Bioclimatic Tall buildings

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Abstract:
This paper discusses major new trends of sustainable tall building design. It sheds some light on the reasons behind the proliferation of tall buildings worldwide as well as the move towards mixed-use Bioclimatic tall developments. Some technical features of tall buildings are reviewed in terms of vertical layouts, structural themes, wind adaptation and so forth. Strategies to generate tall buildings sustainable design ideas are illustrated. The paper concludes that Bioclimatic Tall buildings could be the answer to tackle the sustainable growth of the world future cities and communities. It emphasises the sustainable qualities that can be replicated in any given particular context.

Keyword: Tall Building design, bioclimatic architecture, Sustainability, Mixed use, vertical communities.

1. INTRODUCTION

Since their emergence in the late nineteenth century, tall buildings have been introduced as viable solutions to many of the world's developed and developing cities' and community's problems such as increased population and limited land. However, the late twentieth century rouse concerns on energy consumptions and ecological degradations both locally and globally. Bioclimatic tall buildings respond to classical tall buildings' problems of excessive energy consumption and large material exploitation, besides local and macro ecological well being.
According to the United Nations state of the world cities report in 2012/13, it is reported that the world population will be concentrated in urban areas. [1] This is particularly evident in developing countries since major cities are susceptible to mass migrations from rural areas in the search for better jobs, services and quality of life. Bioclimatic tall buildings could provide a sustainable option for accommodating this unprecedented growth of population in urban settings worldwide.
Currently Oldfield P. and Wood A. [2] 2008, pointed out that most of the first two decades of 21st century tallest buildings are spaced between mainly in Asia and the Middle East figures 1 and 2. This is basically backed by the economic growth experienced in these locations compared to their western counterparts who are under a deep recession. Besides, this last decade experienced an unprecedented growth in Tall buildings' heights in these regions too. This was as expressed by CTBUH categorization of height based on 300m intervals, for which supper tall buildings are over 300m and mega tall for those beyond 600m, figure 1.

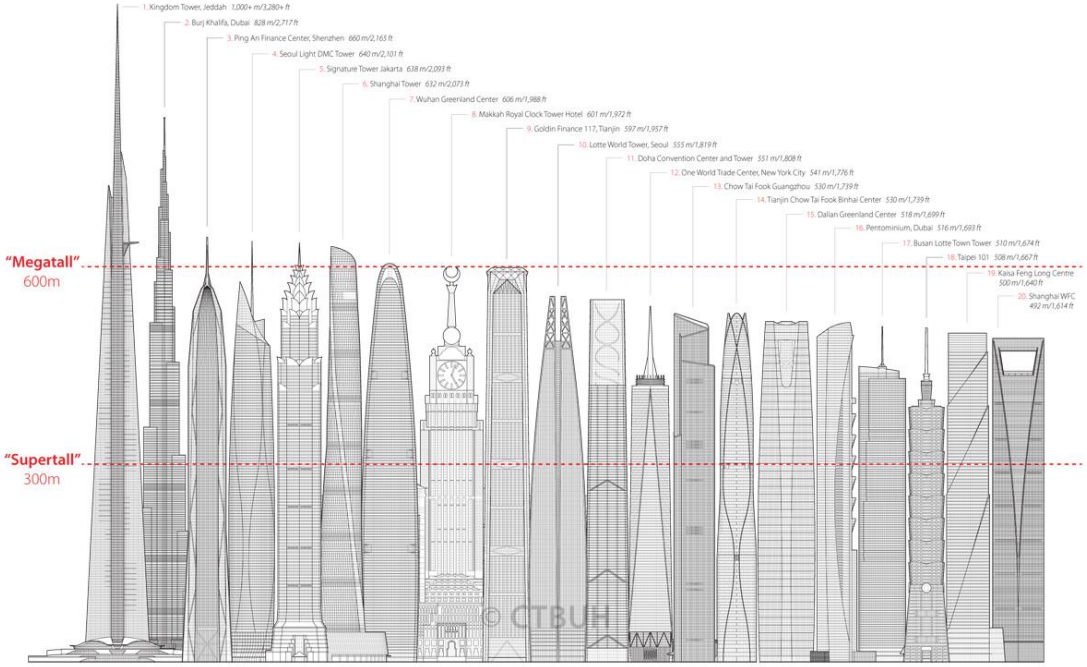


Diagram of the World's 20 Tallest in 2020 (estimated as of Dec 2011) © CTBUH

Figure 1, the definition of the terms Super/Mega Tall. (Courtesy of CTBUH)

In addition, the last decade have witnessed the first ever building to exceed the 800m height in Burj Khalifa, Dubai and possibly the proposed new kingdom tower to be in Jeddah, Saudi Arabia would exceed the barrier of one kilometre in height, figure 1.[3]

It's worth noting here that we are running a tall buildings design studio as an adjunct course with the CTBUH at design studio-7 (the semester just before graduation), in which we experiment with new ideas and practices circulating within the realm of sustainable tall buildings.

