Title: **Sustainability and the Tall Building: Recent Developments and Future Trends**

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Sustainability and the Tall Building: Recent Developments and Future Trends

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Abstract
As a major energy consumer, the tall building does not ordinarily conjure images of sustainable design. But a new generation of tall buildings is incorporating new developments in technology and design to produce smarter, energy-efficient buildings. This paper will show that tall buildings

Tall buildings conceived as "vertical garden cities" can use urban space and resources more efficiently and, at the same time, create more user-friendly and habitable buildings. Consequently, future sustainable high-rise buildings will need to be even more energy-efficient and functionally diverse with emphasis on multi-functional tall buildings that consolidate living, working, retail, and leisure spaces into a single building. The relationship between tall buildings and their urban infrastructure must also be considered. Transportation systems, water and waste distribution, energy, and heating and cooling must be considered relative to the tall building and its impact on the city's physical resources and infrastructure in terms of sustainable design. Finally, concepts such as mega-structures and mega-buildings will need to be revised and allied with new building systems technology to meet the challenges of future sustainable tall buildings that are integrated with their urban habitats.

Figure 1: Swiss Reinsurance Headquarters, London, 2003, Foster and Partners.

Introduction
Until recently, tall buildings have been viewed as mega-scale energy consumers with little regard for sustainable architecture. However, this is changing with a new generation of high-rise buildings that have been designed with energy conservation and sustainability as their principal criteria. Cities throughout the world are growing rapidly creating unprecedented pressure on material and energy resources. According to the World Commission and Environmental Development or Brundtland report, *Our Common Future,* sustainable design is an effort to meet the requirements of the present without compromising the needs of future generations by encouraging the wise and prudent use of renewable resources, alternative strategies for energy production and conservation, environmentally friendly design, and intelligent building technology. It adds that "Sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs" (WCED, 1989).

Two crucial elements are addressed in this definition of sustainable development. First, it acknowledges the concept of "needs," especially with regards to disparities between rich and poor, such as food, clothing and shelter essential for human life, as well as other "needs" to allow a reasonably comfortable way of life. Second, it accepts the concept of "making consistent" the resource demands of technology and social organizations with the environment's ability to meet present and future needs. This includes both local and global concerns and has a political dimension, embracing issues of resource control and the inequities that exist between developed and developing nations. In this way it endorses the notion of sustainable development as improving rather than merely maintaining the quality of life within the limits of the carrying capacity of supporting ecosystems. (Williamson, et al., 2003).

While the concept of sustainability is becoming accepted by architects and planners as well as by relevant private and public institutions, there is little worldwide consensus on what specific actions should be taken. In their search for models that incorporate sustainable principles of design, many designers and planners have looked to history and vernacular architecture in particular. For example, passive systems of climate control used by builders of vernacular architecture in the past, such as shading and increasing the thermal mass of walls, and using natural ventilation and plantings, are being incorporated into many "green" buildings that reduce their need for costly, mechanical environmental control systems.

However, while such lessons can and have been readily transferred from vernacular houses to modern houses and other small building types such as schools, community buildings, and the like, they are less easily transferable to large modern building types for which there are no historical precedents, either of scale or complexity (Abel, 2003). This is especially true for tall office buildings, since the large internal spaces they require make it difficult to achieve levels of natural lighting or ventilation in the deeper parts of the building. Strong winds or driving rain on the higher parts of very tall structures mitigate against keeping windows open all the time, further complicating the problem.

The invention of mechanical air-conditioning by Willis Carrier in America in 1939 and its widespread use in the post-war years effectively shaped vertical architecture in the latter half of the twentieth century. Encouraged by clients who wanted larger amounts of rentable space to increase the depth of offices, designers increased the depth of office floor plates, further reducing the penetration of natural light and increasing the need for artificial lighting, hence using more energy. Fully glazed and sealed curtain wall systems, as pioneered by Mies van der Rohe and Skidmore, Owings & Merrill, let in more light but increased the solar gain, which had to be offset by the cooling system. Research has shown that sealed, environmentally controlled buildings also can contribute to physical and psychological health problems. The concept of an "International Style" enabled by modern technology that could be arbitrarily applied anywhere in the world is being challenged by architects and planners today. It is no longer possible or prudent to ignore external climate and cultural differences by reproducing standardized towers without regard for region.

Buildings such as the Swiss Reinsurance Building in London, the Menara Mesiniaga Tower in Malaysia, and the Conde Nast Building in New York are just a few examples that represent a new generation of sustainable high-rise buildings that are challenging conventional high-rise building practices and incorporate a powerful visual expression with smart building systems.

Tall buildings conceived as "vertical garden cities" can use urban space and resources more efficiently and, at the same time, create more user-friendly and habitable buildings. Consequently, future sustainable high-rise buildings will need to be even more energy-efficient and functionally diverse with emphasis on multi-functional tall buildings that consolidate living, working, retail, and leisure spaces into a single building.

