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Sustainable Development of High-Rise Building using Bioinspiration Concept

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Abstract: ***This paper examines Buildings is the main destination for the nation's control provisions. High-rise buildings due to their huge range require much more resources for their structure compared to low-rises. In addition, they use more power and emit greenhouse gasses; as a consequence, they have main environmental impacts. Therefore, high rises seem to be no sustainable. With increasing popularity of high rises, achieving a towering stage of sustainability has turn into the leading theme of the architectural designs. Hence, the efforts for combining technology and biology are largely these days. Bioinspiration is a concept that talks about the ideas inspired by natural history and it has been obtainable as an best solution for the conflicts between scenery and person behavior. As it said, nature is an excellent and the final response to the problem of sustainability. Therefore, architects have employed bioinspiration move toward in their designs to reduce buildings unhelpful impacts on the surroundings and reach overall architectural sustainability. This paper studies different approaches and levels of bioinspiration and discusses their application in high-rise buildings. It is shown that employing different principles of bioinspiration may result in diverse outcomes in terms of tall buildings sustainability***

Keywords: Bioinspiration, integration, sustainable architecture, tall buildings, technology transfer

1. Introduction

It is projected that by 2030, 5 billion people will live in urban areas throughout the world (United Nations, 2001). Whereas 30 per cent of the world population lived in urban areas in 1950, the proportion of urban dwellers climbed to 47 per cent in 2000 and is projected to rise to 60 per cent by 2030. Energy shortage, global warming, urban sprawl, air pollution, overflowing landfills, water shortage, disease, and global conflict will be the legacy of the twenty-first century unless we move quickly towards the notion and implementation of sustainability. Survival of the human race depends upon the survival of the cities--their built environment and the urban infrastructure. This will warrant vision, commitment, and action through partnership and commitment of governments, policy makers, experts, and the involvement of citizens. It will require collaboration of urban planners, architects, engineers, politicians, academics, and community groups.

Sustainable Architecture

In 1983, the UN established the World Commission on Environment and Development in an attempt to resolve the conflicts arising out of the aspirations of the developed and developing worlds. In 1989 they published “Our Common Future” or the Brundtland Report (WCED, 1989), which launched the concept of “sustainable development” and was reinforced in 1992 at Earth Summit in Rio. It called for Development which meets the needs of the present generation without compromising the ability of future generations to meet their own needs.” Sustainable architecture is environmentally conscious, energy-saving, and utilizes responsive and renewable materials and systems (Newman, 2001). Ecological and environmental concerns have expanded beyond the issue of the consumption of non-renewable energy sources. Sustainability essentially aims for ecological balance.

The High Performance Tall Building: Environmental awareness extends to both the urban environment and the context in which a tall building is placed as well as its interior environment. The issues of outdoor microclimate and indoor air quality as well as the potential toxicity of materials and chemicals used in building components, systems, and furnishings are also of concern to the building users. In a broad sense the term “green” is often used for a sustainable, which essentially describes design, construction and maintenance practices that minimize or eliminate the negative impact of a building on the environment and on the users.

Tall buildings are massive consumers of energy. They are the dominant elements in urban architecture due to their scale and purpose, and should be the focus of sustainable design. A high performance tall building is one that achieves the peak efficiency of building functions while meeting the requirements of optimum performance employing green technologies. These technologies and innovations offer radical changes to the built environments in terms of energy usage, structural performance, and environmental effects. In other words, a high performance tall building warrants an optimal approach to design for maximum sustainability. Designing a sustainable tall building, therefore, requires a 360-degree view of the entire building enterprise considering the local and global environment, the availability of renewable and non-renewable resources, community impact assessment, and the collaborative input of architects, planners, engineers, social scientists, behavioral scientists, and other community-based groups. Clearly, the design process is significantly complex since the designer has to understand the building performance in terms of different design factors and variables and under differing conditions. Some overall benefits of high performance design are: energy efficiency, design flexibility, resource conservation, indoor environmental quality, etc. (Donaldson and Lippe, 2000).

The Design Factors

The principal design factors that are crucial for achieving a high performance tall building are site context, environment, structure and use of materials, energy consumption, use of water, ecological balance, community development, etc. Because of these diverse aspects of design for tall buildings which have enormous scales as a building type, the amount of information that guides the design is often very complex, and shared by professionals of different disciplines. Further, the design factors assume different forms, such as conceptual, schematic, physical, economic, environmental, and socio-cultural. This demands smart design and integration, which hold the key to high performance buildings. The design team comprising different professionals must aim for the common goal set early on that "the building will offer optimum performance" and must have a respect and understanding for each other's mission. This goal must have clarity and be performance oriented, attainable, and mostly measurable.

