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Why Tall Buildings? The Potential of Sustainable Technologies in Tall Buildings

Abdel Rahman Elbakheit†

College of Architecture and Planning, King Saud University, Riyadh-11574, P.O. Box 57448, Kingdom of Saudi Arabia

Abstract

This paper discusses major strengths of tall buildings that distinguish them as sustainable solutions for the built environment. It sheds light on some of the key attributes of tall buildings as well as materials and technologies that could boost their performance environmentally, economically and technically as well as the natural habitats containing them. Tall buildings are portrait as major successful options for accommodating the ever increasing urban world population, with little negative impact on ecologies and environmental habitats worldwide. The role of tall buildings as 'vertical garden sub-cities' mitigating modern city problems of 'urban heat islands' and sprawling cities is explored. A few building examples as well as city developments are presented which represent the new generation of sustainable tall buildings that are setting trends for future projects incorporating innovations in materials and building systems and designs.

Keywords: Tall Buildings, Sustainable Architectural designs, Integration and optimization of building systems

1. Introduction

The history of tall buildings in north-America from the late nineteenth century reveals that buildings are a reflection of the knowledge, technology as well as the needs of their era (Ali and Armstrong, 2008). Unlike other building types, tall buildings had evolved very rapidly in adopting the ever increasing technical solutions that are in many ways very essential for their existence as well as operation (i.e., mechanical and electrical lifts, HVAC systems, lighting, etc. Obviously, this had developed gradually by realizing the possibilities of structural solutions for high-rise buildings first (Khan, 1974) then came the other services. In addition to this and Due to the size of tall buildings, they are by far having the greatest energy demand and consumption. Buildings in general consume the greatest share of energy and carbon emissions. With the residential sector have over 60% and 7% for commercial sector. Whereas as per square meter consumption commercial buildings consume greater energy than residential (Yeang, 1999). Therefore trying to reduce energy use per square meter in high rise buildings would lead to proper control of energy and provide bench marking for improvement in performance. According to M.M. Ali and P.G. Armstrong, a rate of less than 150-250 KWh/meter square per year would be acceptable for full mode HVAC high rise in temperate or equatorial regions.

†Corresponding author: Abdel Rahman Elbakheit
Tel: +00966-1-469-6603
E-mail: Abdel.Elbakheit@hotmail.com

2. Sustainable Building Design:

Recent developments in the sustainable architectural building design have been attributed mainly to efforts of various engineering and scientific attributions. Whereas the delivery of sustainable architecture where building design forms the basic fundamental components, has been undertaken by architects for decades if not century's through vernacular architecture and passive architectural systems. These two distinct trends are manifested in what we can call smart buildings, intelligent buildings, energy efficient and sustainable buildings for the former trend and green architecture, sustainable architecture or passive driven architecture for the later.

High-rise building can make benefit of both approaches, with more emphasis on the former trend. Since it depends mostly on system solutions in structural, mechanical, electrical, transportation, natural lighting, ventilation and façade design. Having said that, the ingenuity of the sustainable architectural design would be expressed in striking the balance between systems drawn from shared attributes and the spatial relations drawn from functional, social or economic requirements. Such comprehensive design solutions can be seen from Fosters' design of the Commerz bank in Frankfurt, where vertical means of circulation, structures and natural ventilation, day-lighting and air conditioning are incorporated in a central core forming an atrium. The plan having a triangular shape, accommodating two office halls and the third closing side is an on-floor garden alternating every ninth floor. Façade curtain walls provide maximum daylight from all around the building as well as from the central atrium. Supply

natural ventilation is also drawn through the double skin façade with heat recovery to exhaust air. These measures resulted in high efficiency in energy use and lowered the operating costs considerably. Some other tall buildings also adopted this notion of the 'vertical garden' as in the National commercial bank in Jeddah designed by Gordon Bunshaft of SOM architects. Further future success of tall buildings could rely on mixed-used development for residence, work, commercial and leisure incorporating the vertical garden sub-cities.

