Title:	**Innovations in Sustainability at Height: Experimental Tall Buildings**
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Subjects:	Architectural/Design Sustainability/Green/Energy
Keywords:	Energy Renewable Energy Sustainability
Publication Date:	2008
Original Publication:	CTBUH 2008 8th World Congress, Dubai
Paper Type:	1. Book chapter/Part chapter 2. Journal paper 3. **Conference proceeding** 4. Unpublished conference paper 5. Magazine article 6. Unpublished

Innovations in Sustainability at Height: Experimental Tall Buildings

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Biography

Peter Land leads two research based, design development studio groups in the College of Architecture at the Illinois Institute of Technology. One focuses on wide span and the other on high-rise concepts. Both employ innovative structural technologies and natural energy systems. Structure and wind turbine modeling in collaboration with the IIT Aerospace Engineering Department. Parallel with the studios, Prof. Land conducts a research seminar on technology developments in structures and energy systems. Peter Land was educated at the Architectural Association School and the Royal Academy Schools in London and holds the A.A. Diploma, Masters Degrees in City Planning from Yale University and in Architecture from the Carnegie-Mellon University. After experience in the UK and the USA, his professional accomplishments also include the formulation and direction of projects for the United Nations, including the planning and construction of the 450-unit PREVI neighborhood in Lima, Peru, with experimental building technologies. Design proposals for the first US Lunar base for NASA. A long-range program to develop housing and planning typologies for high-density, sustainable urbanism. Projects from his studios were exhibited in the 2007 Summer Exhibition of the Royal Academy of Arts in London. He lectures about his work at universities and conferences in the USA and overseas.

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Abstract

As global concern and competition intensifies over diminishing fossil fuel reserves, the need grows to conserve energy, develop renewable resources and more efficient ways to build. In a rapidly urbanizing world these objectives must be considered a top priority. Therefore, an experimental approach to the design development of high-rise structures, forms and energy systems should be promoted in the search for ways forward in the planning and design of the future built environment. Extraordinary new ideas, materials and technologies have appeared in other fields, some of which have application in building. Therefore, an ongoing reconnaissance of new developments in other fields and the transfer of technologies where appropriate should be considered standard policy. The projects shown follow the objectives of this approach and reveal some fresh ideas and concepts which have opened-up new avenues that are being further developed. The projects indicate a few of the wide range of interesting new possibilities and ideas for high-rise solutions. Some projects emphasize innovative structures, others energy systems and some ingeniously combine both. The intention is to demonstrate that with new technologies and an inventive approach unique solutions for new challenges unfold.

Keywords: High-rise, experimental, sustainable, renewable energy.

Introduction

The paper reviews a selection of high-rise projects developed at the Illinois Institute of Technology in a research based studio group led by Professor Peter Land in the College of Architecture. A technological university with its range of specialized resources is an appropriate setting for development work on new design and technical ideas, particularly for concepts and knowledge in the rapidly advancing high-rise field. This is especially true for energy and structural ideas aimed at increasing efficiency in the use and the new objectives for a building to actually produce energy, utilizing renewable resources, such as wind, sun, geothermal, etc.

The next phase of work on the projects with turbines and other wind power features is accurate performance evaluation with wind tunnel and digital simulation. Founding for this phase of research and design development has been applied for. Also, the author acknowledges the contributions of many advanced level students who have worked with the author in the development groups over several years. Some concepts have been worked on more than once, and more than one student has been involved in certain projects.

This presentation shows the main features of a few projects taken from a larger body of work carried out over several years. It also discusses some of the ideas, which have emerged during the course of this work, and principles currently being pursued by the author and his IIT group in current development work. Reference can also be made to the earlier paper given by the author at the CTBUH World Congress, New York, 2005. Some of the projects and ideas included in this article have been developed in detail but space does not permit a full descriptive text and all drawings of each project to be included. The emphasis of the projects is on innovation in configuration, structural and energy concepts. Some proposals contain the seeds of innovative ideas not yet fully emergent. The main idea underlying the work is to shape a single tall building or a complex so that it performs new functions, which a changing economic and cultural reality requires. Concomitantly, new developments in technology in general and materials and structures in particular have opened-up remarkable possibilities and solutions for the new challenges.