For high performance buildings, the full integration of architecture and engineering is crucial. A well integrated high performance building may incur a slightly higher cost than a regular one which is however offset by lower operational cost (Ali and Armstrong, 2006).

An integrated process is necessary because of their scale and the fact that green design affects so many different elements of a building, such as daylighting, which in turn concerns siting, orientation, building form, facade design, floor-to-floor heights, interior finishes, electric lighting controls, and cooling loads, among other things. A green or vegetated roof, with its impact on storm water runoff, building structure and form, thermal insulation, and plantings, is another example where integration must be considered (Malin, 2006).

Integration among the hardware components of building systems is approached with three distinct goals: Components have to share space, their arrangement has to be aesthetically resolved, and at some level they have to work together or at least not conflict with each other (Bachman, 2003). Bachman lists three types of *integration*: physical integration, how components share space or fit together; visual integration, how they achieve visual harmony; and performance integration, how they share functions with other components and systems. The Hong Kong and Shanghai Bank Building, designed by Foster and Partners, in Hong Kong is an example where the visual expression of the physical systems and components of the building creates a powerful aesthetic impact.

Integration Web: The Tall Building System Integration Web (*see Figure 1*) is a tool to assist architects and engineers in the decision-making process at critical stages by clearly defining the relationships of all physical systems and subsystems of a tall building (Ali and Armstrong, 2006). While all buildings require integration, sustainable tall buildings require a greater level of integration at the early stages of the design process because they require coordination of complex, interdependent systems. However, over-emphasizing integration at the conceptual phase of a project can also be a drawback especially when considering LEED (Leadership in Energy and Environmental Design) credits. The checklist of LEED points can be helpful in identifying measures to pursue, many of which benefit from an integrated approach. But focusing on individual credits too early in the design process can also get in the way of design integration producing a point-chasing mentality, which drives up project expenses by causing people to forget how the points work together. During initial meetings, it is more useful for a team to focus on sustainable goals and opportunities on a broader level (Malin, 2006).

Technology Transfer

Technology transfer" refers to the process whereby the techniques and materials developed in one creative field, industry, or culture are adapted to serve another (Pawley, 1990). It is a synergistic process through which the research and development effort of the donor field is exploited in order to lighten the cost-burden of the pre-production phase of the receptor field. One example that has been applied to building construction is the automatic assembly line, which originated in the automobile industry, where building a complex mechanism in large numbers and on a scale that required robotics and machine production methods (Giedion, 1948). Like buildings, it required the coordination of machines, materials, and labor in interdependent processes regulated by time. New developments in aeronautical engineering, production and assembly methods, and new materials often find their way to the building construction industry. The design of a jumbo jet, for example, can be compared to a building in terms of scale, integration of complex systems and intelligent technology, structural engineering to resist wind loads and create an efficient, aerodynamic design, and the development of new materials to increase strength and reduce weight and drag. Like tall buildings, aircraft are self-contained environments with their own micro-climates. Because they often fly at high altitudes, their interiors must be pressurized to withstand external air pressures and to maintain comfortable pressure levels within for occupants to maintain proper sensory response. Like a tall building, they are designed and assembled on a large scale, which requires careful planning, coordination, and integration of complex systems. This integration begins at the earliest stages of design to avoid costly mistakes during fabrication and assembly. Composite materials have been developed for fuselages to increase strength and reduce weight. Carbon fiber is light-weight material that can be laminated to produce an extremely strong cladding material for the exterior surfaces of jumbo jets. The manufacturing process of carbon fiber is very expensive, however, and involves nano-scale technology. Hence, there is only one major manufacturer of carbon fiber materials in the world today. The aircraft industry has recently used carbon fiber reinforced composite material for the latest 787 jumbo jets. Although carbon fiber composite materials have not been widely used in tall buildings to date, they hold great promise in reducing the weight and mass and increasing the structural strength of columns, girders, trusses, and beams of supertall buildings in the future. A 40-story multi-use carbon tower," designed by architect Peter Testa, has been proposed as a visionary project (Beedle *et al.*, 2007).