3. Strategies of Sustainable Design in High-Rise Buildings

No doubt that the corner stone of sustainability is to reduce or eliminate over exploitation of natural resources beyond the rate at which they can naturally regenerate. This obviously can be achieved through efficient use of resources and indeed energy is the most important here. A far better step is to rely on true sustainable sources of power and material, which can be attained from sun rays, wind power, geothermal power and so forth. Considering the first two options high-rise buildings provide very high potential with very large surface area that could be utilized to harness solar rays for heating, lighting, buoyancy cooling/ventilation and electricity generation (Elbakheit, 2008). Wind power with suitable collecting/converting devices on the other hand has very high potential due to the acceleration of wind profile with height in urban areas. Tall buildings by virtue of their height can benefit from high level of wind speeds in the mainstream of the atmospheric boundary layer. (Irwin et al., 2008) However, this high wind may also challenge the stability of the design and shape of tall buildings due to vertex shedding and oscillation of the building structure. Tall buildings response to wind can still be achieved through proper choice of forms, inertial frequencies, masses, and damping measures, Fig. 1. This can be achieved through thorough understanding of the potential and limitations of the technologies (Irwin, 2009), and the available resources of a given location. In fact this is an area of great potential to create and develop systems serving the main domains of functional, technical and socio-environmental needs or requirements as well as sustainability issues.

An example where wind structural loads analysis further enhanced the architectural solutions of form is Burj Dubai/Khalifa tower where the structural stability is achieved through a series of optimizations for (i.e., shape, Stiffness, mass and damping) as well as the architectural design requirements, (Adrian smith and Gordon Bill architects, 2008; Baker et al., 2008). Recently in CTBUH 2011, Y. Tamura has shown that tapering high rise buildings will result in better stability at the top of tall buildings, with reservations on some tall building plans.

Further examples for the socio-economic drives shaping high-rise building design can be experienced in some design proposals for Chonggae Canal, Seoul, Fig. 2.

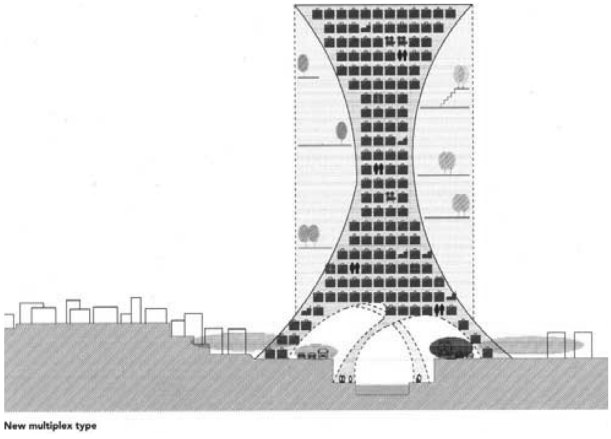


Figure 2. schematic proposal for Chonggae Canal were Multiplex buildings are proposed spanning the canal (Jacoby, 2007).



Figure 1. Building Forms to improve high rise stability, generate wind energy and maximize natural light from North elevations and energy Generation form Southern Facades (Dr. Abdel Rahman Elbakheit Tall Buildings' Studio., King Saud University 11-2012).

Derived by limited available land, developers vie to generate multiplex types (i.e., high-rise buildings based on culture and commerce) which are in a continuous state of redevelopment to create other forms of needed spaces within them such as leisure or the reincarnation due to new upgrades within existing activities. This notion for development of the canal is also accompanied by relinquished control of access in tall buildings that allow flow of the commercial areas for instance to occupy several levels as well as connecting to the street level.

4. Sustainable Systems within Buildings' Fabric

Many available building materials that have been newly developed to improve the environmental credentials' of buildings by reducing loads of heating/cooling, lighting or air conditioning could be used with better efficiencies in tall buildings as well as to other building types. However, this is particularly evident due to the cumulative nature of duplicated floors inherent in tall structures that would lead to increased savings, higher efficiencies and larger environmental benefits. Among the materials and technologies we find:

4.1. Innovative insulation materials

Newly developed insulation materials that can provide higher insulation value and therefore more energy conservation and less energy loss add positively to the green building performance. Some new insulation materials are transparent or semi-transparent with high insulation value so they can be used alone as a building material in walls. Due to their transparency they can provide a level of day lighting to the interior as well. Thus serving different functions in an energy efficient way.

