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Article

Tall Buildings and Urban Habitat of the 21st Century: A Global Perspective

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Abstract: The tall building is the most dominating symbol of the cities and a human-made marvel that defies gravity by reaching to the clouds. It embodies unrelenting human aspirations to build even higher. It conjures a number of valid questions in our minds. The foremost and fundamental question that is often asked: Why tall buildings? This review paper seeks to answer the question by laying out arguments against and for tall buildings. Then, it provides a brief account of the historic and recent developments of tall buildings including their status during the current economic recession. The paper argues that as cities continue to expand horizontally, to safeguard against their reaching an eventual breaking point, the tall building as a building type is a possible solution by way of conquering vertical space through agglomeration and densification. Case studies of some recently built tall buildings are discussed to illustrate the nature of tall building development in their respective cities. The paper attempts to dispel any discernment about tall buildings as mere pieces of art and architecture by emphasizing their truly speculative, technological, sustainable, and evolving nature. It concludes by projecting a vision of tall buildings and their integration into the cities of the 21st century.

Keywords: Tall buildings; new technologies; urban design; future cities; sustainability

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1. Introduction

Because of their enormous scale tall buildings demand extraordinary determination and endurance from many stakeholders including owners, developers, planners, architects, and engineers. They exert significant demand on infrastructure and transportation systems, and affect the historic fabric while reshaping the city's skyline. They also influence the micro-environment by casting shadows and blocking views and sunlight. Tall buildings consume massive quantities of energy and require a high operational cost. For these reasons some critics have viewed tall buildings as an undesirable display of extreme form of technological surge intruding upon the existing built environment that matches the human scale, and hence, an "urban evil" that reduces the quality and way of urban life. In the wake of the collapse of the World Trade Center (WTC) towers in New York in September, 2001 some skeptics took a pessimistic view by calling skyscrapers "death traps" and hastily and unfairly predicted their demise.

The opposite just happened, however, as interest in tall buildings grew unabatedly in the building community following the WTC disaster. The past decade has proved that these views are untenable at best because we have witnessed an unprecedented construction boom of tall and supertall buildings soaring higher and higher worldwide. This is corroborated by the Council of Tall Buildings and Urban Habitat (CTBUH), which went even further in observing that the past decade has witnessed the completion of more skyscrapers than any previous decade in history. This resurgence of tall buildings is notwithstanding the recent global economic recession. An aggressive race to earn the world's tallest building title continues, while at the same time, cities are constructing higher buildings in greater numbers in cities as diverse as Shanghai, Shenzhen, Hong Kong, Dubai, Riyadh, Mumbai, London, to name only a few.

The WTC catastrophe forced the building community and the public to again raise a fundamental and recurring question: Why tall buildings? Upshots to this are the other related questions: Why are tall buildings inevitable; why are they reshaping the skylines of cities; and why do we need more of them in the 21st century?

2. A Brief Early History of Tall Buildings

Many 19th century American architects went to Paris for training and education and brought back with them ideas that influenced their architecture. In Paris, the Eiffel Tower, at 300m (984 ft) in 1889, was surely a catalyst for new heights with its remarkable architectural qualities and became known as an engineering masterpiece. The U.S. also exported cultural and architectural ideas and developments to Europe that included the skyscraper, a clearly American innovation with its beginning in Chicago.

The steel-framed structure of the 10-story Home Insurance Building is generally recognized as the first skyscraper, built in Chicago in 1885. A series of tall buildings, relatively large at the time of their construction, were built at the turn of the century. These include the Wainwright Building of 1890 in St. Louis, the Guaranty Building of 1895 in Buffalo, New York, and the Reliance Building of 1895 in Chicago. This trend continued in New York with the Flat Iron Building of 1903, continuing to the Chrysler Building of 1930, and the Empire State Building of 1931. Following a pause in construction during the Great Depression and World War II years, tall building construction re-appeared in Chicago in the 1960s.

Enormous progress was made in the development of tall buildings after World War II, first in the U.S., followed much later by some Pacific Rim countries, parts of Europe, and the Middle East. Although technology has advanced and the architectural style of tall buildings has evolved, the architectural planning concept of vertically stacking a series of floors and achieving spatial efficiencies by increasing the net-to-gross floor area has remained almost the same. Despite architecturally ambitious thinking, as well as technical and structural advancement, the primary focus remained on economic viability and technological and constructional limitations. Beginning with the last decade of the 20th century, this has changed, however, in favor of sustainability, innovative façade treatment, free-form massing, and iconic architectural vocabulary.

3. Arguments against Tall Buildings

Many critics lament the loss of our old way of life and consider tall buildings as oppressive symbols and unnecessary intrusions into the urban fabric lowering the quality of the city dwellers' natural social life. They may have a point as tall buildings are not free from some basic problems. The question is whether the benefits of tall buildings outweigh their demerits. Here are some areas of concern worth pondering over.

3.1. Economic Considerations

Undoubtedly, there are some inherent drawbacks of tall buildings from an economic point of view. Construction of these buildings requires an extra cost premium because of their need for sophisticated foundations, structural systems to carry high wind loads, and high-tech mechanical, electrical, elevator, and fire-resistant systems. In addition, a large core area is needed to accommodate elevators and building services systems. Although skyscrapers provide more interior space than typical low-rise buildings on a given plot of land, they also cost more to significantly fortify them against the fierce natural forces of gravity, high winds, and earthquakes. A high slenderness ratio for serviceability and motion control demands greater stiffness of the structural system and thus taller buildings become more expensive. While about 70% of a skyscraper's floor plate is generally usable space (the remainder being the building's elevator core, stairwells, and columns), more than 80% of low-rise spaces are typically useable [1]. Tall buildings also suffer from higher operational costs, such as high energy consumption, elevator maintenance, emergency response preparedness, *etc*. Depending on the socio-political circumstances, they potentially could be viewed as targets for malevolent attacks. Moreover, in difficult economic times, towers simply may not generate enough sales or rental value to recover the cost of high quality of design, materials, and detailing and support their mortgage and operational costs. This situation risks producing low quality towers that aim for maximizing floor area at the expense of good design.

The economic viability of building tall is ultimately a matter of location and local conditions. It can be the lowest-cost solution in a developed country in a location with other high-rises where the needed infrastructure and urban services are in place. Tall buildings fit in well where business and organizational structures are geared to large-quantity operations; where building materials are plentiful; and where there is an adequate force of skilled labor. Building tall could be the highest-cost solution when these conditions do not exist. Without great care in such situations, the cost of adjacent land could be pushed up to create higher costs for structures yet to be built. Further, in some situations where land costs are low, as in smaller cities, tall buildings may be unprofitable because of anticipated high vacancy rates. Also, to be considered is the general economic climate at the particular point in time.

The impact of tall buildings on property values varies. In some places, because of newly generated traffic and crowding, property values in nearby neighborhoods may diminish. The opposite also could be true due to the growth of the area showing signs of economic prosperity. The concentration of jobs and services may create a higher demand for land which increases their property values. Increasing property prices in cities make housing in locations accessible to livelihood opportunities and services increasingly unaffordable for many sections of the population.

3.2. Environmental Impact

Tall buildings produce adverse effects on the microclimate, due to wind funneling and turbulence around them at their base causing inconvenience for pedestrians. Also, tall buildings cast large shadows, affecting adjacent properties by blocking sunlight. Towers are environmentally damaging when they fail to incorporate energy efficient design solutions in their heating, cooling, and ventilation systems. However, tall buildings may have potential environmental advantages, such as ample access to sunlight and wind for the incorporation of solar panels, photovoltaic cells, and wind turbines.

Tall buildings require an abundance of energy for operation and utilities. Many high-rises use more energy per resident than a well-built townhouse, and not much less than a small, well-built, single-family home. The Canada Mortgage and Housing Corporation (CMHC) states in this regard, "… on a floor area basis, (high-rises) consume more energy than single-family dwellings—even though the high-rise unit has much less exposed exterior surface" [2]. More detailed research is, however, needed considering various factors like building height, orientation and internal layout, materials, window-to-wall ratio, location, *etc*. to draw definitive conclusions. They also require a great amount of embodied energy, the energy needed to construct the building and to produce and transport required materials. Tall buildings, however, save energy for a city because people do not need to travel too far for business. Moreover, there is less power loss in a city's power grid. One of the principal problems with tall buildings of the past, even those offering great architecture, has been the failure to consider how the structure meets the ground and affects the surroundings at its base and street life. Disappointingly, this remains a common problem. Many tall building developments offer little to promote active pedestrian and social life at ground level. From an urban design perspective, environmental impact assessment is essential for any new tall building project.

3.3. Civic Infrastructure

A tall building can create problems, such as overcrowding around it that can decrease the quality of life unless conceived and adequately mitigated during the planning stage for the building's long term function. Tall buildings surely increase demand on transportation and infrastructure. Possible mitigation for increased traffic includes expansion of traffic capacities on roads and at intersections and multiplication of public transit options, which require major public works and construction. Traffic impact assessment studies should be required to identify its effect on the existing transportation systems. Likewise, a new tall building will place additional load on the existing power grid, water supply, and sewer systems. If a tall building is built in an undeveloped area, new cost-intensive infrastructure must be provided.

3.4. Socio-Cultural Factors

Society and culture play a key role in accepting or rejecting tall building development. In societies where living in a high-rise is the norm, local culture will have no problem with adding new tall buildings. People who were born and reared in tall buildings usually have no problem continuing to live in that environment. In contrast, people in some traditional societies who have been living for centuries in low-rise buildings may initially feel uncomfortable with living in high-rises until they become adjusted to the new lifestyle. Indeed, the type of social community created in the high-rise is different from that found in the low-rise.

Residential tall buildings, in particular, are linked to the social effects. Many scholars have expressed concerns about the socio-psychological impacts of living in high-rise housing. While high-rise housing may be desirable for single people and couples, it may be less desirable for a family with children. Some sociologists argue that the environment of tall buildings can make inhabitants feel claustrophobic by creating a rat-cage mentality. It is argued that low-rise living is closer to nature and facilitates a stronger community-oriented social life. As structures grow taller and taller, tenants become out of touch with the city life below. Constantine Doxiades, a reputable urban planner and architect, summed up this pessimistic feeling with these forthright words [3]: "High-rise buildings work against man himself, because they isolate him from others, and this isolation is an important factor in the rising crime rate. Children suffer even more because they lose their direct contact with nature, and with other children. High-rise buildings work against society because they prevent the units of social importance—the family, the neighborhood, *etc*., from functioning as naturally and as normally as before."

We note, however, that we are living in an era different from the time when Doxiades wrote his above statements. Clearly, not all present-day developers, architects, and planners are prepared to accept his disconsolate assertion.

3.5. Perception

An aesthetically unpleasant tall building may harm the image of a city. Some ill-conceived tall buildings have created a stigma in the public's mind. The demolition of the Pruitt-Igoe housing project in St. Louis in 1972 has been ingrained in the minds of a generation of planners and architects. The demolition occurred in response to strong residential dissatisfaction and high levels of criminal activity. Economic class, race, and poor planning, as well as insensitive linear blockish brutalist architecture, have been identified as reasons for the failure of this project [4]. To many people, tall buildings became synonymous with cheaply built, poorly maintained, blocks of apartments or offices detached from the ground plane which did not meet the needs of their users. Some tall buildings also failed by not considering the social and community life of their residents.