2. Methodology:

The methodology of the research is based on investigations of the real motives and driving forces that shaped the design and construction of tall buildings in the past up to the present to establish trends followed to envisage Tall buildings. This is realized through studying and analysing real case studies, extracting information from published statistics and general relevant literature review. We know from the museum of tall buildings in New York that the first wave of tall buildings (i.e., 1870-1910) came by after the great Chicago fire, where the need for premises was at its highest, So high demand was the main reason behind the birth of tall buildings[4]. This factor is echoed by the united nation report mentioned in the introduction and seems to be valid up to sometime into the future. In terms of the profession we find that some notable Architects produced genuine work that becomes regarded as inspirational by peers for quiet a period of time predominantly in America where tall buildings originated. Just to name a few we have Louis Sullivan (1856-1924) to whom the exaltation of early office buildings was attributed. Followed by a number of architects of whom was Mies Van Der Rohe (1886-1969), who introduced paradigm shift in his Seagram building 1958, New York. Mies introduced the curtain wall facades that have been used widely in tall

buildings around the world together with his philosophy of 'less is more'. However, when Mies first introduced the full glazing facade idea (i.e., 1921) this technology was non-existent at that time. Only when structural glazing was developed it was possible to sheath the entire facades with glazing. This brings to mind that the design development of skyscrapers although was initiated by master architects, but was developed through the technical and genius of the engineers who tackle the various issues of structures, safety, vertical transportation, energy consumption and so on...

Obviously, tall buildings requires technology as a vital necessity in their construction, vertical transportation, as well as in their operational life span. Extensive use of glazing necessitated the use of air conditioning as exposed glazing produce the green house effect, which is a major concern in summer time. Overnight, glazing losses heat faster by radiation to the sky, which cool buildings beyond habitable conditions, especially in cold regions. This resulted in normally high operational costs due to the use of air conditioning.

The energy crisis of the 70's (73-1983) exasperated the problem of high running costs and might have slowed down high-rise buildings proliferation up to early 21st century, figure 2. In the same time, the crisis brought about intensive research into ways and means to reduce energy demand and more interestingly the move towards renewable sources of energy. As a result more understanding of material properties used in construction to achieve greater environmental results such as natural lighting, natural ventilation, better thermal properties, cleaner indoor air and so forth. One of the renowned architects who experimented with a combination of environmental strategies and architectural forms is Norman Foster. He introduces vertical zoning of tall buildings that enhances the appearance by adding more sizable elements into facades.[5] In addition it provided more access to natural light and ventilation and decentralizes services. A new move towards what is called Bioclimatic skyscraper is launched around the world to design green tall buildings that are responsive to local climatic conditions, sustainability, energy efficient, satisfy, the needs of its communities and cities.