Building Management Systems

Innovative building technologies such as computer-based smart or intelligent building systems can play a major role in managing the energy usage. The increasing reliance on computer technology and automated systems can be directed toward achieving a sustainable functioning of skyscrapers. The Building Management System (BMS) is a centralized control system to manage the operations of the various building systems such as fire protection, security, communication networks, elevators, HVAC systems, etc. The environmental data collection and control system is usually incorporated within the BMS which can also be used to control more passive features like opening windows and shading devices. The component of the BMS that deals with energy-related services is controlled by the Building Energy Management System (BEMS), also known as the Energy Management and Control System (EMCS), which may in some circumstances function autonomously. The control system need not be located on-site and the supervision of the system can be centrally for multiple building complexes or for a number of similar buildings in outlying areas.

Energy Performance

Although a tall building may be designed to be sustainable and energy efficient, it's actual performance in this regard needs to be assessed and verified. Computer software packages for assessment methods are developed and constantly upgraded to offer designers a tool for determining the energy performance and lifecycle costs for the buildings they design. Extensive research is needed to measure the performance of sustainable tall buildings that were recently built. While this seems to be a straightforward task that may merely involve collection of data on year-round energy usage on a global scale for a building, the challenge lies in finding out the relative energy consumption for different systems, such as mechanical and HVAC, lighting, computing, elevators, etc. The utility companies keep track of the total energy consumed and not the energy consumed by each system in a building. Being aware of the breakdown of energy demand of a building in terms of its systems will enable designers to design the building in a more efficient manner. Another area of research will be the development of strategies for making recently built tall buildings sustainable. This obviously is a much bigger challenge since it involves remodeling and reconstruction.

2. Literature Survey

A new generation of sustainable tall buildings is challenging conventional high-rise building practices and setting trends for future projects incorporating innovations in materials and intelligent building systems.

Menara Mesiniaga: Ken Yeang and T. R. Hamzah were among the first architects to apply ecological principles to their "bioclimatic skyscrapers." The Menara Mesiniaga in Subang, Malaysia, designed in 1992, presents an early model building for the physical translation of ecological principles into high-rise architecture (Abel, 2003).

Swiss Reinsurance Headquarters:
Foster and Partners developed new technological, urban planning, and ecological design concepts in the Swiss Reinsurance Headquarters building constructed in 2004 in London. The steel spiral "diagrid" structure creates an aerodynamic form that provides the lowest resistance to wind and diminishes demands on the load-bearing structure, as well as the danger of strong downward winds in the area around the building. The office spaces are arranged around a central core with elevators, side rooms, and fire escapes. The net-like steel construction of the load-bearing structure lies directly behind the glass facade and allows support-free spaces right up to the core.

Conde Nast Building: The Conde Nast Building at 4 Times Square of 1999 in New York City is a 48-story office tower, is the centerpiece of the 42nd Street Master Plan prepared by the 42nd Street Development Corporation, a public/private consortium created to promote the redevelopment of this traditional heart of Manhattan (Wired New York, 2007). Designed by Fox & Fowle Partners, many of its innovations are considered standard for office buildings today.

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The Solaire: Located at Battery Park in New York City, the Solaire is the first residential high-rise building in the U.S. to integrate green features in a comprehensive way (Carey, 2006). It is a 27-story, 293-unit luxury apartment building located on the Hudson River developed by the Albanese Organization and designed by Cesar Pelli & Associates. Its sustainable features include PV panels incorporated into the building's facade, a planted roof garden, and fully operational blackwater treatment system. It is based on guidelines developed by the Battery Park City Authority, which address five areas of concern: 1) Enhanced indoor air quality; 2) Water conservation and purification; 3) Energy efficiency; 4) Recycling construction waste and The use of recycled building materials; and 5) Commissioning to ensure building performance (Carey, 2006).

The Pearl River Tower: The Pearl River Tower is a 990-foot (300-meter) tall "net-zero energy" mixed-use building, which will be completed in 2010 in Guangzhou, China. Designed by Adrian Smith and Skidmore, Owings & Merrill, it has a curved glass facade that directs air flow through narrow openings in the facade that will drive large, stainless steel wind turbines to generate electrical energy. The building's aerodynamic shape, which resembles airplane wings turned vertically, was developed in collaboration with Rowan Williams Davis & Irwin, Inc. of Ontario, Canada using the RWDI-Skin suite of proprietary analysis tools, including its Virtual wind simulation modeling (RWDI Group, 2007).