The inexorable approach of the end of the petroleum age, accompanied by a rise in energy costs with negative economic consequences, is a challenge, which must be taken seriously by present and subsequent generations. All our collective inventiveness must be applied to meet this challenge on several fronts. The nature of the challenge and what should be the long range priorities and new technologies required, are imperfectly understood at this time. We are only at the beginning of a new chapter in defining and developing future, renewable energy technologies. However, it is already clear that the built environment must become ultra efficient in its use and conservation of energy. Furthermore, technologies and very interesting design ideas are emerging which enable a building to generate the energy it requires for its own operation and, in some cases, for export.

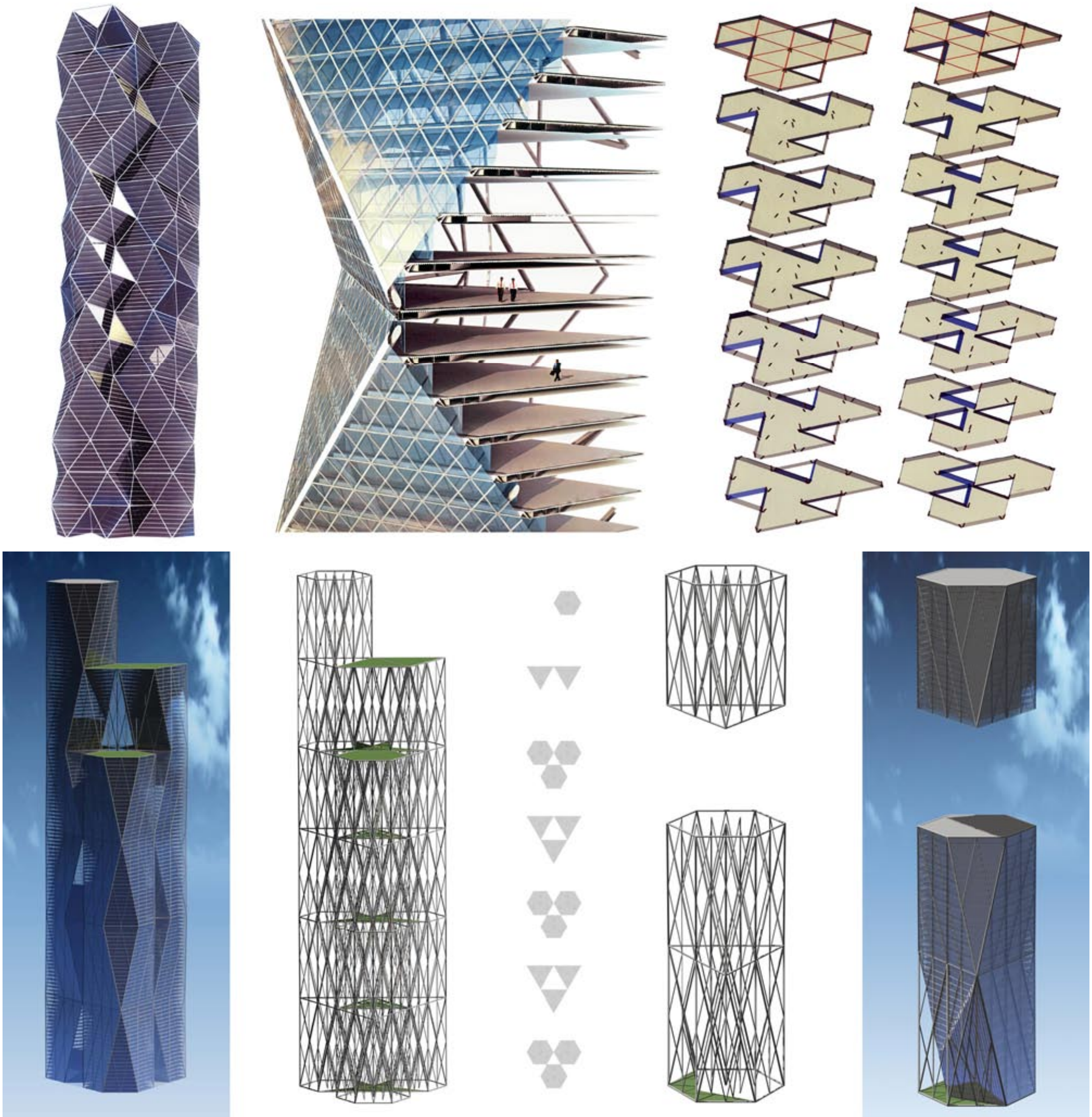


Figure 1 & 2. Triangulated megaframe structure

The equal-lateral, triangulated structure geometry with a base to height ratio of 1:1 extends over approximately eight floors. Clustering of the structure pyramids allow a flexible articulation of the overall clustering form giving interior atria and through space. A flexible location of the vertical circulation cores and service modules, which penetrate the diagrid floors, is accommodated by the structure concept. The exterior glass skin defines the prismatic overall form. For comparative study, a triangulated structure geometry with a base to height ratio of 1:2 extending over approximately sixteen floors is also shown. The spatial and structural differences are interesting.

Structures

Part of the energy equation is that structures comprising the built-environment must also be more efficient by using less material more effectively and employ the new generation of advanced materials, components and structural concepts. The basis for critical assessment of the built environment must be performance. Aesthetic evaluation may be independent but within the criteria of performance and the search for a more economic, natural and therefore better built environment. In some projects the building form is influenced by the energy concept, in others by the structural concept, in several by both.