4.2. Innovative glazing materials

Much advancement in glazing materials has been made, whether in improved thermal properties, in terms of U-values or visual properties in terms of self-tinted and self cleansing glazing. Generally glazing was one of the major drives for advancement in the building industry and to it many of the new concepts of building design are attributed. Furthermore, many of the passive architectural systems typical to masonry constructions such as stack effect and /or displacement ventilation can be enhanced with the addition of glazing such as in Atriums, glazed double/multiple facades, Sunspaces or conservatries. New glazing materials that are combined with photovoltaic

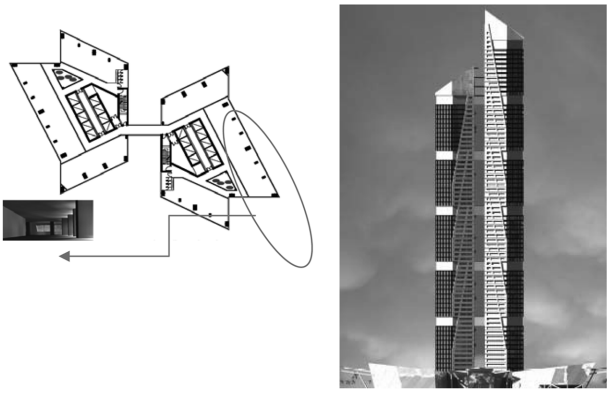


Figure 3(a). Office building natural lighting, open plan offices up, South façade for Natural Lighting and Energy Generation (Dr. Abdel Rahman Elbakheit Tall Buildings' Stu., King Saud University 11-2012).

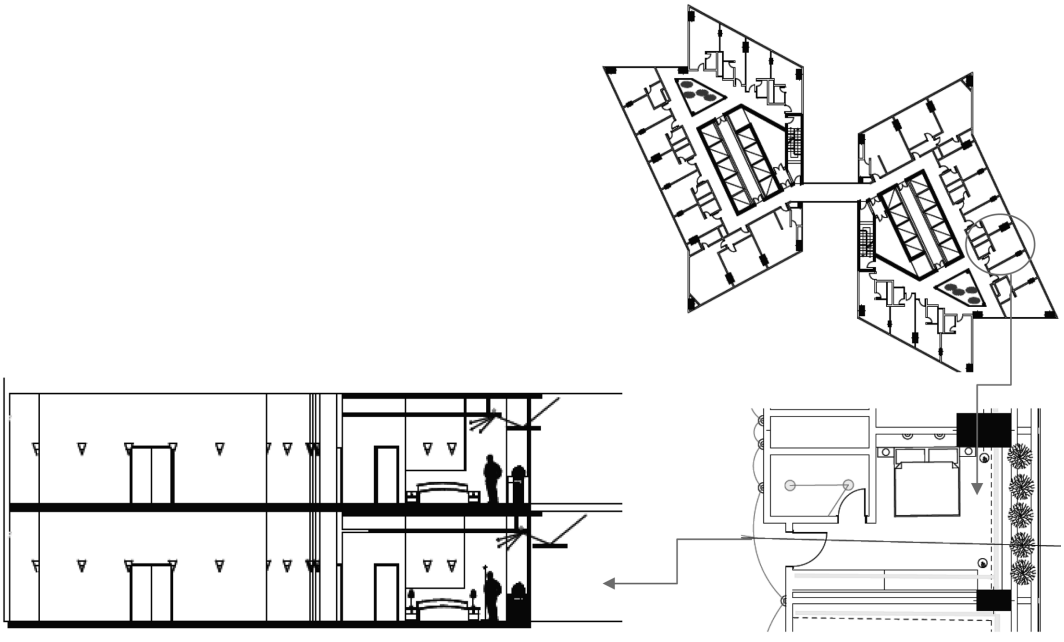


Figure 3(b). Hotel rooms natural lighting by Light shelves, Plans and Section (Dr. Abdel Rahman Elbakheit Tall Buildings' Stu., King Saud University 11-2012).

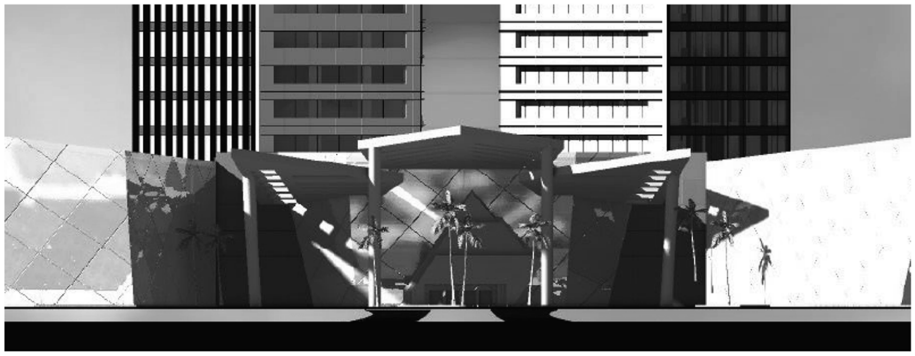


Figure 3(c). Hotel main Entrance View. (Dr. Abdel Rahman Elbakheit Tall Buildings' Stu., King Saud University 11-2012).

cells can acquire both glazing building component function and electricity generation.