3. Implementation

Increase sustainability

Built environment is held responsible for environmental and social problems like excessive waste production, energy, and material use and greenhouse gas emission attributed to the habitats humans have created for themselves. With this rapid development of urban construction, a mechanism should be applied to reduce these harmful effects. Bio mimicry suggests innovative and eco-friendly approaches that can provide compatible and flexible solutions. Any organism in nature avoids excesses and overbuilding, attains maximum efficiency with minimum material and energy. Nature recycles everything and finds a use for everything, adapts itself to local conditions, runs on the sun and other natural sources of energy, and uses only the energy and resources that it needs. Bio mimicry provides a wide range of solutions for structural efficiency, water efficiency, zero-waste systems, thermal environment, and energy supply, which are essential for any sustainable building design. Nature itself is a great mentor for living in harmony with it, for instance, we can learn from plants that how they make use of air pollution and convert carbon dioxide into oxygen. Considering bio mimicry levels (organism, behaviour and ecosystem), mimicking an organism alone without mimicking how it is able to take part in the larger context of the ecosystem it is in, has the possibility to produce designs without environmental impact. Because mimicking organisms is just a specific feature, for instance, designing a building in the form of cacti (simple shape imitation) may not increase building overall sustainability. In behaviour level bio mimicry, the behaviour of the organism is mimicked. In this level, designers have to figure out if the organism behaviour is suitable for human beings to imitate, and which part its behaviour will increase building sustainability. For example, mimicking the building behaviour (and outcome of that) of termites might be appropriate for the creation of passively regulated thermally comfortable buildings. Mimicking the social structure of termite colonies would not be suitable however if universal human rights are valued. Ecosystem level bio mimicry has the advantage of being used along with other levels of bio mimicry (organism and behaviour). It can also be used in different temporal and spatial scales. This approach has the potential to be used in two metaphoric and practical levels. Designers with little ecological knowledge can apply metaphoric level in their design, but still there is a chance of increasing building sustainability as said. On the contrary, profound understanding of ecology and biology is required for using ecosystem bio mimicry in practical level so this makes it difficult for the architects to use this complex level of bio mimicry.

High-rise Buildings

Tall or high-rise building is a type of building with a small footprint and roof area in comparison with its huge façade surface. Tall buildings construction is the result of the scarcity of land and the urban population growth.

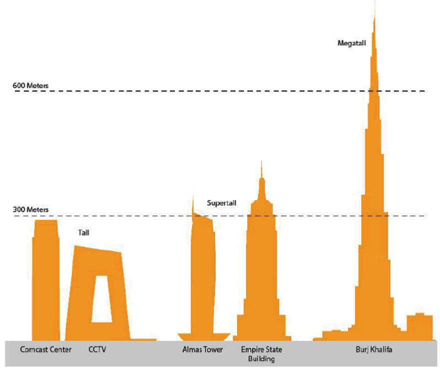

Figure 2: Classification of buildings based on height [16].

Tall buildings with the average height of 50 to 300 meters. This building type constitutes 90% of the total tall buildings worldwide.

Supertall buildings with the average height of 300 to 600 meters. This building type constitutes 10% of the total tall buildings.
Megatall buildings with the average height of 50 to 300 meters. This building type constitutes 0.05% of the total tall buildings around the world.

Living in tall buildings has its own advantages. It can offer accommodation for a wide range of people close to their workplace that causes fewer work trips and less fuel consumption. The modern high-rises provide amenities such as shopping centres, pools, gyms, and public spaces for social interaction so that residents do not need to find other places for these activities. Residents of upper floors often enjoy the pleasant view. On the other hand, there are disadvantages that may cause people resistance to live in high-rises. Some people feel isolated from the surroundings in tall buildings. Although there might be private balconies for each floor, they are not functional most of the time either for their small size or for strong winds. Living adjacent to many strange neighbours might be difficult and sometimes troublesome.