However, such misperceptions of vertical architecture are changing. Improvements in the design of tall buildings and the way they connect with their surrounding environment have resulted in a new generation of humanized buildings that are harmonious with their urban contexts. In Australia, Harry

Seidler designed tall buildings—the Riverside Development in Brisbane, Grosvenor Place in Sydney, and the QV1 Office Tower in Perth—with landscaped public plazas which contribute to the quality of urban life. Skygardens in the Menara Mesiniaga in Kuala Lumpur, Malaysia, and the Commerzbank in Frankfurt, Germany, and an open ground-floor garden in the Capita Centre in Sydney, Australia, show how green spaces can be incorporated into tall buildings, even on the most cramped central city sites, thereby contributing to the sustainability of these cities.

3.6. Public Safety

Many people are afraid of getting trapped during a fire in the upper floors of a tall building. Despite such natural feelings of danger, it is comforting, however, to know that available data and statistics reveal relatively small percentages of injuries and property damage caused by fire in tall buildings. Improving fire performance and safety involves provision of passive and active control measures such as fire-resistant materials to achieve code-specified fire rating, appropriate egress in building layout, compartmentalization to prevent fire spread along with appropriate fire suppression, fire detection and alarm systems, sprinklers and fire extinguishing systems, detailed emergency action and evacuation plans, *etc*. Smoke migration in a tall building during a fire is a major threat to life. In the design process, this threat is usually addressed through structural design, HVAC, and smoke-spread modeling techniques. These techniques attempt to identify aspects of building design that could permit smoke to propagate and threaten occupants and fire fighters. Many contemporary buildings rely on HVAC smoke control and pressurization systems to contain smoke by applying positive pressure above and below a fire floor and in stairways.

The malevolent destruction of the WTC towers in New York reinforced opinions about tall buildings as unsafe and caused some critics to conclude that this event marked the end of tall buildings. However, such criticism and perception did not impede tall building development in any way since the past decade has witnessed an unprecedented wave of new construction of tall buildings around the world. The collapse of the WTC has actually initiated rigorous research to improve tall building safety, security, and other aspects such as environmental quality. Particularly, investigators at the U.S. National Institute of Standards and Technology (NIST) have carried out extensive research on the causes of the collapse and on ways to improve tall buildings' safety [5]. Many developers, architects, and engineers have taken advantage of such research findings and recommendations by taking them into consideration. Replacement of the WTC includes plans to reconstruct tall buildings at the same location again. The groundbreaking ceremony for the new 541 m (1776 ft) tall One World Trade Center (earlier called Freedom Tower) took place on 4 July 2004. The developer plans to build additional towers on the site in the near future.

3.7. Historic Context and Placemaking

With regard to the built heritage, tall building proposals often are challenging and problematic because of their inevitable impact on the historic urban fabric. Insertion of tall buildings into this fabric undoubtedly alters the traditional skyline of the city. The impact of high-rise development is critical for the conservation of the built heritage of cities such as Kyoto, Shanghai, Athens, Jerusalem, Damascus, London, and Paris, to name a few. Many cities suffer from a lack of a strategic approach to managing tall buildings. Buenos Aires, Sao Paulo, and Mexico City are losing their local distinctiveness and urban character through the arbitrary *ad hoc* construction of tall buildings.

The design of new tall buildings should complement, not conflict with, the historic fabric. For instance, in the City of London, the fine medieval grain of the streets could be better maintained by the relatively small footprint of tall buildings rather than the much bigger footprint of "groundscrapers." Many European cities have regulatory control mechanisms that attempt to protect the built heritage. Similar regulations can also be found in countries like Israel and Australia. In the U.S., limits on heights of tall buildings prevailed for Los Angeles and Philadelphia for a long time, although these past limits have now been lifted. Most cities have now embraced pro-growth agenda and although the importance of built heritage elements varies from city to city, most cities are relaxing the regulations in favor of new tall buildings.

Another challenge is to make tall buildings support placemaking. Many tall buildings—both the sculptural iconic and simple "refrigerator" boxes—seem to have been designed as disconnected, stand-alone, "isolationist" pieces. The prevailing transportable "one-size-fits-all" cookie-cutter skyscraper model has created a striking global homogeneity. Instead, tall buildings should integrate with their immediate and city-wide socio-economic web. Future tall buildings should foster placemaking by relating to their specific locations, respecting the built heritage, and connecting with the local socio-cultural conditions.

3.8. Digital Revolution

Wireless and paperless communications have facilitated the interaction of people at disparate locations in various parts of cities, across countries, and around the world. People can work at home, other locations, or on laptop computers while traveling. The Digital Revolution has created a mobile and connected workforce. The Global Village of the early 21st century has declared that "distance is dead" and business can be carried out in the relatively inexpensive low-rise suburbs via electronic communication.

It may be argued to the contrary that human interaction in clustered environments has historically persisted. Apparently, efficient telecommunication has reduced the importance of the centrality of the urban core and thereby has increased the viability of less expensive and convenient suburban sites as venues for conducting business. Although pessimists have raised concerns about the persistence of tall buildings in high-density urban cores with low- to mid-rise buildings, and enthusiasm for supertall towers may wane in the near future—this has not yet happened. These predictions also conflict with the history of high-rise development, expected population explosions, and rapid urbanization. The ability of telecommunications to substitute for people interacting in proximity is questionable at best, since the needs for face-to-face conversation and seeing the body language of other parties are important elements in the business world. Despite decreasing costs of telephone services and email connectivity, physical proximity still matters. Evidence indicates that a majority of telephone and email contact is between people in close physical proximity [6]. Face-to-face contact remains crucial for communicating complex and intricate knowledge. After all, humans are an inherently social and gregarious species. Chemistry between people cannot be substituted by digital links.

4. Arguments for Tall Buildings

Despite the many challenges enumerated above, there is good reason for cheer. Tall buildings have many practical advantages that are worth exploring and exploiting.

4.1. Population and Migration Trends

Among the most pressing issues that have spurred tall building development and will likely continue, is the exponential increase in urban population worldwide in conjunction with wealth accumulation. Currently, almost half of the world is urban when 20 years ago it was only one-third. By 2030, it is expected that about 60% of the world's population will be urban. In 2050, over 80% of the world population will live in urban areas when the world's population is expected to reach 9 billion. At that time, all major cities of the world, particularly those in Asia, Africa, and Latin America, will have enormous populations, probably ranging from 30 million to 50 million, or more [7]. Accommodating such a large population in cities will be a colossal challenge. Horizontal scale of cities is continually being strained with no alternative but to build upward to accommodate people.

Rural-to-urban migration is one of the causes of urban population increase. Between 1945 and 1985, the urban population of South Korea grew from 14.5% to 65.4%, and to 78.3% of the total population by 2000. In China, it is projected that by 2025, 350 million people will migrate from a rural to an urban environment. Marcos Fava Neves predicted: "This will require five million buildings…equivalent of ten cities the size of New York" [8]. In other words, Chinese cities need to build to accommodate a population increase equivalent to the U.S. population in just 13 years. In such cases, high-rise development is almost certain to be part of the solution.

4.2. Global Competition and Globalization

The ongoing trend for constructing tall buildings around the world reflects the increasing impact of global competition on the development of the world's major cities. These cities compete on the global stage to have the title of tallest building with which to announce the confidence and global stature of their growing economies. An iconic tall building enhances the global image of the city. It is likely to put the city on the world map, thereby signaling and promoting its significant economic progress and advancement. Political leaders have supported constructing tall buildings to present their countries as emerging global economic powers. For example, Prime Minister Mahathir Mohamad of Malaysia publicly and strongly backed the building of the then tallest building in the world, the Petronas Towers in Kuala Lumpur, as a symbol of Malaysia's entry into the global economy. Likewise the ruler of Dubai had enormous influence in transforming it from a fishing town to a world-class commercial city with the construction of sky-hugging ultra-tall buildings including the Burj Khalifa and other towers.

In some parts of the world, globalization has immensely promoted local economy and consequently the construction of tall buildings. The City of Shenzhen, China, for example, was a small fishing village in the 1970s. Due to global forces and rapid foreign investment, it was transformed to a modern city of skyscrapers with a supertall tower like Shun Hing Square, one of the tallest in the world, dominating the Shenzhen skyline to compete with the nearby towers of Hong Kong. Foreign nationals have invested billions of dollars for building factories and forming joint ventures. It now is reputedly one of the fastest growing cities in the world, and is one of the most successful Special Economic Zones (SEZ) in China. Shenzhen's population has increased from 30,000 to more than 13 million during the last two decades. The city is home to the headquarters of numerous high-tech companies that house their offices in major tall and supertall buildings.

4.3. Urban Regeneration

Many city centers in developed countries that suffered from migration of their population to the suburbs in the 1970–1990s have witnessed a major return to their centers in recent years. The convenience of urban living once again is gaining favor by a greater number of today's population. Younger people desire city-center living where they can find residences close to work. The older members of society desire to live in the city to free themselves from the demanding maintenance of properties, to reduce driving, and to escape the feelings of loneliness and isolation experienced in suburbs. City centers provide plenty of socio-cultural activities and services that cover daily needs such as shopping, groceries, and healthcare within walking distances. Therefore, many cities are witnessing an urban renaissance and a desire to return to high-rise living in city centers. Tall buildings are viewed as tools to encourage central living and working. Construction of new attractive high-rises can also beautify and revitalize dilapidated districts and neighborhoods within the urban core and surrounding areas. This improves the quality of life in these areas by minimizing or eliminating social ills such as crime that might have been prevalent there.

4.4. Agglomeration

Tallness of buildings is also a matter of agglomeration in business districts. Urban agglomeration hinges on proximity of activities, and tall buildings do just that. Clustering of tall buildings fosters urban synergy among the diverse activities and specialized services. The high concentration of activities creates "knowledge spillovers" between firms in the same sector and across sectors that lead to increased innovation. In a denser and varied environment, knowledge can spill into unintended fields, and a significant share of knowledge transfer occurs informally. David Audretsch explains: "Since knowledge is generated and transmitted more efficiently via local proximity, economic activity based on new knowledge has a high propensity to cluster within a geographic region .... Greater geographic concentration of production leads to more, and not less, dispersion of innovative activity…." [9]. Clearly, the presence of an abundance of firms offering similar products spurs competition, innovation, and efficiency. Agglomeration improves economy of scale and can increase productivity through access to denser markets. Access to competing suppliers helps firms procure more efficient, cheaper, and more appropriate inputs. Researchers have attempted to quantify the impact of agglomeration. Colin Buchanan et al.'s research shows that "a doubling of employment density within a given area can lead to a 12.5% additional increase in output per worker in that area; for the service sector, the figure is far higher at 22%" [10].

4.5. Land Prices

Land prices always have been a prime driver for constructing tall buildings. A phrase for skyscrapers came from Cass Gilbert in 1900, "A skyscraper is a machine that makes the land pay" [11]. In large cities, properties are very expensive, and buildings logically grow upward. Low land costs clearly keep buildings closer to the ground; tall buildings are not an attractive option for small towns where land is cheap. Carol Willis has coined the expression "form follows finance" in which she argues that the economics of tall buildings play a key role in shaping a tall building [12].

Land prices recently have been significant drivers for tall building development in many cities seeking to re-populate their urban centers with residential-recreational complexes inserted in the predominantly commercial-retail Central Business Districts (CBD). These relatively new markets help drive up city center land prices, which makes building tall for investment return increasingly necessary. In the City of London, land prices are among the highest in the world, and great economic advantages exist for developers to maximize the rentable floor space of an area of land by building high. Consequently, London has witnessed a recent boom in tall building construction.