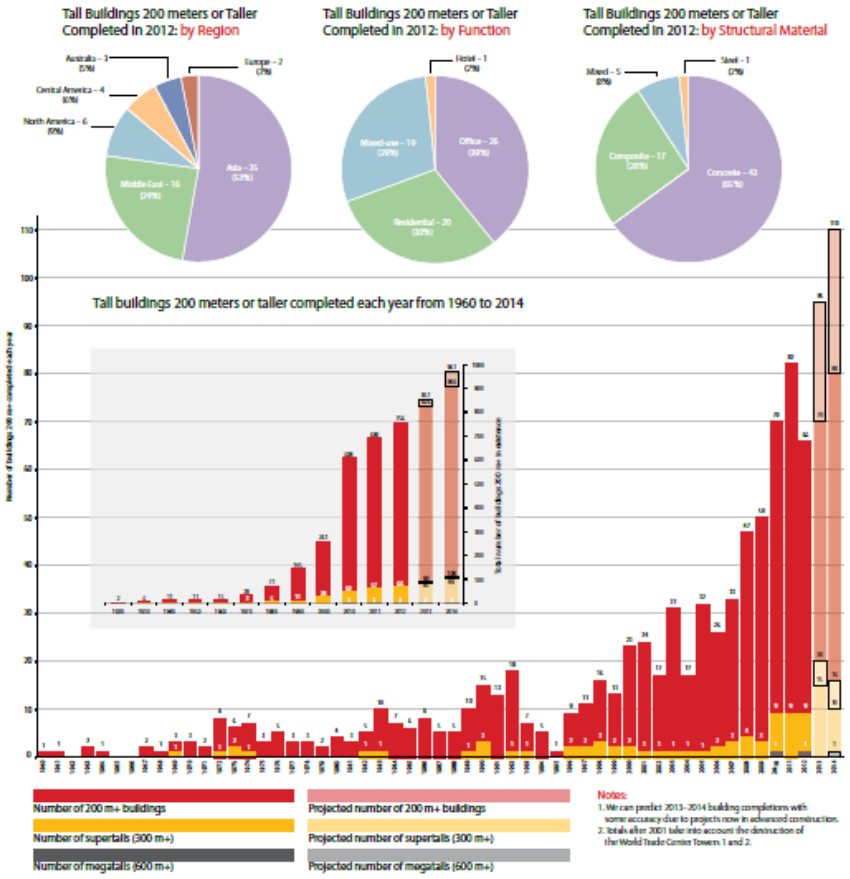


Figure 2, Tall Buildings 200m or taller completed each year from 1969-2014. (Courtesy of CTBUH)

Bioclimatic tall buildings are the main focus in tall buildings design studio the author leads. Where students are given several sites within the city which are pre-planned for high-rise developments. They would be briefed of the project ideas, challenges and guided through the studio programme stipulated. They are encouraged to foster a sustainable design strategy that accommodate a mixed use tall building. Herein after we discuss some of the trends in sustainable tall buildings around the globe, which are also object of our design studio.

3. TRENDS OF CURRENT TALL BUIDLINGS DESIGNS:

3.1. MIXED USE:

Mixed-use Tall Buildings are increasingly becoming a wide spread phenomena in today's tall buildings landscape. The CTBUH defines a mixed-use tower as the one with more than one function, each occupying a significant amount of the total floor area or height of the building, whichever is the greatest. This move towards mixed-use design is mainly due to the fact that monoculture single use buildings (i.e., where a single use occupy 85% or more of its total floor area) may be closed or vacant for parts of the day, but

Mixed-Use buildings can be active 24hrs, with corresponding benefits in sharing heat/Cool, improved security, sense of community, flattening of travel peaks, balancing of economic waves, immediate access to workplace and facilities. The community can be 'in the building', not somewhere, you commute to (i.e., leave the building to find). Therefore, the current trend with tall buildings is to tailor them as mixed-use developments for maximum utilization offered by such developments.

3.2. ENVIRONMENTAL AESTHETICS:

Bioclimatic tall buildings are tall buildings' that are consciously designed to treat site environmental contexts of movements of the sun and wind, ground typology, and so on …when these local issues are addressed successfully they will inevitably acquire more comfort to occupant while reducing energy consumption for light, ventilation and A/C that ruminatively lead to less emissions of greenhouse gases that harm the macro ecological well-being of our planet earth. Bioclimatic skyscrapers unlike their conventional counter parts (i.e., the air-conditioned darkened glass office towers) rely on environmental solutions in their design and operation as well as their aesthetics'. They can be planned as vertical communities stacked along the height of the tall towers. One of the pioneering architects in Bioclimatic scrapers is Ken Yeang[6], were he perceives tall building as a vertical urban design exercise instead of the usual horizontally dominated urban design/planning. Tall building would have vertical high streets, neighbourhoods, precincts, communal spaces etc. just as urban development's features would have on the ground.[7] For more cons and pros of Bioclimatic tall buildings refer to table 1.
Communities are complex, Bioclimatic design requires greenery, solar shading, ventilation openings, solar facades and much more... different building users require different floor-to-floor heights and glazing percentages.... and putting these all together into Tall buildings produce many and varied shapes, to reflect the many functions and to improve behaviour in wind...etc.. 'Beauty' can emerge from the intrinsic achievement of a good working design that has excellent engineering. A new architecture has emerged, not just under the skin, but in the whole appearance of buildings. Paradigm breaking buildings like Crystal Palace and the Pompidou centre were living examples for system based thinking of architecture for their use of glass, steel and unconventional design[8]. But now we know how these building materials of glass, concrete, steel and the rest of the list of building materials better. How they can be used responsibly and environmentally friendly. This is true both in their acquisition and their procurement and assemblies into buildings, together with the expected operational characteristic to achieve comfort with in buildings without compromise in high operational costs.