The relationship between tall buildings and their urban infrastructure must also be considered. Transportation systems, water and waste distribution, energy, and heating and cooling must be considered relative to the tall building and its impact on the city's physical resources and infrastructure in terms of sustainable design. Finally, concepts such as mega-structures and mega-buildings will need to be revised and allied with new building systems technology to meet the challenges of future sustainable tall buildings that are integrated with their urban habitats.

Early Skyscrapers

The first tall buildings in the late-nineteenth century in Chicago arose from necessity. After the Great Chicago Fire of 1871, developers and architects were faced with a daunting task: how to rebuild an entire city in a modern way using fire-resistant materials. This need was augmented by the fact that, as in cities all over the world, people willingly congregate there in large numbers to seek work, do business, and enjoy the diverse social and cultural attractions that only cities can offer. Development in cities like New York and Chicago was spurred by the emergence during the same period of large industrial and financial organizations requiring headquarters and office buildings located in city centers situated strategically along transcontinental railway and water routes. Chicago's location, situated in the center of the North American continent and connected to other states and Canada by rail and barge, was especially fortuitous and made it one of the fastest growing cities in the world by the beginning of the twentieth century (Abel, 2003). As the city grew, so did its buildings, which grew at least as high as economics and current technology allowed.

Figure 2: Guaranty Building, Buffalo, New York, 1895, Adler & Sullivan.

The most important factors in skyscraper development during these early years were the invention of the iron frame (which rapidly was replaced by rolled steel with the development of the Bessemer process), and the Otis mechanical lift in 1854. These early developments in technology were supplemented by the "curtain wall," which was hung from the exterior frame at each floor. Since it was not structural, it could be made of thinly cut stone, glass, metal, or any other material that could be mass-produced.

The early high-rise buildings in Chicago were forthright expressions of the cast iron and steel frame clad with a fire-resistant material, such as stone or brick. This so-called "commercial style" was both unpretentious and functional. Early tall buildings, such as the First Leiter Building, designed by William Le Baron Jenny in 1875, were based on the "perimeter block concept." After the Great Fire, Chicago was laid out in a grid-iron pattern of large blocks based on the survey of the United States commissioned by Thomas Jefferson in the early nineteenth century. Coupled with affordable land prices, this required buildings with extraordinarily large floor areas that filled the entire block. In order to bring natural light and ventilation into the interiors of these original high-rise office buildings, architects configured the buildings around atria, as in the case of the Rookery designed by John Wellbourne Root, or in H-, I-, E, or L-shapes.

Louis Sullivan is credited with redefining the tall building as "a proud and soaring thing" by emphasizing its vertical structure and developing a clear organizing vocabulary of base, stem, and crown based on classical archetypes. In office buildings, such as the Wainwright Building in St. Louis in 1891 and the Guaranty Building in Buffalo in 1895 (Fig. 2), he opened up the retail spaces at their bases using large areas of glass and massive columns to support the floors above. Ornamentation in the form of terra cotta and cast iron spandrel panels was introduced at the base and cornice of the building. The shaft ascended vertically without visual interruption from the base and was terminated by the overhanging cornice. Sullivan's high-rise architecture demonstrated that the tall building was no longer merely a functional container, but was an art form in its own right.

Building construction contributed to the local and regional economies. It also created jobs for skilled craftsmen and builders who came to Chicago looking for work. Almost all the materials used for building construction in Chicago were produced locally or regionally and shipped by rail or barge. Rolled steel was produced in mills as close as Gary, Indiana and Youngstown, Ohio. Clay, an abundant resource throughout the mid-west, was used for bricks and terra cotta. Stone quarries in Indiana produced much of the limestone favored by Chicago architects and stone masons, who often carved it into ornamental designs.

As more high-rise buildings were constructed, adventurous architects and engineers launched a process of reinvention of the type. They experimented with new technology and forms in order to reach higher than before, or to change social and cultural circumstances. Frank Lloyd Wright's Larkin Building of 1903 in Buffalo, New York, with its full-height atrium, open office floors, and peripheral service towers, became an important precedent for future office towers. It changed the relationship between space, structure, and services by creating an "organic," unitary central space that visibly bound everyone in the building together. The Rockefeller Center of 1940 in New York, by Raymond Hood et. al., created a new prototype of urban design involving the first fully integrated cluster of tall buildings rather than a single tower. It was the first skyscraper to develop a public realm with a public open space that converts to a skating rink in winter, extensive, multilevel pedestrian links, and numerous shops, cafes, and restaurants. Rockefeller Center also inspired many of the multi-functional towers that are built today that incorporate retail, office, and living programs in one or more high-rise buildings. This strategy promotes sustainable design by consolidating compatible live/work-related activities into relatively smaller areas of the city, thereby increasing density without compromising livablity.