In cities like New York, Hong Kong, and Singapore, there is hardly any choice other than to build tall because geographic boundaries limit horizontal growth. In Singapore and urban Hong Kong, land prices are so high that almost the entire population lives in high-rise apartments. Of Hong Kong's total expanse of land, only around 25% is buildable; and yet it needs to house some 7.5 million inhabitants. Land value is unbelievably high, in the range of $30,000 per square meter, and therefore, developers maximize the site by building very tall buildings, between 50 to 80 floors [13]. In the case of New York, Rem Koolhaas, in his book *Delirious New York,* explained that Manhattan has no choice but extruding the city grid vertically [14]. Similarly, in Mecca, Saudi Arabia, land nearby the Sacred Mosque (*Al-Masjid Al-Haram*) is limited and extremely expensive and, therefore, has recently witnessed significant high-rise development, including the ultra-tall 95-story Abraj Al-Bait Towers.

4.6. Land Preservation

Sustainability promotes compact urban living and density is viewed as a tool to create more sustainable city. Many planners and institutions such as the Urban Land Institute in the U.S. are supporting this view: "By strategically increasing the number of dwelling units per acre, cities not only will go a long way toward meeting their sustainability objectives, but also will be competitive, resilient, and great places to live" [15].

Dense arrangements help preserve open space—a core goal of sustainability—that aims at preserving many different types of open spaces, including natural areas in and around cities and localities that provide habitat for plants and animals, recreational spaces, farm and ranch lands, places of natural beauty, critical environmental areas (e.g., wetlands), and recreational community spaces. Protection of open space ensures that prime farm and ranch lands are available, and it prevents flood damage. The availability of open space provides significant environmental quality and health benefits that include improving air pollution, attenuating noise, controlling wind, providing erosion control, and moderating temperatures. Open space also protects surface and ground water resources by filtering trash, debris, and chemical pollutants before they enter a water system. In many instances it is less expensive for a community to maintain open space that naturally maintains water quality, reduces runoff, and controls flooding than to use engineered infrastructure, such as water filtration plants and storm sewers. Lands with natural ground cover have no surface runoff problems because 90% of the water infiltrates into the ground and only 10% contributes to runoff. However, when 65% of the site is covered with impervious surfaces, 35% of the precipitation contributes to runoff. On paved parking lots, where the paving surfaces are impermeable and allow for a small amount of infiltration, about 98% of precipitation becomes runoff [16]. A 2002 survey of 27 water suppliers found that for every 10% increase in forest cover in a municipal water system's watershed, the cost of water treatment decreased by 20% [17].

Tall buildings can support dense arrangements and help in preserving open and natural spaces by accommodating many more people on a smaller amount of land area than can low-rise buildings. When developments expand vertically, public space, agricultural lands, and wilderness remain untouched. Tall buildings maximize building area with a minimum physical footprint. Accommodating the same number of people in a tall building of 50 stories *versus* 5 stories, for example, requires about one-tenth of the land.

Commercial and residential towers free the ground plane for ample green space, which supports human connectivity and social vibrancy. Through his "Towers-in-the-Park" model, Le Corbusier advocated the high-density city mainly for the purpose of increasing access to nature. Freeing up spaces for parkland brings about "essential joys" of light, air, and greenery. This will support creating healthy and walkable communities as well. Consequently, a number of key world cities in recent years have adopted policies that support tall building development [18].

4.7. Climate Change and Energy Conservation

Global warming could cause changed climate patterns like droughts and excessive rainfall, and disrupt agriculture. According to a NASA study, the Arctic perennial sea ice has been decreasing at a rate of 9% per decade since the 1970s, and is likely caused by climate change. These issues are significant for living conditions since they can profoundly impact our cities. For example, a 6 m (20 ft) rise in sea level would submerge all of South Florida [19].

Consequently, fighting global warming and reducing CO_2 emissions are becoming prime goals of many cities. The Kyoto Protocol was created in 1997 to fight global warming, and over 180 states joined the protocol by 2009. The increase in emissions will result in damaging the climate and hence the desperate need to stabilize carbon emission can hardly be overemphasized [20].

Tall buildings as a built form consume more material and energy resources in their construction, operation, and demolition than the low-rise or mid-rise buildings. By themselves they consume an enormous amount of energy, but have the potential to consume less energy than low-rise complexes since they have many energy-effective attributes such as agglomeration, savings in auto fuel and travel time, and reduction in losses in power lines, *etc*. The roof is a prime source of energy loss in a building in addition to the façade. As such, a 50-story building of 10 apartments per floor has one roof and 500 single-family homes each having the same floor area of an apartment have 500 roofs. Clearly, energy loss from 500 roofs is greater than that from one roof. Also, power in tall buildings can be served with a shorter length of distribution lines, and hence decreased power losses, than in low-rise complexes, when identical total space served is considered. However, pumping water to higher floors and operating the elevators consume additional energy in tall buildings. Foster *et al*.'s research supports the above observation that on the whole, tall buildings save energy relative to an equivalent floor area of low-rise buildings. They explained: "Manhattan can be considered the greenest place in

America, if measured by energy use per inhabitant. If New York City were a state, it would be 12th in population and last in energy consumption” [21].

A new generation of tall buildings, “green skyscrapers,” improves energy efficiency, and helps to combat global warming. Tall building design that incorporates energy-saving technologies also can substantially reduce CO_2 emissions. Green skyscrapers dubbed “zero energy” buildings have the potential to produce as much energy as they consume, or can act as “batteries” by producing even more energy than they consume, and are described as “positive energy” buildings, and can deliver energy to the city’s power grid. The green skyscraper model is important since the building sector today accounts for 30% to 40% of total energy use.

4.8. Infrastructure and Transportation

The high cost of maintaining expansive infrastructure hurts taxpayers and contributes to the fiscal crisis that many local governments face. The cost to provide and maintain public infrastructure and services for a given community in new sprawling development is higher than to service the same community in a “smart growth” or infill development. By and large, vertically configured buildings facilitate more efficient infrastructure**.** Simply put, a 500-unit single-family subdivision requires many more roads, sidewalks, sewers, hydro lines, power and gas lines, light standards, fire hydrants, *etc*., than that of a tall building, which allows integrating these systems efficiently in a dense manner. Therefore, tall buildings can play an important role in creating sustainable cities.

Tall buildings are generally recognized as an efficient type of compact development that helps reduce travelling distances and carbon emission. Compact development is needed since the outward expansion of cities into the suburbs has resulted in an increase in travel time and energy consumption, as well as CO_2 emission. A comprehensive review of dozens of studies, published by the Urban Land Institute, uncovered that since 1980, the number of miles Americans drive has grown three times faster than the population and almost twice as fast as vehicle registrations. The researchers conclude that one of the best ways to reduce carbon emission is to build compact places where people can accomplish more with less driving. Compact development reduces driving from 20% to 40% [22]. Compact development also maximizes the opportunity for combining journeys. Lunch hours and journeys to and from work can be utilized for errands such as shopping, banking, and going to the library or dry cleaners. In so doing, people maximize the efficiencies of their journeys. A concentration of multi-story development reduces costs and energy involved in transportation and urban services. Studies illustrate that cities such as Hong Kong and Singapore, where clustering of tall buildings is the norm, are among the world’s most transport-energy efficient, and environmentally friendly. Tall buildings in a compact urban core can reduce the per capita carbon footprint of a city with respect to suburbia.

4.9. Human Aspirations and Ego

According to Roberto Assagioli, a pioneer of psychosynthesis theories, the conception of height has to do with “self-realization,” “self-actualization,” and “human potential”; and consequently, humans always have admired tall structures since ancient times. A commonality of the “seven wonders” of the ancient worlds (e.g., the Temple of Artemis at Ephesus, the Lighthouse of Alexandria, and the Great

Pyramids of Egypt) is that all are tall and visible. Human spirit and resilience were the driving forces behind the skyscraper phenomenon that started in the late 19th century.

Tall buildings can project a sense of socio-economic power and promote the city as a leading and modern commercial center. Skyscrapers epitomize people's pride in their cities, and showcase the achievements of warm architectural passion and cold engineering logic [22]. Tall structures provide identity for a city, such as Big Ben and the Shard in London, the Eiffel Tower in Paris, the Space Needle in Seattle, Willis Tower in Chicago, Burj Khalifa in Dubai, and so on.

Observation decks celebrate human ascendance over the sky and the surrounding landscape by providing unique panoramic views of the world below. Humanity has a preoccupation with building large and building tall to defy gravity. "Tall has power." Imagining large cities without skyscrapers is antithetical to the human spirit, pride, and identity.

Therefore, human ego has a role in building tall. The skyscraper offers pride to citizens and politicians, as well as to those involved in the design and construction of a structure—the tallest, biggest, strongest, and most beautiful, *etc*. At the 2009 CTBUH conference, Chicago Mayor Daley was asked, "Do you see a future in which Chicago would again be a world leader with the 'World's Tallest Building'?" He answered, "I hope so, sure, I am always looking for developers and architects and all those in the financing for taller buildings. Yes, I think it is important for us, it really enhances the skyline. It shows that we are willing to challenge our city, and especially with taller skyscrapers. Yes, I am 100% for it" [23].

4.10. Emerging Technologies

The evolution of the tall building has led to major advances in engineering and technology. As today's technology becomes increasingly sophisticated, architects have an opportunity to build taller and implement their desire for the latest and utmost aesthetic expressions of tall buildings. Developers and architects increasingly are employing new technologies and aesthetics to boost their reputation, prestige, and enhance their business. They have been pushing the boundaries of how architecture is perceived by the society and architecture's potential for unconventional design through visionary projects and technological innovation. At the time of this writing, some are continuing with such visions of building up to as high as 3.2 km (2 mi) piercing through the clouds. Indeed, new technologies are motivating architects and engineers to provide new innovative and attractive design.

The demand for high-quality tall buildings has resulted in the advancement of science and engineering. Proliferation of information technology has facilitated the design and construction of tall buildings with limitless possibilities. The use of Building Information Modeling (BIM) and Geographical Information System (GIS) by architects, planners, and engineers has become ubiquitous. The search for higher quality encouraged research in areas such as building service systems, computer sciences, façade engineering, glazing, daylight and heat control, structural framing systems, ceiling systems, lighting, ventilation, exit strategies, water recycling systems, among others. Tall buildings have challenged technology itself and allowed us to build towers more efficiently and sustainably; and to create internal environments that are comfortable, productive, and energy-efficient. The prevalent green movement has propelled the design of high performance tall buildings employing intelligent technologies and smart materials.

Present and future research addresses the possibilities of using powerful technology such as nanotechnology and biomimesis. Scientific tall building research is generating new products such as anti-reflective façade coatings with designs based on moth's eyes! Technological advances, such as the use of blast furnace slag in high-strength concrete, offer higher performance and sustainability benefits.

5. Developments in Structural Systems

Structural systems play a key role in determining the form of a cost-effective tall building. Because of the current trend of pluralistic architectural style, structural systems have become more varied and somewhat lost their inherent logic by conforming to the predetermined form-giving by the architect. The style and aesthetics of buildings are integrally related to the horizontal and vertical configurations. Earlier, the advent of computers, in conjunction with a boom in the construction industry following the Great Depression and World War II, facilitated the development of new structural systems and forms.