Table 1. Cons and pros of Bioclimatic tall buildings

Cons of Bioclimatic scraper	Pros of Bioclimatic scrapers
They can affect the quality of space around them. (windy surroundings)	Can enhance the skyline
Affect historical sites	Can reduce the need to commute when they are mixed use
Consume a lot of building materials	Can be designed for better savings when designing for natural lighting.
	Can be designed for better savings when designing for natural ventilation.
	Can reduce energy demand.
	Limit heat Islands, more areas for lawns
	Limit sprawl growth in cities.
	Vertical streets and communities.
	More economical to design for sustainability
	Wind and solar energy generation

An example of how natural lighting design strategies are employed for lighting daytime in all levels of a tall building is in figure 3 below,(i.e., Building No.10 from the left in figure 1) where the building form and structures are designed to maximize natural lighting mainly from the north by placing a full glazed curtain wall capturing north light. The structure of the building was made symmetrical about East/West axis. Thus the South elevation is identical to the North, but fitted with Solar panels to generate electricity.

Figure 3, (left) exterior perspective. (Top interior and bottom right section) Foyer naturally lit. Lotte Jamsil Tower, Seoul Korea, Curtsey of KPF.

3.3. Linking the towers:

An increasingly gaining momentum idea is the notion of the Ground scrapers and sky bridges, which provide circulation at low and high levels ensuring greater safety levels for occupants and as extra means of egress in tall buildings. Bridges can provide another level of recreational services, and enable services and water sharing. It enhances the social and economic viability of the towers, especially if they have retail and need to maximise footprints. Bridges are recommended as a prime strategy for making buildings safer in cases of emergency or fire exists, and should be considered whenever adjacency makes underground links or sky bridges possible. A living example of such development is ‘The Linked Hybrid, a building complex in Beijing, China, winner of the Best Tall Building Overall Award by the CTBUH in 2009. Designed by Steven Holl architects, figure 4.

Figure 4. The Linked Hybrid, a building complex in Beijing, China. Sky bridges create a unique aesthetic and a new pattern of clustering of tall buildings, and function as a safety feature in the event of emergency evacuation.

3.4. Ideas for high-rise Buildings:

In the studio of tall buildings we are running in our college we try to adopt tall buildings briefs that engage the functional aspects of the projects with the sustainable Ideas and technologies in a bid to create culturally responsive architecture that respect the identity and context of the place, while relying on the best technologies of the time**.** Quoting from Eldemery 'We should associate our thinking with adaptation of technical innovations in order to absorb and integrate them into meaningful cultural systems'.[9]

Here are a number of samples ideas, themes or strategies adopted in our tall buildings studio to generate workable programmes for tall buildings:

Education tower, Sim-City, City of the Old, Eco laboratory, Sun tower, Solar

power tower, Vertical farming, Inhabited Bridges tower, Sport city, Distorted tower, Rotating tower, Magnetic tower, Tessellated tower, Algae tower, Minimum surface (wing) tower, Wind tower, Living Mesh, Always Building tower, Never finished tower, Plug in city, Biologically growing tower, Water Catching tower, Flower Tower, Tree tower, Walking tower, Fibonacci tower, Recursive structure, Exoskeletal, Light transmitting, Cultural symbol, Olympic monument, Urban gateway, Music tower…..You may think of more.

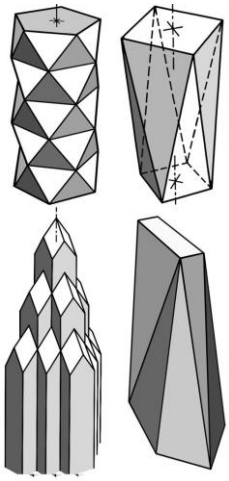
3.5. Architectural Image of Tall buildings:

Tall building projects have high capability to serve as strong statement in the urban set-up of cities as it is clearly visible not only from its immediate surroundings, but throughout the cityescape. In this respect they have an iconic and symbolic dimension to what a city stands for or aspires to achieve. Therefore it is absolutely imperative that not only they have to be sustainable in theme and operation/practice but also act sensibly and responsibly to the cultural context or heritage, which they are erected in. This means not only are they made to provide high efficiency in usable total floor areas but also be sustainable by reducing high operating costs. Tall buildings should be perceived as a logical continuation to the cultural setting of any particular location. Thus, the visual impression or technically the design of facades and form of the building has the most critical impact. Good examples in this regards are khalifa tower[10] in Dubai and city gate building in Abu Dhabi[11] figures 5 and 6.

Figure 5(above), Capital Gate, Abu Dhabi, Designed by RMJM.
Figure 6(right), Burj Khalifa, Dubai, Designed by Adrian smith.