While no one seriously considered sustainable design as a factor in the design and development of tall buildings until relatively recently, these early skyscrapers demonstrate how through necessity and limited technology architects and engineers were able to develop pragmatic and innovative approaches to the most basic design issues of structure and form, natural light and ventilation, program, and materials. During the nineteenth- and early twentieth- centuries there was little awareness or concern for the environmental impact of industry. As scientists and others became aware of the hazards to human health and the environment created by industrialization, laws were enacted that have regulated industry and the environment.

Building Systems and Integration

Sustainable design is a comprehensive way of thinking about the built environment and its impact on future generations. It also requires the thoughtful integration of architecture with building systems such as structure, mechanical (plumbing, heating and cooling), electrical (including information systems), transportation (escalators and elevators), and cladding systems. Since each system and subsystem is interdependent in a sustainable network, sustainable design is "front loaded" compared to traditional design. This is done by "value engineering" studies and cost analysis by cost consultants. Decisions that are made early in the design process have the greatest impact on energy efficiency, natural light and ventilation, and human comfort, among other things. If these issues are considered during the conceptual and schematic design phases, sustainable buildings do not necessarily have to cost more or be more complicated than buildings constructed using conventional construction practices. Therefore, design integration and a systems approach where each component is considered part of a greater whole is critical to sustainable design.

Much theory on the application of instrumental knowledge in building design assumes a systems approach—that is, the structuring of knowledge and technology into systems and subsystems by consultants and specialists associated with the building construction and design process. The thinking about sustainable development is often represented in terms of three conceptual subsystems—environmental, economic, and socio-cultural. These subsystems are viewed as interdependent and appropriate to general development issues, but ignore two critical subsystems related to actual buildings—the building and the building users. Thus, an appropriate building-centered system model might be constructed from the relationships among five subsystems such that:

- The *Environmental* subsystem uniquely contains the subsystem *Society*.
- Subsystems of *Economics, Occupants,* and *Building* overlap both the *Environment* and *Society* subsystems.
- The subsystems *Economic, Occupants,* and *Building* have positive interactions.

This approach brings relevant knowledge from the subsystem disciplines into something of a conceptual whole. Needs can be ascribed to parts within each subsystem, and these will relate to the inputs and outputs of that system. Overlaps and interconnections obviously occur and understanding these is just as important as understanding the behavior within each subsystem (Williamson, et. al., 2003).

A tall building, therefore, can be understood likewise in terms of systems and subsystems in which Environmental systems of Indoor Air Quality, Comfort, and Serviceability can be related to subsystems of Structure, Transportation, Mechanical (HVAC, plumbing, and electrical), and Cladding. In sustainable tall buildings the interdependence of these systems and subsystems becomes immediately apparent where the design and construction of one subsystem such as structure, for example, impacts other subsystems such as the locations of mechanical risers in the core and between floors.

Most of an office building's energy consumption over its lifetime is in lighting, lifts, heating and cooling, and computer use. Urban buildings such as skyscrapers can be made more sustainable by architecture that responds to the conditions of a site with integrated structure and building services. Effective use of passive solar heat and thermal mass of the building, high levels of insulation, natural daylight and ventilation, and wind power are just some of the ways to minimize fossil energy use. Narrow rather than deep floor plates maximize daylight in tall buildings and operable windows or ventilation devices provide fresh air.

In densely built-up areas, Combined Heat and Power (CHP) is a highly effective energy system. This system can be installed in individual buildings and supplies electricity and hot and chilled water that can augment or at least supplement municipal systems. The use of solar photovoltaic (PV) panels on the roofs and facades can also contribute to the energy supply of tall buildings, even in cities that are overcast for long periods of time.

The challenge to achieving sustainability in tall buildings is their inherent energy requirements for vertical transportation, heating and cooling, and communications. However, they also have advantages over low-rise buildings that typically use more valuable land area than vertical high-rise towers. When we compare the land use and energy requirements of a high-rise building to a small city, the advantages of concentrating people and services into a vertical city becomes evident.

Design teams of architects, planners, and engineers need to collaborate with clients to develop a vision for sustainable design. Ken Yeang and other architects are demonstrating that “bioclimatic” skyscrapers can be energy-efficient and related to their site and culture. These building often incorporate the same amenities that are found in the city including sky gardens within buildings that contribute to interior air quality by filtering pollutants.

Figure 3: DeWitt-Chestnut Apartments, Chicago, 1963, Skidmore, Owings & Merrill.