As tall buildings are becoming increasingly taller, as with other man-made structures, the greatest danger is, and has been, the danger of collapse due to lack of structural integrity for standing up to the fierce natural forces of gravity, wind, and earthquakes. For tall buildings wind forces primarily control the design of the structural system. A building's slenderness ratio (ratio of height to least width) has a major influence on its structural efficiency. Although for wind loads dynamic influence becomes important at a slenderness ratio of about 4 and above, it starts being highly critical at higher values [24]. Efficient structural systems can be employed to control the effects of wind for tall building. Aerodynamic modifications of the building form in conjunction with structural optimization are effective design approaches for reducing wind-induced vibrations in tall slender buildings, which are subjected to across-the-wind motion caused by vortex shedding. In this phenomenon, wind hits a building's façade swirling around adjacent faces revolving in the form of vortices. They break away from the building on one side and then on the other, and continue this effect. As each vortex breaks away, wind speed on its building side rises, lowering the pressure and pulling in its direction. Thus, the building experiences a side-to-side repetitive push because of the alternating effect of the vortices. Large vortices tear away and re-form themselves whipping the tall building resulting in aerodynamic instability. The principal approach to aerodynamic modification is to "confuse" the wind by disrupting its streamlined flow as a boundary layer and not allowing it to re-organize by creating mild turbulence around the building. Such modifications are implemented by providing a building's cross-sectional shape, varying the cross-section along the height, slotted or chamfered building corners, fins, stepbacks, through-building openings, sculptured tops, *etc*., which are compatible with currently prevailing pluralistic building forms. Different types of damping systems introduced in such buildings can also significantly improve structural efficiency.

Buildings in seismic zones warrant additional considerations; the principal among them is the requirement of ductility which provides for adequate energy-absorption capability of the structure. Tall and slender buildings are less vulnerable to seismic forces because of their smaller fundamental natural frequencies with regard to low-rise or mid-rise buildings. Tall buildings with low natural frequencies founded on rocks or hard soils with higher ground frequencies perform even better because the seismic forces are not significantly amplified. However, these buildings must still be provided with sufficient ductility.

Fazlur Khan pioneered a groundbreaking concept based on his realization that as buildings become taller, there is a "premium for height" due to lateral wind forces and, consequently, demands on the structural system exponentially escalate, increasing total material consumption [25]. He developed and refined the revolutionary tubular building concept. Modified versions of the basic framed-tube form, such as bundled tube, braced tube, composite tube, and tube-in-tube, to name a few, appeared on the building scene. These concepts have been employed for both steel and concrete buildings. The concept of "premium for height" led Khan to develop the revolutionary height-based systems charts classifying steel and concrete high-rise structures in 1969 that acted as a template for designers for structural system selection [25]. Expanded height-based systems charts based on a broader classification of interior and exterior structures were later proposed by Ali and Moon [26]. A new buttressed tube system was employed by Bill Baker and his associates at SOM in the Burj Khalifa building as the latest innovation. The large concrete structural core acting as a solid tube is now gaining more significance in resisting lateral loads. This was employed in the 610 m (2000 ft) tall Chicago Spire Tower project (unbuilt) designed by Santiago Calatrava and engineered by SOM. Thus the move in structural circles now seems to be toward the interior structural system that allows the architect to articulate the façade system for unobstructed views of the outside looking from the inside and achieve desirable unhindered architectural expression.

Tall buildings transfer large magnitudes of loads to the ground and hence strong foundations are necessary for such buildings. Where bedrock is encountered at a reasonable depth from the ground surface, loads are transferred through piles or caissons. In softer soil and where bedrock is not available at a reasonable depth, a mat foundation is the usual choice. In many cases, piles or caissons are combined with mats to increase the foundation capacity or to distribute the loads more uniformly to the piles or caissons. In general, foundation design is based on thorough subsurface investigation, and although it is a technical challenge, it is not a major impediment to contemporary tall building construction. An early example of a building with such a challenge in foundation design is the One Shell Plaza building of 1971 in Houston, Texas. The project was originally envisioned as a 35-story building due to foundation limitation of the soil at the site. But the building was later designed and built by changing the height to 52 stories. The entire structure was made lighter by building in lightweight concrete on a mat foundation and high strength concrete was used to reduce the size of structural members, thereby making the additional 17 stories a possibility. Tall buildings should never be built in seismic zones where liquefaction of soil may take place.

A recent trend for some time has been to build multiuse tall buildings to maximize rentability during fluctuating real estate market conditions and the convenience of the occupants. It is possible that different vertically stacked structural systems can be designed to optimize the overall structural performance and facilitate the use of different architectural plans catering to the needs of the occupancy and the arrangement of mechanical and other physical systems with minimum interference with the structural systems. Even the architectural expression can be vertically varied this way, if desired, to reflect the type of occupancy and for the sake of creating aesthetic diversity. This, of course, calls for further research.

6. The Contemporary City and Its Transformation

Exponential growth of cities, especially those in developing countries, is creating megacities with the population of 10 million and more at a rapid rate. The modern city has become so vast and encompasses so many different densities of development, diverse kinds of activity, and such a variety of communities, that it is unlikely that any singular design concept could emerge to give form to a large city. The center of gravity of tall building construction has lately shifted from the U.S. to East Asia and the Middle East and, to some degree, Europe and India. The urban landscape represented by tall buildings in New York, Chicago, Houston and some other U.S. cities, reigned supreme with supertall buildings. The tallest building of the world, until 1996, was the 442 m (1451 ft) high Willis Tower in Chicago. That title was stripped by the Petronas Towers in Kuala Lumpur standing at 452 m (1483 ft). Soon after, in 2004, Taipei 101 in Taipei surpassed the Petronas Towers by soaring to a height of 509 m (1670 ft) to become the world's tallest building. It retained the title until Burj Khalifa was completed in 2010, which rises to 828 m (2717 ft).

The development of tall buildings in the Pacific Rim countries began in Hong Kong and, to a lesser extent, in Singapore. Hong Kong has many similarities with New York: both are land-starved and surrounded by water; both are port cities with perfect harbors; both are important cities of international trade and commerce; and both cities had large population. Considering all these factors, they consequently embraced tall buildings as their dominant building type. Beginning in the 1970s, the "Manhattanization" of Hong Kong was complete by the end of the 20th century. Today, both Hong Kong and New York are identified as international skyscraper metropolises. Hong Kong has surpassed New York in most areas of urbanism: population density, number of tall buildings, and the effectiveness of mass transportation. This is despite the fact that many of the notions of American architects envisioned earlier materialized in Hong Kong years later, e.g., the recently built International Commerce Center, the tallest building in Hong Kong, and the Two International Finance Centre. Some other Asian cities where major urban transformation is taking place are Shanghai, Kuala Lumpur, and Taipei.

Shanghai's skyscrapers rival those of New York, Chicago, and Hong Kong. Along with the emergence of spectacular skyscrapers, the city's Maglev train line and other transportation networks and plans for a large number of subway lines, the city has experienced a major transformation. This integration of the city's tall buildings with its transportation infrastructure has attained a remarkable level through blending the vertical and horizontal scales of the city. Pudong, a newly developed area that is Shanghai's flagship development zone, has a large number of tall buildings and is a magnet for attracting business centers of financial organizations, including international ones. Construction of China's tallest building, the Shanghai Tower rising 632 m (2074 ft) and poised to be completed in 2014, will stand alongside the Shanghai World Financial Center (presently the tallest in China) and Jin Mao Building.

High-rises are being built in many cities of India to keep up with the large migration of people to cities from rural areas. However, Mumbai being the financial capital of India, which is experiencing a high economic growth rate next to China, has a large number of high-rise proposals being considered by the authorities. A number of tall buildings have been built and others are under active consideration.

Currently, the 117-story, 450 m (1,476 ft) high World One Tower in Mumbai, India, purported to be the world's tallest residential building, is scheduled to be completed in 2014.

Another city of enormous growth, in recent times, is Dubai, the most populous city of the United Arab Emirates (UAE). Their earliest skyscraper was the 149m (489 ft) Dubai World Trade Center of 1979. In 1999, the iconic Burj Al Arab caught the world's attention with its iconic sail-shape reaching to 321 m (1053 ft). Since 2005, Dubai has entered into an era of emerging skyscrapers and an increasing number of high-rise buildings. However, the most remarkable skyscraper in Dubai is the Burj Khalifa of 2010, rising to about 828 m (2717 ft), which has assumed the title of the world's tallest building, exceeding the height of the 509 m (1670 ft) tall Taipei 101 of 2004, and the tallest freestanding CN Tower in Toronto, Canada that rises to 553 m (1815 ft).

The race for height continues. Other cities vying for spectacular height in the Middle East are Abu Dhabi in UAE, Doha in Qatar, and Riyadh and Jeddah in Saudi Arabia. A common thread in all these developments is the accumulation of wealth, prestige, and aspiration to be part of the global and regional economy.

6.1. Tall Buildings and Recession

Although the year 2008 marked the beginning of a global economic crisis, it witnessed extensive high-rise construction and was labeled a "bumper year for skyscrapers". Geographically speaking, the tallest 10 buildings completed in 2008 reinforce the prevailing trend that Asia and the Middle East are becoming the center of high-rise construction globally. Of the 10 tallest buildings on the 2008 list, six are located in Asia (all in China) and three in the Middle East (all in Dubai).

The year 2009 continued the high-rise construction boom. It was a successful year for the American high-rise. During this time, the U.S. constructed three of the five world's tallest buildings: the Trump International Hotel and Tower in Chicago (423 m/1389 ft); Bank of America Tower in New York (366 m/1200 ft); and Aqua in Chicago (262 m/858 ft). Chicago is also home to more tall buildings above 200 m (656 ft) completed in 2009 than any other single city in the world; five such towers opened in Chicago that year, while no more than three such buildings opened in any other city worldwide. However, Asia, in particular China, remains the center of the world's tall building construction. Over 50% of all buildings 200 m (656 ft) tall or taller completed in 2009 were in Asia, with some 36% in China alone [27].

Despite a continuing economic recession, the year 2010 has been the most active in the history of skyscrapers. Building heights and volumes of high-rises have increased. CTBUH data show that 66 buildings with a height of more than 200 m (656 ft) were constructed in 2010—exceeding the previous record of 48 buildings completed in 2007. On 4 January 2010, Dubai celebrated the grand opening of the world's tallest building, Burj Khalifa. Some other notable buildings completed in 2010 are the Nanjing Greenland Financial Center (450 m/1476 ft) in Nanjing, China; the Index (326 m/1070 ft) and HHHR Tower (318 m/1042 ft) in Dubai, UAE; and the Capital City Moscow Tower (302 m/989 ft) in Moscow, Russia [28].

In the following, a few case study examples of recent spectacular tall buildings of the 21st century are presented. These towers dramatically contrast with their predecessors from the 20th century in terms of placemaking, form, materials, internal spaces, and energy efficiency.

7. Case Studies

7.1. Trump International Hotel and Tower

Designed by SOM and completed in 2009, the 423 m (1388 ft) tall 92-story Trump International Hotel and Tower in Chicago is the tallest residential and the largest concrete building in the U.S., and the tallest building in North America since the construction of the Willis Tower (formerly Sears Tower) in 1974. The building's centrally located site offered the opportunity to create active open space for the city. It provided a connective link for the Chicago Loop, North Michigan Avenue, and the riverfront. Considerable urban design considerations were given to the building during its planning stage to adequately link it to its surroundings. The designers shaped the building to reflect its orientation along the water by making its south side parallel the river bank, and at its base, provided a three-level walkway that anchors the waterfront and creates a lively environment with restaurant and shopping. The tower's massing opens up an expansive promenade until it meets the water. This delightful gathering place includes retail, pedestrian walkways, and a landscaped riverwalk park. The promenade establishes a pedestrian link between North Michigan Avenue and State Street. On the north side of the tower, the site plan creates a landscaped walkable link between the Wrigley Building arcade to the east and Wabash Avenue to the west (Figure 1).

Figure 1. The Trump International Hotel and Tower in Chicago. It is the tallest residential and the largest concrete building in the U.S. A special feature of this building is that it is one of the largest buildings, which was partially opened to the public during construction. This required a feat of planning, mixed-use programming, and construction with the collaboration of the owner, architect, construction manager, and the City of Chicago [4].