Some of the researchers into tall buildings images/forms in the Russian Academy of Architecture and Building Sciences have grouped the main themes of building forms in about 21 categories as presented in figures 7-19 below[12]. Obviously there are no limits for architects' creativity in this respect, but the main issues of integrity, suitability and sensible handling of the cultural connection and progression to the architectural context should be among the

main points to consider in dealing with tall building designs, a matter that can be a subject of further study in the future.



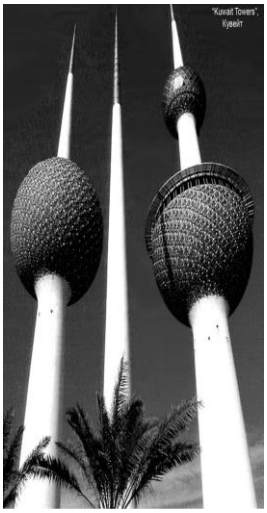
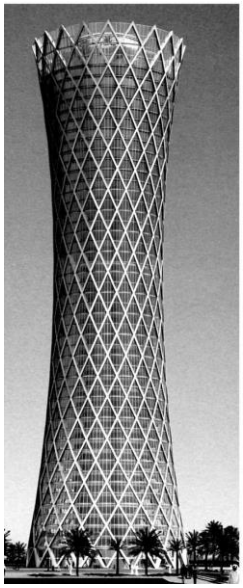


Figure (7) Crystal Forms. Figure (8) Cylindrical Forms. Figure (9) Conical forms.



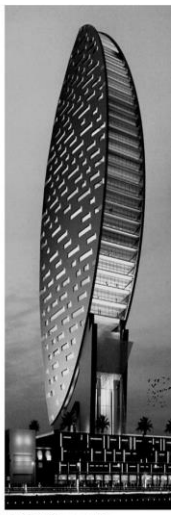
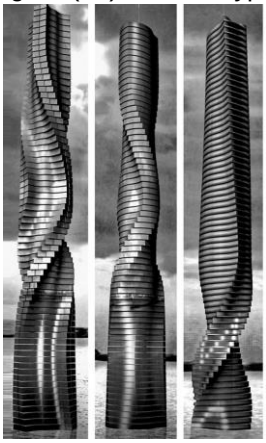
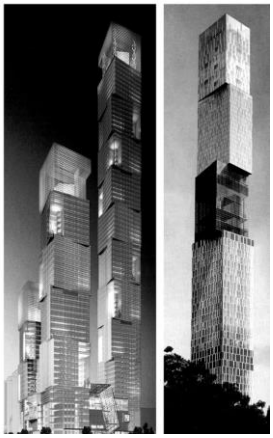
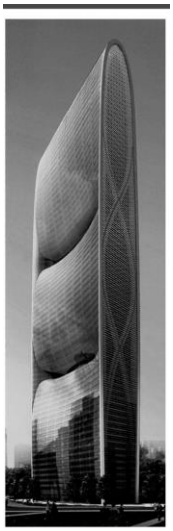


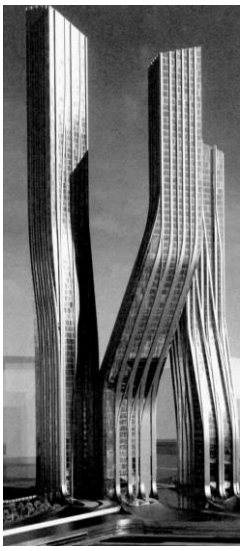
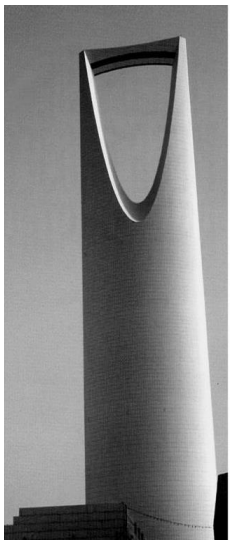
Figure (10)Funnel/ Hyperbolic forms. Figure (11) Disc forms.





Figure(12) Spiral-forms. Figure(13) Multi-Block. Figure(14) Arch-form. Figure(15) Lens-forms



Figure(16) Frame forms. Figure (17) Inclined forms. Figure (18) Bent Figure (19) 'Eye of a needle' form.(Courtesy of Andrey V. Korotich).