Structure, Materials, and Services. The integration of structure and services has clear advantages in improving the serviceability and efficiency of tall buildings. Kenneth Frampton calls the visual expression of the building structure and its intentional integration with other major systems the “tectonic order” (Frampton, 1995). Vertical pipelines and ducts occasionally run through floors resulting in perforations. From the perspective of physical integration, structure is often made to contain the service systems. Conventionally, the interstitial space between floor and ceiling layers normally carry the horizontal distribution of HVAC, electrical, and lighting services. Hollow structural members, which are stronger in bending than solid members if they are made of the same weight of material, are also appropriate conduits for the distribution of service elements. Structural systems selection, then, generally involves the choice of the lightest-weight members of the most economical-grade material, allowing the most efficient configuration that is appropriate to the anticipated loads. Structure acts in visually expressive ways creating either an open frame or a closed shell for the envelope to fill.

Prior to 1965, the design of structural systems for skyscrapers was done in a conventional way by fastening together beams and columns to create a stiff structural grid for resisting wind forces. Fazlur Khan was the first structural engineer to question this approach and to tackle the entire issue of structural systems for tall buildings by devising a whole range of structural systems: framed tubes; braced tube; mixed steel-concrete systems; and superframes (Ali, 2001). The DeWitt-Chestnut Apartments in Chicago built during 1961-1963 (Fig. 3) were designed by Bruce Graham and Fazlur Khan of Skidmore, Owings & Merrill. They were the first attempt to construct a high-rise building whose structural mass would not be affected by wind loads in the same way as traditional rigid beams are affected. The structural tube in its perimeter reintroduced the traditional load-bearing wall as an active element in the building’s behavior under stress. Tube buildings – particularly the bundled tube system that was used for the Sears Tower (in steel) and One Magnificent Mile (in concrete) buildings in Chicago – offered a new architectural vocabulary through different massing possibilities (Ali, 1990).

More recently, the need for openness in the exterior facade desired by architects and owners resulted in the structural elements resisting lateral loads to be located in the core rather than at the perimeter. Most supertall buildings, such as the Petronas Towers, Jin Mao, etc., use this concept in the form of outrigger-and-core systems or a variation of it employing composite construction, i.e., combining steel and concrete as the structural materials.

The evolution of design proceeds with programming and mass modeling. Since September 11, 2001, perception by the public has become an important consideration to make tall buildings structurally sound and secure from terrorist acts. Studies on floor-to-floor heights, lease spans, core plans, floor plate modules, façade glass area, etc. are carried out by the architect to optimize floor space in conjunction with marketing analysis. Since tall buildings cannot be tested as full-scale models, structural engineers carefully study the structural systems at this stage keeping in mind the constructability of the structure. The engineers and architects communicate through computer-based drawings and sketches to offer their design intents. Many major decisions are made through this schematic design phase. A good working relationship between the architect and the engineer is important for effective collaboration, although occasional adversarial conflicts are necessary in order to develop an optimum design from both view points. Local regulations and infrastructure constraints must be researched before commencement of the design process for all disciplines including the mechanical, electrical, and plumbing systems.

Mechanical Systems. Integration of structure, mechanical systems, and facades has been a significant factor in achieving energy-efficient tall buildings. At the same time that the designer is selecting the materials and components that are to be used in the skyscraper, consideration needs to be given to the technical means for operational systems. Solutions should be chosen that meet the criteria of an overall energy balance and materials recovery and reflect the latest technical knowledge on the use of environmentally compatible forms of energy. The majority of energy use and a similar proportion of carbon dioxide emissions are associated with buildings, with 60% attributed to the residential building type and 7% to the commercial office building. However, on a per-square-per-meter basis, commercial buildings consume greater energy than residential buildings (Yeang, 1999).

The significance of success of a green or other large intensive building type's operational systems lies in achieving a lower energy consumption level per annum (in kWh/m^2 per year).[1] In a typical commercial skyscraper, by far the highest energy used in its operations is the HVAC systems, followed by artificial lighting systems. The other elements, such as elevators, plumbing, and sewerage systems) contribute marginally to the operational energy costs of the building (Yeang, 1999). An argument has been made that as operational energy efficiency improves, these components used in the skyscraper's life cycle will become less important than the embodied energy used in its construction (Lawson, 1996). However, unless the building approaches virtually zero energy consumption in its operational phase, it is likely that the "initial energy costs" of a green skyscraper will remain small compare to the "operational energy costs" (Yeang, 1999).

During the 1950s and 1960s suspended ceilings and molded floor slabs of concrete and steel were developed as a "multi-purpose power-membrane" in which technical rationality and economy emerge as new architectural objectives consistent with the mechanized environment (Banham, 1990). Eero Saarinen achieved the first integrated structure/mechanical solution in his General Motors Technical Center in Warren, Michigan (1950) by combining structural thickness with space for the horizontal distribution of mechanical conduits by using boldly angled triangular structures (Abalos and Herreros, 2003). His solution demonstrated how the related concepts of climate-controlled space and building depth could come together in the ideal of a space that was free from physical obstructions.