A special feature of this building is that it is one of the largest buildings, which was partially opened to the public during construction. This required a feat of planning, mixed-use programming, and construction with the collaboration of the owner, architect, construction manager, and the City of

Chicago. The tower combines 60 floors of luxury condominium units stacked over 11 floors of hotel units, with parking spaces, and a number of amenities, including a restaurant, banquet space, health club/spa, and lounges. Such stacking of the different programs on top of one another creates an adaptable building. A main attraction of living in Trump Tower is the close-up views of the waterfront and some of Chicago's most well-known buildings. Through a series of setbacks at different heights, the tower closely relates to its neighboring buildings like the Wrigley Building, Marina City towers, and the IBM Building. The tower's design is much influenced by the presence of water in the nearby Chicago River; for example, a 10.6 m (30 ft) high "structural glass wall, hung from the second floor, resembles a cascading wave" [29].

7.2. Linked Hybrid

The Linked Hybrid provides a compact housing solution in a climate of high housing demand in Beijing, China. The 220,000 m^2 (2.4 million sq ft) pedestrian-oriented Linked Hybrid complex is located near the old city wall of Beijing. Designed by Steven Holl Architects, and opened in 2009, it is a complex consisting of eight 60 m (197 ft) tall asymmetrical towers and a 35 m (115 ft) tall hotel interconnected at their upper levels by a series of bridges. It contains a large number of apartments, commercial spaces, hotel, cinema, a kindergarten, and underground parking.

The Linked Hybrid design was intended to strongly support a "sustainable" social life and communal spirit. This is a positive feature since high-rise living is often criticized for fostering a sense of isolation. This social life is fostered through the spatial organization, which provides a strong connectivity among the complex parts and invites residents of adjacent neighborhoods to enjoy the amenities of the complex. Towers are clustered around a central courtyard and linked through enclosed "streets in the air," or skybridges. Earlier, Le Corbusier proposed "streets in the air" in his Unite d'habitation (but did not link the buildings together until his Algiers mega-structure project). The latter projects, of course, failed because architects and planners did not fully take into account the lifestyles and needs of the inhabitants. The Linked Hybrid promotes interactive relations and encourages encounters in the public spaces that encompass commercial, residential, educational, and recreational opportunities (Figure 2).

The courtyard boosts civic and community life through outstanding landscaping. The complex is simultaneously characterized by a porous pattern, where spaces between buildings seamlessly connect the outside world to the courtyard within. The ground level offers a number of open passages that invite people to walk through the courtyard. People are invited to enjoy the public roof gardens located on intermediate levels of the lower buildings. At the top of the towers are private gardens connected to the penthouses. The multi-layered circulation pattern on the ground and in the upper floors connects the various parts of the development. The design is meant to make the Linked Hybrid an "open city within a city." While Beijing's current development style is "object buildings" and freestanding towers, this "city within a city" envisions linked spaces that support the daily life of over 2,500 inhabitants. It has pushed the envelope by implementing urban design in the sky, that is, three-dimensional urban design. The "streets in the air" concept was presented earlier by Le Corbusier and implemented in a number of residential towers [30], for example, in the *les unites* project. However, in that model, vertical streets were hidden, and meant to mainly separate vehicle and pedestrian traffic. In contrast, Steven Holl exposed the upper-floor streets and crafted them as sculptural, external bridges that visibly connect buildings from one end to the other. Skybridges 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.

Figure 2. The Linked Hybrid, a building complex in Beijing, China. The moderate building height, subtle colors, and façade design employing a square grid pattern make the complex harmoniously blend in with the city's older part. It represents "urban design in the air." Designed by Steven Holl Architects, it won prestigious awards including the Best Tall Building Overall Award by the CTBUH in 2009 [4].

7.3. Bank of America Tower

The Bank of America Tower, completed in 2009, is located in the Times Square of Midtown Manhattan, on West 42nd Street between Broadway and 6th Avenue, across from Bryant Park. It contains 58 floors, reaches a height of 366 m (1200 ft) and employs a low-emission insulating glass curtain wall façade in the deconstructivist architectural style. It was designed by Cook + Fox. Its main use is commercial office space. The form of the building, "with its prismatic upward gradation, follows the model of visions of Hugh Ferriss, developed in the 1920s, and is, at the same time, inspired by natural crystal formation" [31].

The Bank of America Tower is located in one of the most bustling areas of Manhattan, therefore connecting well with the existing transportation systems below grade. Since there were a dozen or so subway lines available on this street corner, the designers opted out of building any parking structures, even though there would be over 4000 people employed in the tower. Although the building does not include parking for its employees, it does provide a winter garden, pedestrian walkway at street level, and public plaza.

In its December 2005 issue, *Popular Science* magazine commended the Bank of America Tower for its ambitious eco-friendly design. The building contains a 5 MW on-site gas generator with heat capture; this piece of equipment provides two-thirds of the building's energy requirements each year. In addition, one of the building's two spires is actually a wind turbine, which generates electricity. The site provides for retention of stormwater and grey water, as well as recycling systems. It is the first skyscraper designed to attain Platinum LEED Certification (Figure 3).

Figure 3. Bank of America Tower in Manhattan. It is the second tallest building in New York, and it employs a glass curtain wall façade in the deconstructivist architectural style. Its prismatic form is inspired by natural crystal formation. The tower connects well with the existing transportation systems below grade [32].

7.4. Burj Khalifa

The tallest building of the world, Burj Khalifa was designed by SOM with Adrian Smith acting as chief architect and Bill Baker as chief structural engineer. Its height is 828 m (2717 ft) with 160 floors. The developer is EMAAR Properties and the principal contractor is Samsung C&T of South Korea. The construction of this mega-tower, whose original name was Burj Dubai, started in 2004 and was completed in 2010. The global financial crisis hit Dubai at the time of the project's completion, causing Dubai to borrow money from oil-rich Abu Dhabi to complete the project. Therefore the tower was renamed to honor the ruler of UAE for his support of the project. The decision to build this ambition-driven tower was based on the government's decision to diversify from an oil-based economy to a service-oriented and tourist-based one, and to draw international attention and foreign investment. The tower was designed as a centerpiece of a grand scheme for a large mixed-use development that would include 30,000 homes, 9 hotels, 19 residential towers, the Dubai Mall, 3 ha (7.5 acres) of parkland, and a 12 ha (30 acre) man-made Burj Khalifa Lake.

The architectural and engineering design concepts of Burj Khalifa have been widely publicized and recorded in literature [14,33]. Its form is organic and biomorphic in nature. The form was based on geometric patterning systems embodied in Islamic architecture and incorporates cultural and historical elements of the region. The triple-lobed footprint was inspired by the flower *Hymenocallis*. The tower is made of three wings forming a Y-shaped floor plan around a central plan. The form also evokes the onion domes, an integral element of Islamic architecture. The three wings act as buttresses to the hexagonal core stabilizing the structure against lateral forces and offering panoramic views of its surroundings, including the Persian Gulf. The entire tower used concrete as the structural material except the spire of the tower, which is composed of structural steel. The exterior cladding system was designed to withstand Dubai's extreme summer and consists of reflective glazing, and aluminum and textured stainless steel spandrel panels with vertical fins (Figure 4).

Figure 4. Burj Khalifa in Dubai, world's tallest building. A remarkable landmark in the middle of a growing complex of skyscrapers, quite a jump from what was a desert landscape. The tower along other tall and super-tall buildings have dramatically altered the cityscape and put Dubai on the world map [34].

The tower will hold up to 35,000 people. It has swimming pools, 900 private apartments, corporate offices and suites, restaurants, sky lobbies, and an observation deck. The building has 2909 stairs throughout its height, and a total of 57 high-speed elevators and eight escalators were installed to transport people and cargo. From a distance, it has stark resemblance to the mile-high Illinois Tower conceived by Frank Lloyd Wright in 1956 because of its look-alike needle-shaped appearance. Like the two other mega-towers—the Petronas Towers and Taipei 101—Burj Khalifa looks enormously out of scale in its context. However, its architect Adrian Smith thinks its setbacks connect it to the surrounding city, both now and for the future. At lower levels the setbacks relate to existing low and mid-rise buildings and those at the higher levels will ensure that the tower will remain connected to the context in the future when more supertall buildings are built.

Although the tower has attained global status, the exorbitant cost to build it in a rather low density city is hard to justify at a time when we note the downturn of the world economy, a possibility that always should have been anticipated, and has reportedly resulted in excessive vacancy rates and revenue losses. The enormous wealth spent on the tower arguably could have been better spent on social and technological projects (e.g., education, research and development, healthcare, *etc*.) and on developing self-sustaining manufacturing industries that the region, as a whole, needs for social uplifting and future long-term economic development. Of course, the Empire State Building also faced a similar fate when it was built, but recovered later and became the symbol of New York. Something similar may happen to Burj Khalifa when the world economy takes an upswing once again. Only the future can tell.

7.5. Marina Bay Sands

Singapore is an island city state that has no room for lateral expansion. Because of its open door economic policy, visionary political leadership, and by virtue of being a strategically located port, Singapore has become a vibrant bright spot in Southeast Asia. Designed as an integrated resort fronting Marina Bay by visionary architect Moshe Safdie, Marina Bay Sands is a 929,000 m^2 (10 million sq ft), high-density, mixed-use resort that brings together a 2,560 room, 265,000 m^2 (2.85 million sq ft) hotel and convention center; complete with shopping and dining, theaters, museum, and a casino, across the water from Singapore's downtown core. Conceived of as a microcosm of a city rooted in Singapore's culture, climate, and contemporary life, the project anchors the Singapore waterfront, creates a gateway to Singapore, provides a dynamic setting for a vibrant public life, and lifts urban design off above ground. By breaking the conventional mold of resort projects, Safdie defined a new urban form for the "Garden City" of Singapore. Although this project does not represent a very large urban area and represent a typical urban design paradigm, it points to an innovative "urban design in the air" model that connects tall buildings at the roof—a concept that can be extended to other floor levels and applied to larger land-starved areas to create public and private spaces in the sky. Such elevated green spaces can also offer panoramic bird's eye views that are lacking at ground level (Figure 5). The project was completed in 2011.

Figure 5. The Marina Bay Sands in Singapore. The SkyPark at the top of the towers connecting them was created due to a shortage of land. Conceived of as a microcosm of an island city rooted in Singapore's culture, climate, and contemporary life, the project anchors the city's waterfront, creates a gateway to Singapore, and provides a dynamic setting for a vibrant public life. It allows visitors to enjoy splendid views of the surrounding environment from the SkyPark. Protected from the winds and lavishly planted with hundreds of trees, the SkyPark celebrates the idea of the Garden City that has been the underpinning of Singapore's urban design strategy. Although this project does not represent a very large urban area, it points to a new urban form and urban design strategy that can be applied to larger land-starved areas by creating public spaces in the sky [35].

With a program of so many hotel rooms, the most efficient massing would have resulted in a single monolithic building. Due to its prominent location within the Marina Bay, it was decided that for Marina Bay Sands three towers would be created instead of one. The concrete towers are set at a height of 55 stories with large "urban windows" between them. The towers spread at the base forming a giant atrium at the lower levels, and converge as they rise. The design of the façades relates to the site context: the glazed west side faces the city center while the east side is planted with lush bougainvillea facing the botanical gardens. Spanning across the top of the three towers is a 1 ha (2.5 acre) garden "SkyPark"—a new type of public space, which creates spectacular views of the sea from downtown, and a new gateway to the city from the sea.