In some projects the objective is to combine the features of uninterrupted continuous, easily divisible floor space with a stiff structure, modular planning and flexible location of elevator cores and service modules. For comparative evaluation, two projects employ fully triangulated or prismatic framing geometry (1, 2). One equilateral triangulation and the other with base to height ratio of one to two. By appropriate clustering of the

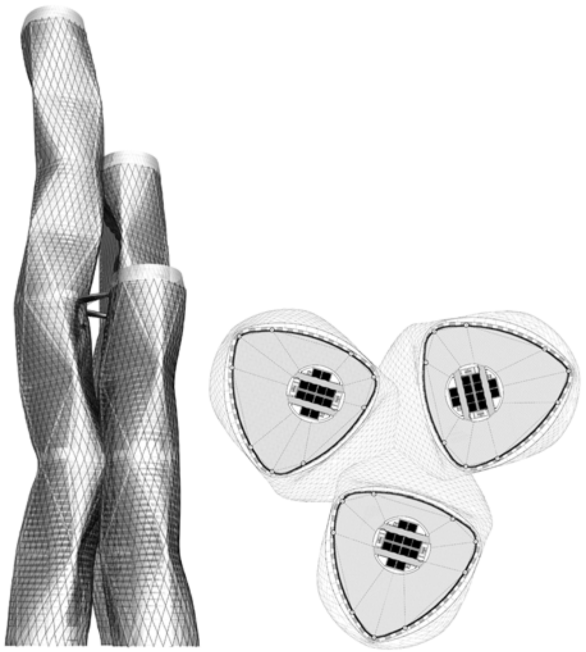


Figure 3. Cranked tower cluster

Triple, cranked tubular towers, coupled each twelve floors. Pedestrian crossover links connect double story, landscaped atria at these levels. Diagrid exterior skins with continuous functional space around circumference of each tower. Through space between towers reduces upwind, downwind air pressure differential and wind loading on the cluster.

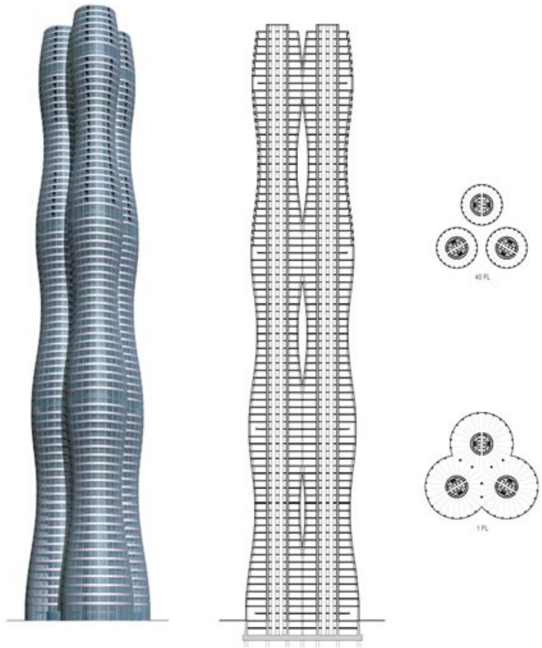


Figure 4. Wave-form tower cluster

Triple, coupled towers with wave form profile facilitated by offset columns on plan radians. Towers detached at minimum diameter levels each twenty floors, giving continuos window wall at circumference of each tower over several stories. Wind and light flows through openings at these levels thus reducing wind loading on tower clusters. Pedestrian cross over points and double story landscaped atria are located at each of the three structural links between towers.

pyramids comprising the prismatic form, natural light can penetrate deep into the overall form, open or enclosed atria can be more freely located and favorable slenderness ratios obtained in the overall structure. This concept is also worked out to allow flexibility in the placement of elevators and service cores and their penetration through triangulated floor structures.