In tall buildings, horizontal distribution of mechanical networks is not the main issue or even the only one at the level of structure. Other factors linked to the technical aspects of the heating, ventilating, and air-conditioning (HVAC) systems include centralization of the equipment on mechanical floors and adequate placement of the vertical service columns, which require integrated solutions.

Beginning in 1960, the concept of the office landscape emerged. This model was based on an unobstructed, continuous, deep, and air-conditioned volume supplied with uniform energy services. The

[1] A general target for full-mode buildings (in temperate and equatorial zones) should be less than 150 to 250 kWh/m^2 per year for the typical conventional HVAC buildings.

changes in planning also led to the further integration of mechanical systems, as floor-to-floor distances decreased.

The London Bridge Tower proposed for 2009, designed by the Renzo Piano Building Workshop with Ove Arup & Partners, uses a floor structure that is a carefully integrated system of raised floors, slabs, tapered steel beams, and mechanical ventilation systems (Fig. 4). This reduces the floor-to-floor height to a very efficient 2.5 ft. (0.77 meters) and adheres to Piano's dictum that a modern building must be "human, technological, energetic, and economic" (Riley and Nordenson, 2003).

Figure 4: London Bridge Tower, London, 2009, Renzo Piano Building Workshop.

In sustainable skyscrapers, priority has been given to passive systems of heating and cooling over active and mixed-mode systems because this is the best way to achieve the ideal level of servicing for ecological design and because it represents the lowest level of consumption of energy from renewable sources. Passive design is essentially low-energy design achieved by the building's particular "morphological organization" (Yeang, 1999).

The masterplan for the Southwark district of London, drawn up by Foster and Partners, proposes construction of several tall office, residential, and mixed-use towers. It includes the Garden Towers, three "eco-towers" of different heights, designed by T. R. Hamzah & Yeang. The tallest tower will be a 35-story apartment building, which will feature "bioclimatic" design adapted for the English climate. The tower comprises two wings set at a slight angle and linked to each other and to a central core across an open atrium by suspended walkways. A system of mechanical louvers at each end of the atrium enables the space to be closed or opened according to weather conditions, ventilating the rear of the apartments through the stack effect.

Facade Technology

Integrated design means getting involved as closely as possible with the people and industries that make the parts of a building and put it all together, from the beginning of the design process, right through to the end. It ensures that spatial concept, structure, and environmental systems are all conceived as one and work in harmony (Abel, 2004).

Foster and Partners is commitment to low-energy, high-performance design, and the advanced technology used. The Commerzbank in Frankfurt, is the first modern skyscraper to use opening windows and natural ventilation. Coupled with the multi-story gardens, which are naturally ventilated, fresh air can be drawn into the offices as much as 80 per cent of the year, which exceeds the German standards.

Parkhaven, designed by Kohn Pederson Fox (KPF) in Rotterdam, uses a helical tube-structure and is promoted as a mixed-use vertical city. At 392 meters high it will eventually be the tallest building in Europe and features a double-skinned climate wall with opening internal windows.

The Uptown Muchen of 2003 in Munich, by Ingenhoven Overdiek and Partner, is 146 meters high and uses an economical single glass skin with high thermal- and glare-resistant properties. Natural ventilation is provided through motor-driven circular windows that move outwards like pistons.

Intelligent Building and Systems Automation

Intelligent building refers to a building that has certain intelligent-like capabilities responding to pre-programmed stimuli to optimize its mechanical, electrical, and enclosure systems to serve the users and managers of the building (Yeang, 1996). The Intelligent Building has evolved into advanced integrated subsystems, which in varying degrees are part of most buildings today. It includes the Building Automation System (BAS), Security System, Fire and Safety System, Communication System, and Office Automation.

New computer modeling techniques are being used to test the effect of different environmental system's on a building's energy-efficiency. Foster and Partner's has used computer models, such as computational fluid dynamics or CFD, in shaping the office tower for Swiss Re, London, and the new headquarters for the Greater London Authority (GLA). The helical structure of Swiss Re creates a more aerodynamic form that minimizes the effect of wind forces. It also allows for a series of "sky courts" that spiral along the inside facade of the building that contribute to its social character and help to regulate its internal microclimate. The GLA design was morphed from a pure sphere—the most efficient geometric form for enclosing a given volume—based on the impact of the sun path and other environmental considerations.

Frank Gehry uses the Catia software system developed by the French aerospace company, Dessault Systemes to translate the complex geometries of his famous museums from three-dimensional working models into construction drawings. However, the Catia system was primarily designed as a manufacturing system, and is generally put into action after a design or building shape has already been determined (Abel, 2004).

Biotech architecture is a sustainable, computer-centered process of architectural design, production, and use that uses smart technology to achieve a dynamic, interactive relationship between a building, its users, and its environment. It is a total design approach that is multi-disciplinary and network-based and involves designing building, subsystems, and components all together in a collaborative process (Abel, 2004).