A tall building is a tower that primarily stands out for being tall. Marina Bay Sands, however, is an example of a different type of tall building project grounded in an unconventional urban design concept. The building has departed from the conformist model of an integrated mega-hotel and its resort, and in doing so, distinguished itself as an innovative typology and a new icon for Singapore.

The SkyPark

Aside from the 929,000 m^2 (10 million sq ft) of building program, the project brief also called for the development of extensive gardens, swimming pools, jogging trails, and public spaces. As one of the aims of the project had been to minimize the height of the podium buildings—seeking to project

Singapore's pastoral hills more than its urban core, the problem cropped up that the complex program left no vacant land suitable for these amenities. Creating gardens on top of the roof of the casino and the convention center was investigated; however, it was found that these were vast spaces lacking views, overshadowed and overpowered by the adjacent hotel towers. The idea emerged to bridge between the three towers in order to reclaim space and create a 1 ha (2.5 acre) park in the sky.

An engineering marvel at 200 m (656 ft) above the sea, the SkyPark spans from tower to tower and cantilevers 65 m (213 ft) beyond its supporting structure. Longer than the Eiffel Tower is tall, and long enough to park four-and-a-half A380 jumbo jets, the 340 m (1116 ft) long SkyPark accommodates a public observatory, gardens, a 150 m (495 ft) swimming pool, restaurants, jogging paths, and offers panoramic views—a formidable resource in a densely built city like Singapore. Protected from the winds and lavishly planted with hundreds of trees, the SkyPark celebrates the idea of the Garden City that has been the underpinning of Singapore's urban design strategy.

The dynamic properties of a tall building structure are particularly hard to predict as many elements contribute to building movement. Colorado-based CPP Wind Engineers was engaged to carry out extensive wind testing on the towers and the SkyPark to provide the design team with the data necessary to develop the engineering approach. In addition to determining the loads for each tower in isolation, it was necessary to predict the behavior and movement of each tower relative to the others. This allowed for strategies to be developed for the spanning steel SkyPark. The test results showed that each tower could sway as much as 2.5 cm (1 in) from center. The design team at ARUP developed a series of aluminum and stainless steel plates, and multi-directional bearings, located at the bridge spans between towers, which act as sliding components and allow for the natural and individual movement of each tower.

7.6. Ecological Design in the Tropics (EDITT)

The 26-story EDITT Tower in Singapore (completion pending), designed by architects T R Hamzah and Yeang (not yet built at the time of this writing), will help increase its location's bio-diversity and rehabilitate the local ecosystem in Singapore, where the natural ecosystem has been badly destroyed. A crucial aspect of urban design is placemaking that connects the outdoor space to the building's space. Tall buildings with vertically stacked floors have a conflict with effective placemaking. EDITT Tower mitigates this problem by creating "vertical places" bringing street life to the upper parts through landscaped ramps upwards from the street level. The verdant high-rise integrates green space and human use areas at a ratio of 1:2 through the well planted façades and vegetated terraces that surround the building. These vegetation areas are designed to wrap around the building by continuously ramping upwards from the ground to the uppermost floor. Thus, the organic vegetation spaces effectively integrate the skyscraper's 26 stories vertically into the surface landscape. This extension of the horizontal plane into the vertical space is further promoted by stretching the street-level shops and pedestrian activities up to the sixth floor along the landscaped ramping system. More importantly, the planting of the tower uses indigenous plants. The organic components were defined based on the survey of plant life in the neighborhood of the building. The EDITT Towers won the 1998 competition for Ecological Design in the Tropics. Construction is pending (Figure 6) [36].

Figure 6. Ecological Design in The Tropics (EDITT) [37].

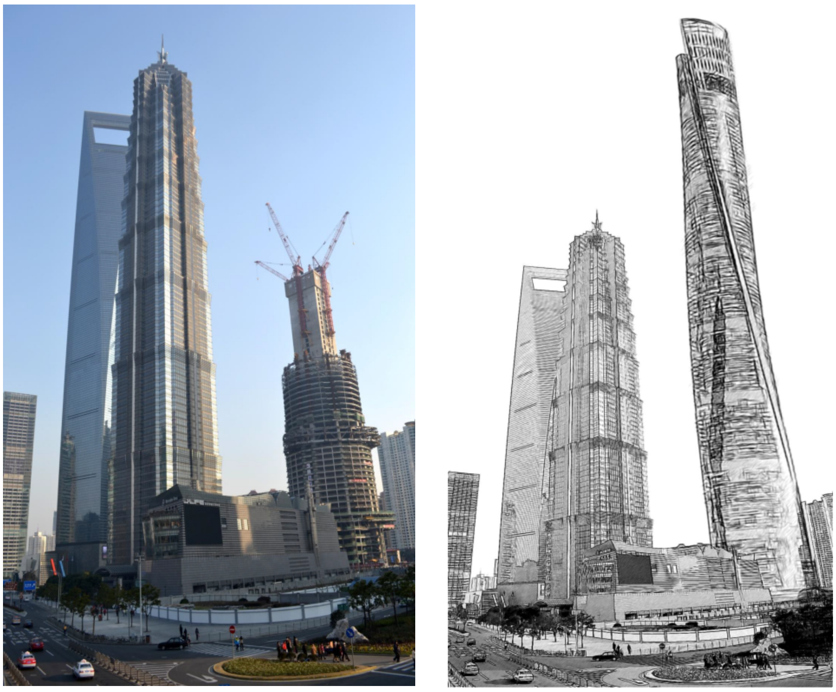
7.7. Shanghai Tower

Shanghai Tower (also called Shanghai Center) was designed by Gensler and is under construction in the Pudong District at this writing. The target year of completion is 2014. When completed, it will be the tallest building in China, rising to 632 m (2074 ft) and having 121 stories; and the second tallest in the world, next to Burj Khalifa in Dubai; and taller than the 588 m (1,929 ft) tall Ping An International Finance Center with 115 stories in Shenzhen, China, also to be completed in 2014. Planning for the Lujiazui Finance and Trade Zone dates back to 1993, in which three supertall buildings were envisioned with this tower next to the Jin Mao and Shanghai World Financial Center. Consistent with the present trend for skyscrapers, the tower's skeleton is made up of a composite steel-concrete structure. Its curved façade and spiraling form heralds the dynamic emergence of China as a modern economic powerhouse.

The rapid urbanization of the Lujiazui district demanded a solution of high density development by adopting appropriate planning and design strategies on the one hand and "breathing room" on the other [38]. Gensler applied the notion of traditional lane houses found in Beijing *hutongs* and Shanghai's *shikumen*, where families live in close-knit dwellings around a communal open space. For the Shanghai Tower, the neighborhoods are transposed vertically, each with its own sky gardens, to foster interaction and a sense of community.

It is a multi-use building comprised of office, hotel, retail, sky gardens, public space, *etc*. The tower is organized in nine cylindrical buildings stacked on top of each other and enclosed by a double-skinned glass façade. The outer layer spins as it rises upward and envelopes nine indoor zones providing public space for visitors. Each of the nine areas will have an atrium featuring gardens, cafes, restaurants, and retail space, and provide panoramic views of the city. The sky gardens are intended to provide visitors a venue to meet, eat, and shop, thereby cutting down the time needed for people to travel on the elevators. Retail and event spaces are also provided at the tower's base. The tower will feature the world's highest non-enclosed observation deck (Figure 7).

Figure 7. Shanghai Tower, currently under construction. When completed in 2014, it will be the tallest in China and second tallest in the world after Burj Khalifa. Consistent with the present trend for skyscrapers, the tower has "out-of-the-box" form. Its spiraling shape with a curved façade heralds the emergence of China as an economic powerhouse [39].



The building is one of the most sustainable buildings in the world. The tower's swiveling, asymmetrical glass façade confuses the organization of wind forces and reduces wind loads on the building. The building's spiraling parapet collects rainwater to be used for the tower's heating and air conditioning systems, and wind turbines situated below the parapet generate on-site power. Further, the gardens nestled within the building's façade create a thermal buffer zone while improving indoor air quality. Power for the building will potentially be generated by wind turbines. This new tower will undoubtedly be a new icon on Shanghai's skyline enriching it further. It will anchor the Lujiazui district and become one of the foremost commercial destinations of the world. It shows a new way of envisioning cities, corroborating the implementation of the vertical theory of urban design. Because of its height and iconic character and undulating, transparent façade, the tower will be visible from all directions and be another new landmark for the city.

7.8. Shard London Bridge

The Shard London Bridge, or the "Shard of Glass," or simply the "Shard" as it is also called, is a residential tower designed by Renzo Piano and engineered by Arup and WSP Canto. Its construction has been completed this year (2012) and is now the tallest building in the European Union. It will open in the first quarter of 2013. It contains 72 stories and rises to 310 m (1017 ft). Its construction has taken place on the site of the existing 24-story Southwark Towers of 1976. The tower has been designed with an irregular triangular shape from the base to the top and will be clad entirely in glass. The Shard will be home to residential apartments (some covering entire floors), a 185-room hotel, office spaces, public performance and exhibition spaces, public viewing galleries, bars, restaurants, retail shops, and more. The tower's developers have sought to accomplish a "vertical community" by combining these many uses.

Designers and developers involved with the tower project were conscious about how to utilize the tower for the advancement of the community and connect it to the urban context, especially in relation to the London Bridge station, which is located close to its site. This culminated in enhancing the station by expanding taxi services, improving pedestrian access, adding bus routes, and improving the overall experience of the station as a public hub for transportation. Other elements of the project indicate a strong penchant towards community. For instance, developers were adamant about creating jobs for local individuals, not only during the tower's construction, but also for employees who will be working in the finished building. More specifically, they anticipate that at least 50% of positions will be held by locals (Figure 8).

Figure 8. The Shard London Bridge Tower (or the Shard) in London, under construction, near the London Bridge Station. Environmental impact was an important consideration for design that had focused not only on local impact, but global as well. The tower is expected to be the most sustainable building in London, with an energy savings of at least 30%. Additionally, developers of the tower see it as a precursor to other construction of its type in the surrounding area, thus sustaining its function for many years to come by influencing future development. When completed, the tower will be an important iconic landmark of the city [40].

7.9. Kingdom Tower

The Kingdom Tower is an ultra-tall skyscraper approved for construction in Jeddah, Saudi Arabia, and will clearly be the centerpiece of proposed development known as Kingdom City located along the Red Sea on the north side of Jeddah. This project confirms the urge to escalate the height to break previous height records continuing in the world. The building has been scaled down from its initial 1.6 km (1 mi) proposal, to a height of 1 km (3280 ft). When built, the tower will become the tallest building and structure in the world. Designed by architect Adrian Smith, it incorporates many distinctive structural and architectural features. The tower and its 50 ha (120 acre) plot, which will include other buildings, will be the first phase of the Kingdom City development, a three-phase project proposed for a large area of undeveloped waterfront land with an area of 5,202,570 m^2 (56,000,000 sq ft).

An observation can be made here: the world's tallest building at this writing—the Burj Khalifa, 828 m (2717 ft)—has a very similar needle-like visual impression when viewed from a distance. In the same vein, the newly proposed Kingdom Tower rises to 1 km (3280 ft) in Jeddah, Saudi Arabia and employs an apparently similar form**.** Figure 9 compares the 1.6 km (1 mi) high Illinois Tower by Frank Lloyd Wright with Burj Khalifa and Kingdom Tower.

Figure 9. Interestingly, The needle-like form of the visionary Illinois Tower of 1956 by Frank Lloyd Wright (left) is replicated in the Burj Khalifa of 2010 in Dubai (center) and the proposed Kingdom Tower in Jeddah, Saudi Arabia (right), when viewed from a distance [41].

