companies[24].

For concrete structures to be really sustainable, we should adopt a holistic approach to the design based on the principle - *strength through durability*' rather than '*durability through strength*'[25].

Summary and Conclusions

Our planet Earth is at peril due to a number of factors which include: population explosion, urbanization, 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 are discussed. The construction industry consumes 40% of the total energy and about one half of the 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 measures are adopted to bring these green buildings within affordability of the common man we cannot attain full sustainability.

A truly green building should be energy efficient, incorporate concrete that contains the least amount of Portland cement and use large volumes of supplementary cementitious materials and recycled aggregates.

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