The greatest challenges and most advanced technology in the construction of the Swiss Re and GLA involved the production of the cladding systems. Schmidlin, the Swiss-based company who made the cladding for both London buildings, created their own detailed computer 3D model of the cladding system for the Swiss Re tower, bridging spreadsheets and production line. The 3D model also included parametric features, enabling both Foster's architects and Schmidlin's fabricators to make changes right up to the last moment, automatically updating the project data as needed. Schmidlin also wrote their own special software linking the 3D model directly to the CNC machines on the production line, so doing away with conventional programming,

Recent Trends

Beginning in the late 1970s and early 1980s, a small number of designers, backed by bold clients willing to experiment with new ideas or looking for a new image, began to reintroduce passive techniques of climate control into office buildings. Usually combined with mechanical systems, they did not eliminate air-conditioning but they reduced maintenance costs while at the same time increasing comfort levels for occupants (Abel, 2004). Using structural elements to provide limited shading, Harry Seildler, working with Pier Luigi Nervi on a tower for the Hong Kong Club and Office Building of 1984, included deep, T-shaped, reinforced beams spanning the full width of the facade. They also applied this strategy to the concrete sunshades of Grosvenor Place of 1998 in Sydney, which are fixed at different angles around the facade following the path of the sun, providing maximum shading at each point. In places where there is no direct sun, they reduce glare.

While external passive devices are effective in shading buildings and reducing power costs, they have no significant impact on the internal spaces or configuration of the structure. Beginning with the National Commercial Bank in Jeddah, designed in 1982 by Gordon Bunshaft of SOM, a quite new genre emerged that broke entirely with previous models of tall buildings (Abel, 2004). Bunshaft took as his model for the monolithic tower the courtyard houses of the Arabian Peninsula, creating an inward-looking building with a V-shaded plan. The V changes direction twice at different levels up the tower, creating three triangular, recessed "sky courts" alternating in height on two faces of the building. The only glass walls, placed on the inside faces of the V, are shaded from the direct sun. The rest of the building is clad in stone from top to bottom. A vertical flue where the alternating triangles overlap creates a "stack effect," encouraging air movement through the sky courts and upwards through the top of the building, helping to cool the glass faces. The service core is placed to one side of the building so that it does not interfere with the internal office spaces and provide additional shade on that side of the building. The design of the building reduces the external temperature at the glass facade by as much as 10 degrees Centigrade, resulting in substantial energy savings.

The Menara Mesiniaga in Subang, Malaysia, designed by T. R. Hemzah and Yeang in 1992, presents an early model building for the physical translation of ecological principles into high-rise architecture. The fifteen-story tower expresses its technological innovations on its exterior and uses as little energy as possible in the production and running of the building. Instead of a continuous facade, the building open and closes in sections arranged in stages around the tower. It has an exterior load-bearing structure of steel with aluminum and glass, and a crowning superstructure for the roof, planned as a future support for solar cells. The interior and exterior structure of the tower is planned around climatic considerations and its orientation toward the daily path of the sun. The massive core of the building, with elevator shafts and staircases, faces east and screens off the penetrating heat up to midday. Deep incisions and suspended aluminum sunscreens on the south facade ward off the direct rays of the noon and afternoon sun into the interior. Most of the office space faces west and north. Around the base of the tower lies a semicircular, steeply sloping garden, which continues into the building itself in the form of spiral terraces planted with grass. This visibly brings the natural environment into the architecture.

Figure 5: Commerzbank, Frankfurt am Main, Germany, 1997, Foster and Partners.

Well-integrated applications of advanced facade technology together with innovative HVAC systems results in significant energy savings and improves indoor air comfort. If the facade and HVAC systems are engineered as two components of the same solution, not only will the performance be better – both initial and operating costs may be significantly reduced.

Norman Foster & Partners have been investigating thermal building skins and integrated service cores in tall buildings in Great Britain and Germany since the 1990s. The Commerzbank of 1997 in Frankfurt, Germany (Fig. 5) was the first high-rise in the world with natural ventilation air-conditioning and natural lighting in compliance with German building regulations that "all office spaces have daylight and visual contact with the outside world" (Lepik, 2004). Foster's design, based on a triangular ground plan, curves slightly outward with an inner atrium at whose corners are located the structural columns with the transport, supply, and waste disposal facilities. The tubular, steel-frame construction makes the 132,000-ton building extremely stable. Offices are contained in two wings suspended between the columns, with a garden on the third side. Nine winter gardens spiral upwards ensure an adequate supply of daylight to the inner workplaces. An intelligent air-conditioning system allows the natural ventilation of all the office space by means of stilts between the inner and outer facades up to the highest floors. Through the recovery of heat and other innovative technology, energy consumption is greatly reduced in comparison with traditional high-rise buildings.