The triangular footprint and slanted exterior of Kingdom Tower is designed to reduce wind load effects. The design of the tower is projected to look like a desert plant shooting upwards as a symbol of Saudi Arabia's growth, as well as to add prominence to Jeddah's status as the gateway to the holy city of Mecca. The 23 ha (57 acre) area around Kingdom Tower will contain public space and a shopping mall, as well as other residential and commercial developments, and be known as the Kingdom Tower Water Front District. The idea of profitability derived from building's high density developments and malls around such a landmark was taken from the Burj Khalifa, where it has proven successful, as its surrounding malls, hotels and condominiums in the area known as downtown Dubai have generated the most considerable revenue out of that project as a whole, while the Burj Khalifa tower has seen no profit yet.

8. Visions of Future Cities and Tall Buildings

Cities of the world, particularly in the developing world, are growing fast with increasing populations. The growth rates vary by community depending upon the local culture, climate, economy, and other factors. As cities grow outward toward suburbia, connected by expressways and other transit systems, they tend to grow toward one another as development occurs along transportation corridors. The resulting urban fabric comprises cities, suburbs, and satellite and island cities that merge into one undifferentiated urban system.

While cities were built in the past for production and the exchange of goods and services, cities of the future will most likely expand to the pressures of exchanging information through digital technology. As cities grow in density, they will have to grow vertically as well, since their horizontal expansion becomes constrained by limitations imposed by the optimum horizontal scale for the functionality of cities. Even farming and other agricultural production activities will probably grow vertically through "vertical farms". Urban design gradually will embrace the vertical dimension of cities. Future cities no longer will be viewed as flat but as a three-dimensional (3D) manifestation of merged horizontal and vertical architecture.

Looking at the negative side, in developing countries there will probably be some poorly planned dysfunctional and out-of-balance cities approaching a "failed city" status. A crisis looming large on the horizon for cities in the developing world is the problem related to complex infrastructure. Transportation gridlock on city streets will reach unbearable proportion. Water and power shortages will be major problems. As the developing world becomes more urbanized, the water crisis will deepen. The world's water supply is finite and by no means will be sufficient for its increasing population. Unless aggressive measures are taken to conserve natural water resources and recycle used water, the future looks questionable. Rapid population growth and migration of the rural population to cities will continue to aggravate these problems. In 2007, the urban population surpassed the 50% mark of the total world population. This urban population will continue to increase. Slum dwelling populations and lack of sanitation in urbanized areas of these countries may reach alarming proportions resulting in problems of chronic unemployment, pollution, ill health, crime, and other anti-social activities. When the number of slum dwellers swells beyond comprehension, these cities will become unlivable.

On the other hand, looking at the positive side, if the developing world becomes economically successful along with the developed world, a different picture may emerge. In a prosperous world with the positive impetus of globalization, some cities will flourish and build upward, resulting in 3D skyscraper cities.

In developed countries, it is possible for the growth of population to be limited and manageable. Newly developed energy sources from nature, such as the sun, wind, ocean waves, geothermal energy, *etc*., will be explored. Innovations in transportation will be pursued. Well-developed cities like New York or London may not dramatically change soon. In old cities, industrial brownfields will be regenerated and renewed. In general, both in economically prosperous developing countries and the industrialized developed countries, layered 3D cities with tall buildings connected by bridges in the sky as discussed below will likely continue to emerge.

Antonio Sant'Elia envisioned future urban architecture as a multi-layered, interconnected urban conurbation of high-rise clusters with industrial expressionism (Figure 10). We can also get a sense of the similar mechanical and industrial visionary design in Russian constructivism. El Lissitzsky designed the Cloud-Iron in Moscow in the 1920s, which can be described as a "horizontal skyscraper." It was one of the most daring fantasy structures. Iakov Georgievich Chernikhov was another visionary constructivist architect, who believed constructive principles are fundamental to human design activity [42]. In the 1930s, he presented a number of sk*etc*hes showing the dynamic of the horizontal and the vertical; a compactly constructive building of monolithic character combining diverse closed and complete volumes with their well-articulated masses; a complex spatial conglomeration of skyscraper elements into an interconnected and integrated whole; a visionary city of giant skyscrapers expressing their verticality; and several complex elevated interconnected structures of well-balanced forms with industrial expression (Figure 11). His design, demonstrating his creativity and foresight, was not implemented because the technology to implement the idea was not available or was just too cost prohibitive.

Figure 10. Antonio Santa's Elia' vision of futuristic vertical architecture. The above drawing is one of his many drawings that were displayed in major exhibitions and galleries including the "Famiglia Artistica" and Como's art galleries [43].

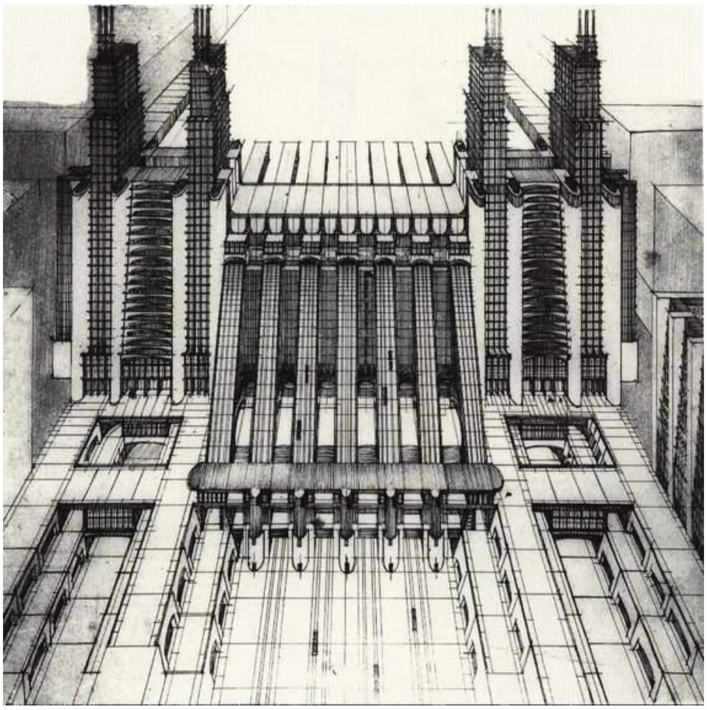
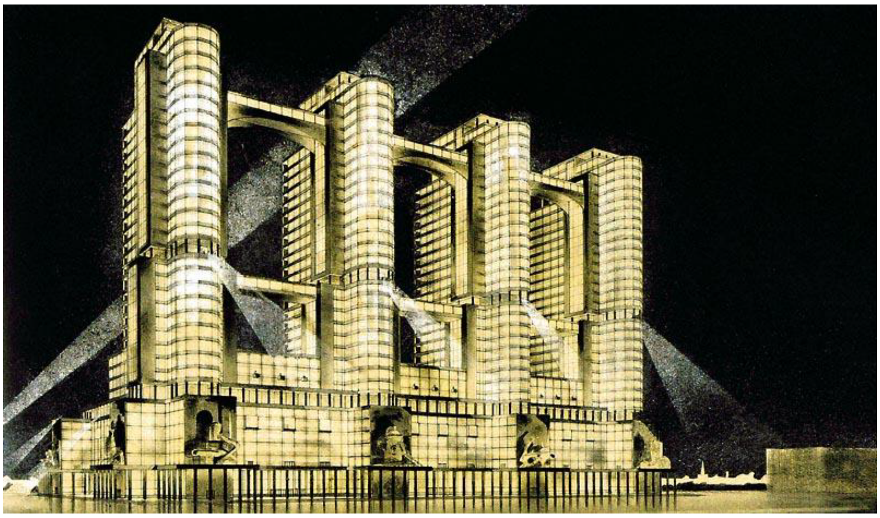


Figure 11. Iakov Chernikhov's vision of urban and architectural design. This sketch represents one of the many sketches that illustrate his approaches and innovative solutions to dense vertical environments [44].



8.1. Technological Innovations and Breakthroughs

Architectural practice always has relied on technological innovations in structures and materials, as well as scientific advancements. Technological breakthroughs in areas such as structural systems, foundations, elevators, fluorescent lights, fire protection, air conditioning, smart materials, *etc*, coupled with the latest digital revolution, have incrementally molded the form, height, architectural design, and functions of tall buildings. Today, the focus continues to be on new technologies and materials that exhibit enhanced properties.

It is clear that the structural system design to support supertall buildings of enormous scale is no longer a major impediment in building to great heights. As we have seen, the range of heights of the recently proposed visionary megatowers is from the 600 m (1,968 ft) high Holonic Tower to the 4000 m (13,123 ft) tall X-Seed 4000. Building heights of 509 m (1670 ft) for Taipei 101 and that of 828 m (2717 ft) for Burj Khalifa have already been reached. Other projects of greater heights are being considered. For example, the approved proposal for building the 1 km (0.63 mi) tall, Kingdom Tower in Jeddah Saudi Arabia will exceed the height of Burj Khalifa. Similarly, the 1 km (0.63 mi) tall Nakheel Tower project in Dubai (now shelved), if built, would exceed the height limit of Burj Khalifa. A new 975 m (3,200 ft) high super tower, Miapolis, planned for Miami, potentially could beat out Burj Khalifa as the tallest building in the world. Designed by Kobi Karp, Miapolis would be a "city within a city," and employ cutting-edge sustainable technologies. When built, it will be the largest LEED-certified structure at any rating level in the U.S. It is expected that with the growth of cities, building heights will increase continuously in conjunction with the improvements in technology for structural systems, materials, elevators, fire protection, energy efficiency, and damping systems. The future primary structural skeleton for supertall buildings may be speculated as an unprecedented, newly developed system, or a variation of an existing system; or possibly a logical vertical combination of two or more systems. The purpose of such systems will be to build higher, respond to multiple uses, and create varied internal environments.

One primary reason why architects and engineers can construct supertall towers is the computing power. As computing time has become faster using digital technology, it is now possible to try multiple alternatives before selecting the optimal solution. Coupled with this advance is the fast pace of construction. Today, for a concrete tower, erection time for a single floor could be as short as three days, which was unthinkable a few decades ago. This increased speed is possible because of improved construction techniques, including better concrete blending and more powerful pumps.

Sustainable skyscrapers will continue to be built. Steel, as a material, may be viewed in poor light because of its high embodied energy during manufacture and low thermal performance. It can, however, be recycled almost indefinitely, thereby retaining the embodied energy for many generations. More steel members, if fabricated of uniform length, can be readily dismantled and re-used for future construction. Concrete, on the other hand, is low on embodied energy during preparation, but the production of cement involves emission of carbon dioxide; a harmful greenhouse gas. Façades of skyscrapers lately have been designed for sustainable buildings by providing double skins, and occasionally triple skins, with innovative ventilation systems. Double-skin façades, with argon-filled cavities, triple glazing, and glass coatings can increase the thermal insulation quality (U-values). The penalty suffered in increased embodied energy of the materials involved to increase the U-values of façades often is paid back in reduced energy consumption over the life of the building. At present, a fascination by architects with glass as a façade material prevails, although its long-term performance remains to be seen. In Toronto, Canada, some residential tall buildings employing glass façades are experiencing problems of water leakage. Air tightness of the façade is a major issue for green tall buildings where pressure differentials from higher winds at the top of a building can cause problems with controlling internal temperatures and drafts. Also, photovoltaic cells, solar panels, wind turbines, *etc*., are being used in recent tall buildings. These developments likely will continue in the future to tap renewable sources of energy. Energy harnessing damping systems that can minimize a tall building's motion during wind or earthquakes someday will become a reality.