4.3. Natural ventilation and day lighting

Natural ventilation is one of the key principles of green building design and its importance is emphasized when employed as a cooling principle in hot or cold climates. The need for fresh air in interior spaces normally gauged as air changes per hour according to a specific standard (i.e., CIBSE or ASHRE standards). However, natural ventilation as a cooling mechanism can be the major determinant for building design concepts either in cold or hot latitudes, The later being of higher importance or necessity. Buildings can be designed on a passive ventilation strategy that employs patterns of natural ventilation without the need for air conditioning. Many of vernacular architecture examples exist with features such as wind catchers, underground cooling, fountains, cross ventilation, internal courtyards and stack effect devices.

Day lighting on the other hand is a field which has also evolved very considerably in the few past decades. Many new devices such as light pipes and light shelves were invented to channel natural light deep into interiors, which are deprived from normal windows or means of natural light, Figs. 3(a), 3(b) and 3(c). These devices have high efficient reflecting surfaces that can transfer over 90% of the natural light through their enclosure to the place where it is needed.

4.4. Building facades

An example of how both passive architectural designs or systems and advanced technical systems can be amalgamated in buildings, is building envelopes. Building envelopes or more technically building facades are the first line of interaction of our buildings with the natural elements and therefore their design is greatly influenced by these elements. Hence, greater emphasis is drawn upon their design with the integration of both active and passive measures, which are increasingly growing trend to reduce energy consumption and contribute in energy generation. Here we will face energy conservation requirement, which normally means resort to tighter u-values of the building fabrics, accompanied with simple passive design measures. While exploiting the elements is usually intended towards harnessing the energy contained in them as a source of renewable energy. Increasingly and as a result of these concepts more trends on building facades emerged. This is manifested by designing facades that incorporate most of the building requirement for solar shading, heating, thermal insulation, cooling or even energy production. This is done through using several devices controlled through sensors and building management systems. Tall Buildings with large façade areas would be more favorable for adopting these technologies and more likely to have a large resource to be utilized or harnessed specially in energy production. (i.e., solar or wind energy).

4.5. Smart services and controls

One of the recent development in building automation services and networks is the development of monitoring



Figure 4. Endowment project of King Abdul-Aziz in Mecca, Saudi Arabia.

station for all building services. Although it is in its infancy (i.e., few manufacturing and providing companies for it), it has great potential for managing, controlling, optimizing and monitoring building services especially for Hugh developments and/or tall buildings. Furthermore, with the introduction of internet wireless communication it could be very easily to control all electric lighting for instance within the hole development to cope with the level of natural light available from a single station, which can even be at a very remote location. This is also true to other services, thus providing hugh cuts in initial costs for wiring for instance, as well as in operation, maintenance and monitoring costs, etc.. An example of such a building or development that incorporates smart services and combines both the size as well as the height (i.e., 550 m high) is the endowment project of King Abdul-Aziz in Mecca, Saudi-Arabia, Fig. 4. It's a development that consist of a large podium (i.e.,13-storey) topped by 7-towers with a total built up area of one million and a half square meter on less than 35000 meter square. It has 6-residential towers, a 5-stars hotel, a convention center, a shopping center and a multi-storey car park. All lighting fixtures, air-conditioning, telephone, TVs, and doors of rooms are controlled from a single monitoring station/board as well as billing. Thanks to an IP network that was the backbone for this installation.

5. Indices of Environmental Performance

In the past two decades, new building standards or regulations in many parts of the world have been adopted (i.e., LEED from the United states green building council USGBC, BREEM from the UK Building Research Establishment BRE, etc.) to gauge the physical properties of building materials against the environmental performance inside buildings and ultimately against the global environmental well being. These indices are based on typical code of compliant that defines the standard that need to be met for a given set of criteria. However, good they may be, according to Olgyay and Herdt 2004; they lack an ecological derived base line, as to what degree they affect the natural ecology they are erected in. These two researchers suggested a new system to gauge the ecological services criteria as an environmental assessment of the construction called 'index of building sustainability' (IBS) coupled with another gauging the efficiency of Operation of the building called index of efficiency sustainability (IES). One of the major advocated of this process is the design towards using limited land and therefore densification of the urban setting into high-rise buildings. Thus choosing to build high-rise becomes the sustainable option to limit land exploitation.