Foster also developed new technological, urban planning, and ecological design concepts in the Swiss Reinsurance Headquarters building built in 2004 in London. The steel spiral "diagrid" structure creates an aerodynamic form that provides the lowest resistance to wind. The shape of the building also diminishes demands on the load-bearing structure, as well as the danger of strong katabatic (downward) winds in the area around the building. The office spaces are arranged around a central core with elevators, side rooms, and fire escapes. The net-like steel construction of the load-bearing structure lies directly behind the glass facade and allows support-free spaces right up to the core. The most innovative element in the inner structure is the inclusion of triangular light shafts behind the facade, which spiral upwards over the whole height of the building. These light and air shafts are interrupted every six stories by an intermediate floor, to minimize the development of drafts and noise.

The Conde Nast Building in New York City is the first ecologically designed North American skyscraper (Riley and Nordenson, 2003). Designed by Fox & Fowle Partners, many of its innovations are considered standard for office buildings today. The facades of the building address the entertainment district of the Times

Square entertainment district to the west and the corporate Midtown area of Manhattan to the east. The building sets new standards in energy conservation, indoor environment quality, recycling systems, and use of sustainable materials. The large areas of glass curtain wall maximize daylight penetration into the office floors and incorporate low-E glass coating to filter out unwanted ultraviolet light while minimizing heat gain and loss. Photovoltaic panels have been integrated in spandrel areas on upper floors of the east and south facades, generating a meager but symbolic amount of electricity by day. Sophisticated mechanical systems ensure high indoor air quality by introducing filtered fresh air into the office environment. Tenant guidelines produced by the architects established environmental standards for living, power usage, furniture systems, carpets, fabrics, finishes, and maintenance materials to ensure indoor air quality and also as a comprehensive strategy to maintain environmental sustainability for the life of the building.

New Urban Forms. As with the buildings themselves, the urban context in which tall buildings have evolved has changed dramatically since their Chicago origins, reflecting both social and technological developments. In particular, the mass production of automobiles spurred a massive population shift from the cities to the suburbs in all parts of the developed world in the second half of the twentieth century. Concerned with the effect of these changes on the countryside, planning authorities in England and Sweden initiated ambitious programs for "exporting" the urban growth of their capitals to surrounding rings of New Towns of 60,000 and more people (Abel, 2003). Based on Ebenezer Howard's concept of Satellite Towns and Garden Cities, the low-density settlements were separated from the capital by "green belts"—areas of open land where new building was restricted—and were intended to offer new places of employment as well as decent, low-cost housing.

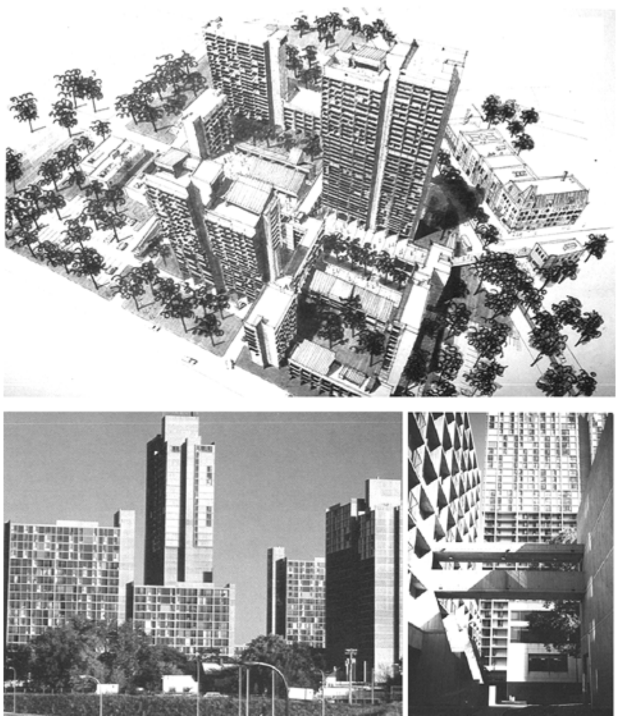

Figure 6: Cedar Square West, Minneapolis, Minnesota, 1962, Ralph Rapson.

Ralph Rapson designed Cedar Square West in Minneapolis in 1962 as a New Town-In Town that combined the vertical garden city with modern planning principles (Fig. 6). Cedar Square suggests that higher densities, mixed incomes, and a variety of uses, building types, and scales should be considered in order to limit urban sprawl and promote social diversity. While these tenets form the basis of most post-modern planning strategies, incorporation of high-rise towers, such as those of Cedar Square, are generally avoided or criticized as possible alternatives to more traditional low-scale buildings. However, there is evidence that reticence about designing high-rise buildings is changing, especially when one considers the variety of high-rise buildings that have been designed by major architects and constructed throughout the world in recent years. New approaches to planning, structure, massing, and materials have resulted in a new generation of high-rise buildings that are more livable, social, and sustainable, which incorporate a variety of uses and amenities including "gardens in the sky."