3.6. Vertical layouts:

The height of tall buildings can be arranged in groups of vertical communities each group comprises possibly 6-10 floor plates fully serviced (i.e., services of electricity, water, A/C, ventilation, etc..) from two services floors on top of them and beneath them. These groups can accommodate different functions or activities. Hence, providing the mixed use nature discussed in point 2.1 above. Obviously some groups could be more related to others in such a way that permits more sharing in services such as lifts and other means of circulation. But this inherent categorization or grouping in communities can lead to distributing the total loads of the whole tower into smaller manageable loads for each community by itself. In addition it provides easier maintenance in the future as well as if any failure might occur in a single community, it affects that single community alone and doesn't hinder the rest of the tower.

4. Wind effects on vertical structures:

The effect of wind forces on tall buildings is more pronounced than that occurring in low-rise buildings. This is mainly due to the fact that at higher altitudes wind speed accelerates as it departs from frictional forces caused by normal heights of the built up urban terrain. In addition, tall buildings are generally having their epic within the main stream wind where wind motion is at its highest. Or as expressed in aerodynamics that wind speed in the boundary layer of the atmosphere would have lower velocities due to friction and expedite speed as it reaches main stream at about 100m above normal building's heights.

Therefore, tall buildings act like sails catching high winds, hence it should be adequately addressed within the structural skeleton of tall buildings. Early tall buildings of the last decade addressed this issue by combining structural stiffness through diagonal supports (see Point 5. below) or some flexibility at the top of towers by means of dump weight as in Citicorp building. Nowadays

there is a growing trend in designing for wind in tall buildings by incorporating the effect of the stiffness of the plan form (i.e., Triangular plans) that enabled designers to go beyond the normal heights of super tall into the mega tall category as exemplified by Burj Khalifa[13], kingdom towers figure 20, and Guangzhou international financial centre IFC, Figure 21.

Figure 20 (Left), Kingdom Tower, Jeddah, Saudi Arabia.

Figure 21 (Right), International financial centre IFC. Guangzhou, China.

Recently more understanding of the relationship between some high-rise buildings forms and wind loading was made possible by Tamura et al[14], as they investigated the form of tower top in different configurations and compared them to a consistent square section tower. They concluded that spearing the tower in different forms of tapering, corner cut, set-backs and helical twisting in different angles would result in lower pressure co-efficient than the initial square section and therefore reduce considerably structural wind loads on tops of tall buildings. However, when undertaking response analysis to determine the safety and habitability on the same building forms most forms were better than the base case of square section with the exception of the set-back form, which had far more worse results. From sustainability point of view, this exposure to high wind might be a good source for renewable energy to be harnessed. However, more research into this combined with safety and habitability of tall buildings is yet to be determined.

5. Structural ideas and stability:

The structural design and stability of tall buildings was the backbone for their proliferation since their emergence in late 19th century. Early scrapers were dominantly of masonry and concrete. They tend to reveal what has came to be known as Architecturally honest expression of structural members in building forms, such as the ingenious work of Fazlur Khan[15] in the 60's and 70's, where building aesthetics were expressed by structural columns in facades. Then came along the idea of core and shell by a wave of some corporate buildings in New York and Chicago in the 70's and 80's of last century. Tall buildings began to relinquish the use of masonry in facades gradually and were being replaced by curtain walls when the glazing industry developed structural glazing and curtain systems capable of withstanding wind structural loads. A development some critics associated it with the

introduction of outriggers used in the Liberty Statue (review in the book Tall buildings, the Museum of Modern Art, New York). Frank Lloyd Wright experimented with what he calls 'tree structure' resembles to what we now call 'shell and core' structure. One of the great advancement in tall buildings structures was the introduction of diagonals as in Bank of China Figure 22 and J. Hancock figure 23, which brought about a great deal of stability in tall buildings against movements of all kinds, specially winds and earth quakes. This was another innovation of F. Khan that for the first time it was possible to build 100 storey buildings with great stability and minimum structural weight. With the development of new technologies and in particular computer simulation programmes for structures it became more possible to venture with new structural ideas with more confidence and less time in working out the essential analysis of forces and designing of structural members.

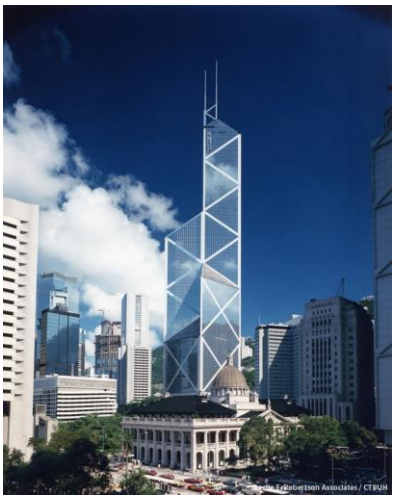


Figure 22(Right), Bank of china, Hong Kong. IMP
Figure 23(above), J. Hancock Centre, Chicago. SOM.