This notion of concentration of development into high-rise buildings may find a further reinforcement when considering other concerns within the micro-climates of urban terrain known as Urban Heat Islands or UHI's. The prime contributor to this phenomenon is the use of construction materials that retains heat in urban areas, thus raising their temperatures by around 10 degrees compared to rural areas, especially night time. Other factors could contribute to this phenomenon; however, they are of a lesser magnitude, such as the anthropogenic activities within urban areas. Bioclimatic Tall buildings in general and especially those with vertical garden courts are more prone for less land in the urban-escape compared to their height. This would reduce the land area that is susceptible for heat accumulation and in the same time maximizing the vertical contact with the atmospheric boundary layer and therefore allow for better heat dissipation to the air. Furthermore thermal sun rays would be less concentrated on vertical surfaces compared to horizontal stratus. Vertical gardens, roof gardens or heavy vegetations within tall buildings would improve the environmental credentials of tall buildings far better in this respect as they can eradicate the effect of heat islands either for an urban setting or a localized micro to meso climate.

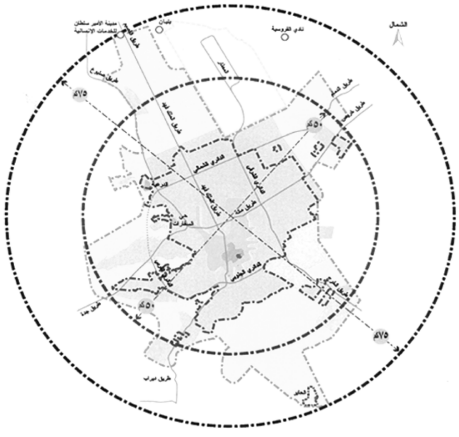


Figure 5. development master plan for Riyadh spanning 50-75 kilometers radiuses from the center (Courtesy of Riyadh municipality).

6. The Need for High Rise Buildings

According to the United Nations report in 2001, it is expected that by 2030 the majority of the world population will be concentrated in urban areas. This is



Figure 6. Panoramic view of Riyadh City Center.



Figure 7. views of natural environment of Riyadh city having many 'Wadis' of natural streams of water and medium density vegetation.

particularly evident in developing countries; major cities are susceptible for mass migrations from rural areas in the search for better jobs, services and quality of life. This poses extra pressure on the natural resources and could be detrimental if appropriate measures are not implemented. Bioclimatic tall buildings could provide a sustainable option for accommodating this unprecedented growth of population in urban settings worldwide. A good example in this regard is Riyadh city, capital of Saudi Arabia.

Since 1955 the city adopted an ambitious plan to expand the city both qualitative and quantitative development backed by the economic boom of the oil industry in the kingdom. This is reflected in the city expanding from less than a kilometer in radius to 50-75 kilometers of development, Fig. 5.

Although the city center has a more cosmopolitan presence of tall buildings resembling those of world class cities Fig. 6, it realized that better management of the available resources could be achieved by erecting Sub centers to solve problems of traffic congestions, city sprawling and costly long term servicing to infrastructures. If sustainable tall buildings are to be realized in these sub-centers this would help to preserve the natural environment, Fig. 7 and provide an efficient way to deliver the right accommodation and services to the ever increasing population of the city.

7. Conclusions

Although the initiation and development of tall buildings was pertained to developed nations, High rise buildings constitute a solution of great potential when considering sustainable development of cities and urban tissues worldwide. They provide densification of the built environment that otherwise could lead to large exploitation of valuable land or even worse a sprawling growth. High-rise buildings would enhance the ecological baseline by reducing exploited land for development. They could also have significant ramifications to reduce heat islands, a phenomenon in modern cites by allowing for more land for greeneries that could have otherwise be used for built developments. Sustainable technologies would benefit from the inherent height of tall buildings in ways that could boost their performance in providing sustainable sources of energy within urban settings. Tall buildings could be erected with Sustainable materials and techniques that preserve the natural habitats of urban settings and provide an efficient utilization to the embodied energy in them. Possibly hugh environmental benefits can be attained by virtue of the cumulative nature of duplicate floors inherent in tall structures that would lead to increased savings and larger environmental benefits, when choosing energy efficient systems and sustainable building materials.

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