A major transformation is likely to occur for skyscrapers in the realm of smart materials. These materials are characterized by those that have enhanced physical properties and can be modified to provide better performances than ordinary materials. Advances in physical sciences have led to a new understanding of changeable materials, particularly those comprising acoustical, luminous, and thermal building environments. Smart materials can be classified as piezoelectric, electrostrictive, magnetostrictive, electro-rheological, shape memory alloys, fiber optic sensors, *etc*. [45]. Additional future research will make these materials readily available and cost effective.

A smart structure is an electronically enhanced, non-biological, physical framework that has a definite purpose, means, and imperative to achieve that purpose and a biological pattern of functioning. The structure functions in such a way to mimic the functions of a biological organism and adapts to changing conditions in the environment. We can expect to see more applications of smart structures utilizing smart materials in future tall buildings.

More recent developments in materials, information technology, intelligent building systems, and environmentally conscious design are transforming the built environment. Increased emphasis will be placed on providing safe, healthy, and comfortable living and working conditions in future skyscrapers accommodating thousands of people. These environments will employ innovative structural systems, new HVAC technologies, innovative internal transportation modes, and intelligent building technologies. Use of new composite materials, carbon fiber, and nanomaterial for future construction projects to produce strong and light structures will become more and more popular. Nanoskyscrapers employing heat-reflecting paint, heat-absorbing switchable windows, hydrophobic coatings, polymer optical fiber lighting, embedded sensors, *etc*., are expected to be built in the 21st century. Two relatively new and synergistic technologies have the potential to transform the way materials are developed and the potential for revolutionary implications of construction materials. These technologies are the discovery and utilization of carbon nanotubes and increasing practicality of modeling materials at the molecular level, which in combination may facilitate the development of new construction materials over the next several decades [46].

8.2. "Hypercities" and New Urban Architecture

A swing has been occurring for some time from the age of industry to the age of technology, compounding the issue of density as society seeks more and more of its livelihood through knowledge-based technology. This shift, coupled with a worldwide population explosion, has led to unprecedented levels of transmigration in a globalized world resulting in socio-economic and physical impacts. Clearly, this phenomenon will influence future urban forms including tall buildings. As revealed earlier, when cities become denser and pedestrian movement increases, the two-dimensional plane of the city reaches its elastic limit—forcing the city to move to its next phase of development whereby it can take no more growth without incorporating other supplementary systems and layers, such as transport, parking, and underground rail, to allow the freedom of movement. This development inevitably thrusts upward into the third dimension to meet the needs of increased density and movement. The tall building in the multi-layered city, with its ability to merge the symbolic edifice of a city or country, as well as being a consequence of exorbitant land prices and economically profitable land use, has been sought as the viable solution to the densification problem of world cities. Density is the destiny of 21st century cities.

The term "hypercity" is used here as a hyperbole for layered 3D cities in which vertical and horizontal architectural urban forms merge to create a vibrant new urban form. Such hypercities will be the likely image of the future. Architects and urban designers have to look at the construction of tall buildings not as their creations of aesthetic quality and perfected artifacts in a city, but as progressive phases of transition, experimentation, and continued search. Recently, as discussed above, architect Steven Holl designed the Linked Hybrid project featuring a cluster of eight 60 m (197 ft) tall towers and a 35 m (115 ft) tall hotel connected at their upper levels by a series of bridges. Located in Beijing, these towers demonstrate, despite their relatively lower height compared to supertall towers, what may come in the future for multi-level, multi-functional connected cities. It can be viewed as architecture in which connections are made both at ground level and in the sky. It represents a layered connected urbanism embodying mixed-use zoning. The apartment complex is porous and open, powered by 660 geothermal wells and creates a microcosm of a layered city. The bridges can have functions such as accommodating the children's school, swimming pool, *etc*. The bridges or bridge-like elements can potentially contribute to placemaking, a problem with tall buildings with vertically separated floors, by integrating street life to these upper-level "streets" and vertical transportation system in the building.

These bridges can be used for different functions and will keep the street traffic uninterrupted at grade level. Some of the bridges can be used for transportation at higher elevations between the towers.

Connecting towers by bridges improves fire safety as occupants of a tower can quickly move from one to another in the event of a fire. Such connectivity also may have major structural advantages, as the individual towers are braced by other towers, provided they are appropriately connected [47]. For ultra-tall towers, such connectivity is particularly important, as tall towers tend to become slender, creating motion control problems due to wind load effects. Of course, there are structural challenges like relative building movements due to thermal variations and wind and seismic forces. Sophisticated structural analysis and detailing of joints can resolve many of these problems. Such structures can positively contribute to the densification of cities and have the potential for remaking cities creating new urban forms. Skybridges have a number of other potential benefits [48]. In addition to the Linked Hybrid, other examples are the Pinnacle@Duxton and Marina Bay Sands, both in Singapore. These building complexes do not stand out because of their verticality alone but also because of their horizontal prominence creating a 3D effect resulting in their compactness due to clustering within themselves (Figure 12).

Figure 12. The Pinnacle@Duxton in Singapore is a major public housing project completed in 2009. It consists of seven 50-story connected towers. It supplies total of 1,848 units of 35 unit design variation. It was the recipient of the 2010 Best Tall Building Asia & Australasia Award by CTBUH [49].

9. Summary and Conclusions

The 20th century was undoubtedly the century of skyscrapers. Although there were many tall buildings built in Chicago and New York in the late 19th and early 20th centuries, a remarkable part of

American history remains the notion of suburban landscape. In 1898, Ebenezer Howard published a book entitled *Garden Cities of Tomorrow*. The idea was to create an ideal medium between crowded urban and desolate rural environments. The garden city movement influenced American city planning in the early 20th century. The introduction of the automobile and highway system was one of the most important events in American landscape history that created extensive decentralization and suburbanization. Side by side with the city cores, tall buildings grew to cater to the needs of commerce and industry. By the end of the 20th century, as we have seen before, many cities of the world, including American cities, reached epic proportions in terms of growth and densification with many skyscrapers dotting the cities. The boom and bust cycles resulted in the occasional flurries and pauses in construction. Many world cities in addition to the American ones now have become skyscraper cities.

Despite the dire predictions of pessimists about the decline of tall building construction in the aftermath of the deliberate attacks on the World Trade Center buildings in New York in 2001 and the subsequent collapse of these towers, tall building construction has actually proliferated since then. The beginning of the 21st century marked a boom in tall building construction, particularly in Shanghai and Dubai. However, the year 2008 brought with it an economic crisis across the entire globe, bringing to a halt the boom of the previous decade and the attendant scrapping or postponing of many tall building projects. Building tall demands wealth, and when money is short no developer will risk major investments like skyscraper projects. The question we may ask is: What can we extrapolate into the future regarding the growth and form of cities, and the paradigms of skyscraper design in terms of technology and human creativity?

Tall buildings are viewed by many as signs of capitalism and their construction is cost-intensive, but they are and will be needed in the future to save farmland, reduce the carbon footprint and automobile dependency, and to save energy. The bad publicity of social housing in Europe and the demolition of the Pruitt-Igoe apartments in St. Louis, Missouri, should not be considered as the basis of criticizing the tall building as a building type. Social problems related to tall residential buildings must be given due attention but should not be given so much emphasis that it negates the benefits derived from tall buildings when the stakes are higher for future generations living in overcrowded cities.

Architects and owners had a tendency in the 20th century, particularly at the high point of the International Style era, to create glass boxes that maximized floor space while foregoing performance, and created a tendency for buildings to be disjointed from a sense of place. Also, the connections between urban nodes generally have been taking place at street level. It is necessary to connect the city at higher levels, bringing functions not normally associated with tall buildings into the vertical realm, thus creating a new urban fabric in the sky.

While iconic towers are aesthetically pleasant artifacts and landmarks in cities, they also are cost-intensive. The trend for out-of-the-box forms was unleashed mainly by architect Santiago Calatrava through his groundbreaking design of the Turning Torso in Malmö, Sweden, completed in 2005. As our economic resources are dwindling and the world population is rapidly increasing, the question to be posed is: Are such buildings and their proliferation justifiable? The projects presented in the 2006, 2007, and 2008 Skyscraper Competition [50] are symptomatic of a trend in the 21st century. However, this trend is probably a fleeting phase, as occurs in the fashion industry, and may not pass the test of time. Iconic tall buildings, if not built to carry out performance-driven design, will eventually become unpopular as they will lose their attractiveness and purpose of being.

Because of the current concern for energy efficient and carbon neutral design to combat the decline of natural energy resources and global warming, the form and functionality of tall buildings are undergoing a notable paradigm shift. Tall buildings are adapting to these new challenges by being re-formed by architects to accept solar panels, wind turbines, and other auxiliary items to exploit renewable energy sources as well as organic bioclimatic environments both indoor and outdoor. This may also be a passing trend as scientists and engineers may someday produce a large supply of safe, clean energy from unknown and untapped sources. Already fracking of shale gas is showing promising results for securing usable fuel. Currently, scientists at Lawrence Livermore National Laboratory, located near San Francisco, are laboring to produce energy by blasting a pellet containing a few milligrams of deuterium and tritium, isotopes of hydrogen that can be extracted from water, with a powerful laser which will cause a reaction like that which occurs at the center of the sun [51]. Proponents of this process, known as fusion, claim that 38 L (10 US gallons) of water could produce as much energy as an oil supertanker. They are operating at the forefront of human knowledge about how to manipulate the tiny particles of matter. Although this process is still tentative, the prospect of making fusion energy work for everyone on the planet cannot be totally ruled out. This and other future innovations in technology such as fracking of shale for gas will affect tall buildings and their design because energy efficiency may not remain a crucial criterion for design as it is today. Of course, an opposite viewpoint could be that given the world's overpopulation problem and dwindling resources, it is highly unlikely that demand for higher energy efficiency will go down or even level up. Energy demands should therefore only increase.

Cities and tall buildings warrant greater attention with regard to ecological design [52]. Some skeptics consider tall buildings as "energy-hungry parasites" feeding upon the surrounding ecosystems and resources. Also, skyscrapers consume huge amounts of discharges into the natural environment, and are therefore ungreen. Others like the authors believe that, despite some element of truth in such skepticism, skyscrapers can be designed as low-energy ecological, carbon neutral buildings and could be the self-evident ecological building type of the future. Skyscraper designers must consider the entire life cycle of these buildings and view them as not stand-alone objects but a part of a larger web of interconnected biological and environmental systems. As a matter of fact, the greater the intensification of urban population through high density, the lower is the energy consumption and the smaller is the carbon footprint per habitant [53].

The race for height is likely to continue. Design simplicity, elegance and order likely will prevail in the future side by side with exploration, design adventure and experimentation of innovative form-giving. Future architects, urban designers, and engineers will face several challenges when designing tall buildings. Some of these will include the debate of whether to build tall or not. The increasing demand and need for buildings to be energy efficient and sustainable will shape the future unless some alternate solutions are found. More emphasis will be placed on the design of tall buildings as part of the surrounding ecology. The likelihoods of accomplishing a global policy for overcoming an unsustainable future will probably be decided in the cities. New questions regarding environmental and interference effects, property and space ownership, regulations, real estate marketability, *etc*., for tall buildings and urban design will, of course, arise. Since tall buildings support the trend of urban population growth and high density in the city, the construction of tall buildings is likely to remain unabated in the future. In the final analysis, cost-effective and aesthetically attractive tall buildings that can adapt to the prevailing technology of an era, local culture, ecology, and context, will succeed in reshaping cities of the 21st century.

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