It also enabled structural engineers to cope with architectural ideas of grouping vertical villages or communities designed to miniaturize tall buildings and giving them a more pleasing or less dramatic effect in the height of towers in the urban scape such as Norman Foster's many buildings around the globe in Hong Kong Bank, Commerz Bank in Frankfurt and Fysalia tower in Riyadh. Structures used for tall buildings to be either solely concrete structure, or steel structure, or a mixture of both as steel/concrete or concrete/steel where the first noted is on top of the other.

6. Sustainability and tall buildings:

One of the strategies to achieve sustainability is to reduce or eliminate over exploitation of natural resources beyond the rate at which they can naturally regenerate, so future generation can get their fair share. This obviously can be achieved through efficient use of resources and indeed energy, which 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 the elements such as sun rays, wind power, geothermal power and so forth. Considering the first

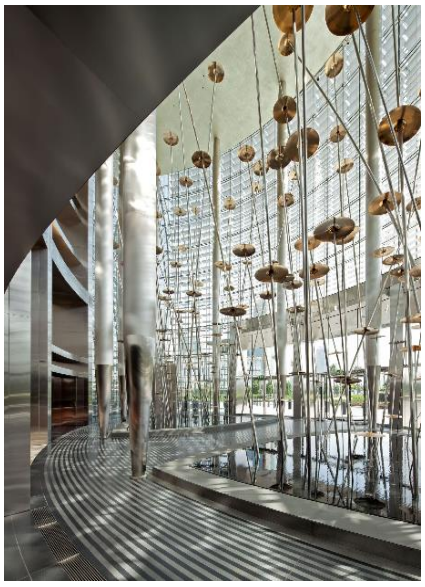
two options high-rise buildings provide very high potential with very large surface area that could be utilized to harness solar rays for heating, lighting, buoyancy cooling/ventilation and electricity generation (Elbakheit, A.R. CTBUH 2008)[16]. Wind power with suitable collecting/converting devices 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. (P.A. Irwin et al CTBUH 2008).

A good example for tall buildings design for harnessing wind energy is Bahrain world trade centre BWTC by Killa S. and Smith R. CTBUH 2008)[17]. The genius of BWTC is in incorporating Sea-land breeze phenomenon into the design of tall buildings, by selecting building form to maximize wind flow and three turbines for electricity generation. It is stipulated that 11-15% of the annual electric energy demand of the centre would be met from turbines generation. However, due to being one of the world's early tall buildings to incorporate this technology, thorough investigations into, safety, control, maintenance, reliability issues were high that in my opinion to great extent hindered the prospects of using more of wind generation but rather limiting it to 11-15% of the demand.

Full power anticipated from each turbine is about 225Kw will be achieved at wind velocity of 15 to 20m/s. Owen to this relatively high wind speed and the sizes of the turbines (29m in diameter) it poses great challenge with regards to safety and structural stability among other technical issues. Whereas the alternative approach is to use smaller sized (1 to 2m diameter 2-10Kw) turbines that can reduce all these technical issues considerably besides being a lot cheaper to procure and operate.(Elbakheit A.R. 2013).[18]

Tall buildings are also a very promising and challenging field for natural lighting provision within them[19]. They can benefit from horizontal surfaces (i.e., light turf) projecting from their facades to reflect high sun angles deeper into their interiors. Thus providing ample illumination with good distribution internally that can eliminate the need for artificial lighting daytime, figure 24.

Good practises such as recycling, grey water reuse or rainwater collection all have high rate of success due to the accumulation of large users/consumers as well as large surface areas to collect rain water/grey water and reuse in tall buildings.



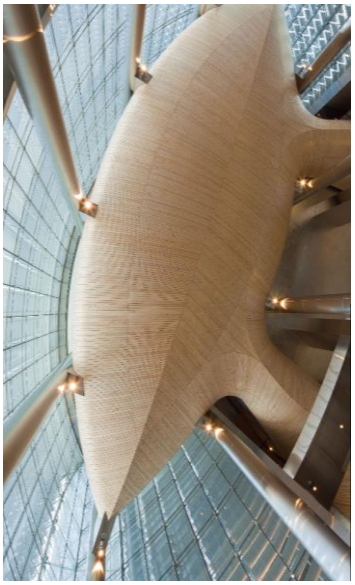


Figure 24, Burj Khalifa Foyer, Sustainable Natural Lighting through Horizontal Louvers (Courtesy of Adrian Smith +Gordon Gill)**.**