Increase Sustainability of tall Buildings

High rises are an unavoidable part of our modern world. The necessity of tall buildings is increasing as a result of land scarcity and its rising prices. Because of tall buildings' large scale and high consumption of energy and materials, their sustainability is more crucial than any other types of building. Buildings are responsible for nearly half of CO2 emissions and they consume nearly half of all the energy produced. The energy consumption is increasingly growing all over the world. The environmental impact of energy production and consumption has become a main concern. Therefore, the efficient use of energy in the building sector is essential. Despite the disadvantages mentioned, construction of high-rise buildings is a necessity because of optimum use of the land and sometimes the need for an urban landmark. Solving environmental, socio-cultural, and economic problems that these high-rise buildings impose, leads the architects towards bio mimicry architecture with a sustainable approach. Because nature does everything on time and there is no waste in it, all organisms are looking for more efficiency and less energy and material use. Therefore, nature is a flawless model for sustainable engineering. Nature is an inspiration for the creative and smart engineering. Thus, we can decrease tall buildings environmental impact by getting inspiration from nature provided bio mimicry principles being incorporated into the design in the early design stage (not just added).

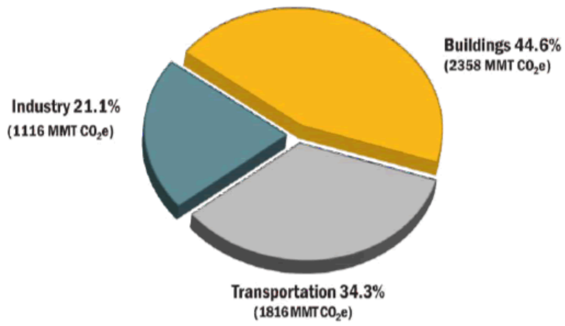

Figure 3: U.S. CO_2 emissions by Sector (Why the building sector, n.d) [21].

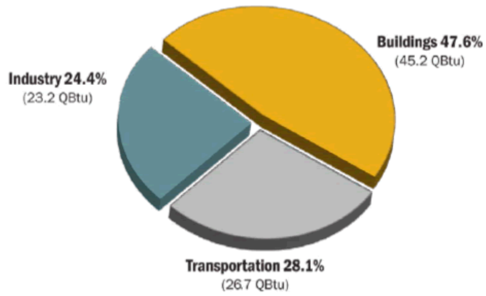

Figure 4: U.S. Energy Consumption by Sector (Why the building sector, n.d) [21].

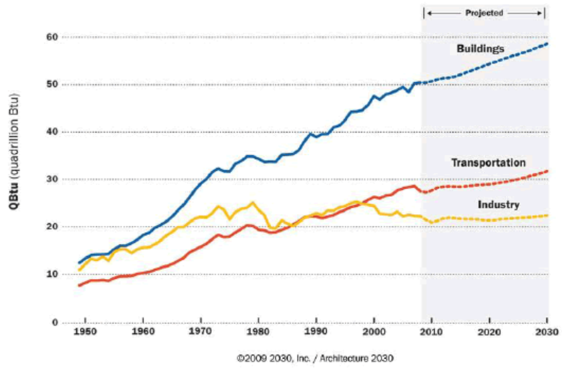

Figure 5: U.S. Energy Consumption ("U.S. Energy Information Administration", n.d) [22].

4. Conclusion

Bioinspiration is emulating nature's strategies to solve problems that humans face nowadays. One of the major problems of the modern world is to promoting sustainability in building sector because of growing number of high-rises and their high energy consumption and negative environmental impact. The study of three tall buildings shows how various approaches and levels of bioinspiration (that are discussed in this paper) can be applied to tall building design. Buildings become more efficient and sustainable when the bioinspiration principles are applied. However, the impacts depend on the level of bioinspiration that is mimicked. Overall sustainability of the buildings increased when the organism behavior or process is imitated rather than a simple imitation of the shape. As we can see in DNA Towers the inspiration that is just at the organism level and shape imitation, slightly increased the level of sustainability. On contrary, MMA Office Building reached the satisfactory level of sustainability through using bioinspiration; both organism and behavior level. In addition, Pearl River Tower employs an organism based bioinspiration and behavior level that substantially enhanced the tower's sustainability. All studied buildings in this paper are based on design looking to biology (problem-based) approach; as most of the architectural designs that employed bioinspiration. It can be inferred that solution based design needs in depth understanding of biology and close collaboration of architects, biologists, and ecologists. Therefore, it is much less frequent in architecture. However, transferring biological principles into human design needs the knowledge of biology and bioinspiration principles in order to boost the sustainability level of buildings. These principles should be incorporated into the design in the early design stage (not just added) to have a major impact on architectural sustainability.

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