A contrary trend to urban dispersal has been seen in cities throughout the world, in which increasing numbers of people are choosing urban lifestyles over suburbia. "Densification"—raising the densities of urban areas through redevelopment programs, often involving tall buildings of all kinds—is now a key part of official planning policy in many city governments. Combined with new investment in urban infrastructures and public transportation systems, such measures are aimed at reducing reliance on private transport and consequently on fossil fuels.

Perceptions of vertical architecture and its impact on densification are also changing. Improvements in the design of tall buildings and the way they connect with the urban sites in which they stand, have resulted in a new generation of buildings that are sympathetic to their urban contexts, yet increase the density of the city.

The landscaped public plazas of the Riverside Development of 1986 in Brisbane, Grosvenor Place of 1988 in Sydney and the QV1 Office Tower of 1991 in Perth , all by Harry Seidler with Pier Luigi Nervi, are good exemplars of how tall buildings can contribute tot he quality of urban life. Buildings such as Menara Mesiniaga and the Commerzbank, with their sky gardens, and the Capita Center of 1989 in Sydney, with its open ground-floor gardens, show how green spaces can be incorporated into tall buildings, even on the most cramped central city sites.

While tall buildings are invariably associated with central city sites composed in large groups of similar structures, new patterns of urban development are emerging in which isolated examples, or “stand alone” tall buildings play an important role, either as landmarks or as self-contained urban nodes in themselves. Aiming to help solve the problem of Tokyo’s growing population and land shortage, Foster and Partners designed the 840-meter-high Millenium Tower in 1989 and situated it in the waters of Tokyo Bay. The multi-use tower has a tube-in-tube structure, pioneered by Fazlur Khan, consisting of a cone-shaped, helical, outer steel frame and an inner circular core of reinforced-concrete columns tied together at intermediate levels by deep horizontal steel trusses. This structural solution gives the tower immense strength and the ability to withstand both wind forces and earthquakes. The enormous height of the tower is broken down into distinct “neighborhood districts” by refuge spaces formed in the high spaces beneath the trusses. A vertical “metro system,” based on the electromagnetic technology developed for high-speed railways and able to move both horizontally and vertically, was designed to take passengers around the building.

Conclusion

The new sustainable skyscraper houses a diverse program organized around a comprehensive system of vertical transportation. Mixed-use structures entail a more complex spatial logic than had been developed for commercial office buildings with connecting space for organizing interior circulation. Public space has now become interiorized within a self-sufficient stratified skyscraper.

Tall buildings conceived as “vertical garden cities” can use urban space and resources more efficiently and, at the same time, create more user-friendly and habitable buildings. Consequently, future sustainable high-rise buildings will need to be even more energy-efficient and functionally diverse with emphasis on multi-functional tall buildings that consolidate living, working, retail, and leisure spaces into a single building. The relationship between tall buildings and their urban infrastructure must also be considered. Transportation systems, water and waste distribution, energy, and heating and cooling must be considered relative to the tall building and its impact on the city’s physical resources and infrastructure in terms of sustainable design.   Finally, concepts such as mega-structures and mega-buildings will need to be revised and allied with new building systems technology to meet the challenges of future sustainable tall buildings that are integrated with their urban habitats.

Future research is needed in order to understand sustainable design in a more comprehensive way and apply its principles to tall buildings. The performance of existing high-rise buildings that have been designed with sustainable features needs to be evaluated. Better integration models need to be developed. More sophisticated computer modeling programs need to be developed to simulate changing environmental conditions that impact the design and performance of tall buildings and to facilitate an integrated approach to design, engineering, and construction. Finally, research from other disciplines needs to be incorporated into the planning and design of tall buildings that will provide a comprehensive approach to understanding and predicting the life cycle costs, energy use, and performance of tall buildings and their impact on their urban habitats as applied to sustainability—both from the viewpoint of energy and resource consumption as well as socio-cultural factors.

Transformations in program, structure, and context as well as changes in climate and the limits of nonrenewable resources have compelled designers to consider alternatives to outmoded models of the environmentally-contained skyscraper. Innovations in technology as well as a re-assessment of the urban and environmental role of the tall building has led to a new generation of tall buildings that integrate structure, mechanical and electrical systems, and cladding technology into a comprehensive sustainable solution. The best tall buildings, according to Guy Nordenson, “can inspire society by the dignity of the language, the example of their social and environmental thoughtfulness, and the evident quality of the social processes by which they are made” (Nordenson, 2003). Like their Chicago precursors, these new tall buildings are not following trends, they are setting them.

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