7. Conclusions:

Tall buildings have undergone tremendous development both in technologies and in design since their emergence since the 19th century. Ideas of sustainable/environmental strategies have advanced the design and vertical layout of tall buildings both functionally, environmentally and possibly aesthetically by miniaturizing their height into more acceptable facades. Mixed -use tall are becoming the main trend for new and emerging tall buildings. Tall buildings have great potential to achieve sustainability as well as to serve as monuments for communities and cities around the globe. Although, tall buildings were first introduced in America, they have proliferated all around the globe and according to CTBUH nowadays have a rate higher than that in America. The sky is the limit for architectural themes and strategies to achieve sustainability in tall buildings design. Care should be taken to preserve the cultural identity of the locality of tall buildings, while expressing the novelty through technical and creative designs. More research is needed to incorporate more sustainable solutions into tall buildings and to better exploit the advantages offered by the height and technologies inherent in tall buildings.

References:

[1]. UNITED NATIONS 2012/13. STATE OF THE WORLD'S CITIES 2012/2013, World Urban Forum Edition, United Nations Human Settlements Programme, 2012, found at sustainabledevelopment.un.org/content/documents/745habitat.pdf, Accessed 19/10/2013

Figure 1, https://store.ctbuh.org/popup.aspx?src=images/Product/large/91.jpg

[2] Old F. and Wood A. 2009, Tall Buildings in the Global Recession 2008: 2020 and beyond, CTBUH Journal, Volume I.

[3] Adrian Smith and Gordon Gill 2011, The evolution of an Idea, CTBUH conference, Seoul, Korea, October.

[4] Tall buildings, Edited by Harriet Schoenholz second edition 2005, Published by the museum of modern art, new York

[5] Skyscrapers, Edited by Dupre, Judith 2008, Published by Black dog and

Leventhal Publishers Inc.

[6] Ken Yeang 2002, Reinventing the Skyscraper a vertical theory of urban design, Wiley-Academy, ISBN 0-470-84355-1.

[7] Ken Yeang 2011, edited by Lucy Bullivant, Eco Skyscraper volume 2, First edition, Published in Australia by Image publishing group PTY Ltd.

[8] Leonard R. Bachman 2003, Integrated buildings-the system basis of Architecture, pp.20-21, Published by John Wiley & Sons, Inc. ISBN 0-471-38827-0

[9] I.M. Eldemery 2009, Globalization challenges in Architecture, Journal of Architectural and Planning research 26:4, pp 343-354.

[10] Skyscrapers, Edited by Dupre, Judith 2008, Published by Black dog and Leventhal Publishers Inc.

[11] Best Tall Buildings 2011, Edited by Antony wood, Council on Tall buildings and Urban habitat Chicago, Routledge, Taylor and Francis Group, New York , London.

[12] Andrey V. Korotich et al 2011, Image of Modern High-rise Architecture, CTBUH Conference 2011, Seoul Korea, October.

[13] Peter A. Irwin 2009, Wind engineering challenges of the new generation of super-tall buildings Journal of Wind Engineering and Industrial Aerodynamics, Volume 97, Issues 7-8, September-October, Pages 328-334, 12th International Conference on Wind Engineering.

[14] Y. Tamura et al, Aerodynamic characteristics of tall building models with various unconventional configurations, CTBUH conference, Seoul Korea 10-12 October 2011.

[15] Technique and Aesthetics in the design of tall buildings, Edited by David P. Billington and Myron Goldsmith 1986, Institute of the study of the high-rise Habitat, Lehigh Universtiy, Bethleham, PA. ISBN: 0-939493-01-2.

[16] Elbakheit, Abdel Rahman 2008, Effect of Duct Width in Ducted Photovoltaic Facades, CTBUH 8th World Congress, Dubai. March 3 - 5, pp.795 - 801

[17] Killa S. and Smith R. 2008m, Harnessing Energy in Tall Buildings: Bahrain World Trade Center and Beyond, CTBUH 8th World Congress, Dubai. March 3 - 5,. pp.

[18] Elbakheit A.R. 2013, Factor enhancing areofil design to harness wind energy generation in buildings, International Journal of building services research and technology, Accepted Septerber 2013.

[19] Natural Ventilation in High-Rise Office Buildings, Edited by Antony Wood and Ruba Salib, CTBUH Technical Guides, Routledge Taylor and Francis Group, New york and London 2013.