Several projects (3, 4) employ the concept of straight or cranked, triple tube clusters. This arrangement permits the perimeter window wall of each tube to be used for most of its height and for light to penetrate through the cluster. Also, cross-linked tubes permit pedestrian communication and transfer between tubes at connecting floors without descending to ground level. This is a considerable advantage for rapid evacuation in case of fire in one area of the building. As tubes are structurally linked, the slenderness ratio of the group can also be favorable. Between linked floors tubes become separated. Air flows through the openings between tubes, thus substantially reducing overall wind load on the tower and cluster.

Wide-span relationship

A tall structure or cluster could have a relationship to the ground via a wide-span, ground-hugging, canopy-envelope structure. Such a canopy, or membrane may form part of an overall environmental concept in combination with the tower(s). Also, it may soften the visual impact of the abrupt relationship of a tower with the ground. It can gather the ecology of a landscape into the environment of the tower and form continuity between ground space and tower space.

Energy

Environmental factors and/or the structural concept may shape building form and skin. North sides will require minimum sun control, in the Northern Hemisphere. East and west sides will require different sun control than the south as solar angles and radiation intensities vary. In general, glass skins may be single, double or both in different areas of the building exterior. In double skins with cavity, the cavity may be part of the overall environmental concept. However, the climate will be the most important consideration in shaping the energy system.

For optimum environmental operating efficiency, building form should be accordingly shaped. Wind-flow uses scooping and 'venturi' effects for air intake and exiting. Use can also be made of the pressure differential between the 'windward' (upwind) and 'leeward' (downwind) sides of a building for through ventilation and surface wind-flow acceleration. Devices for wind-flow intake and exiting can be adjustable and remotely controlled. They may be mounted on vertical, inclined or horizontal surfaces. Photovoltaic arrays may also be similarly mounted, adjustable and remotely controlled. Maintaining the optimum angle of arrays in relation to the varying angle of incoming solar radiation is important for maximizing electrical output.

The 'tunable' double skin glass façade is devel-

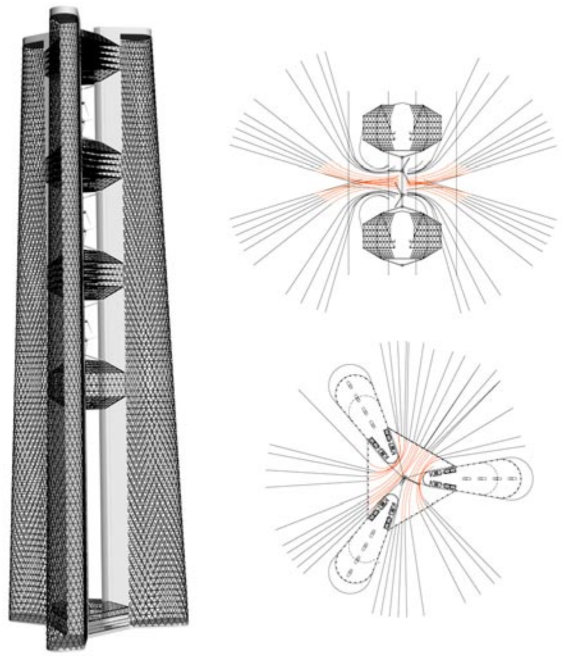


Figure 5. Airfoil towers with middle wind turbines

Three airfoil towers, focus and accelerate airflow to middle horizontal axis turbines. These are mounted on a rotating center column permitting the entire turbine to turn so the rotor blades are always perpendicular to the incoming wind front. Inner ends of towers enclose fire rated vertical circulation and support 'flying atria' with gardens. Pedestrian and structural linkage between towers and turbine column support, are located at these points.

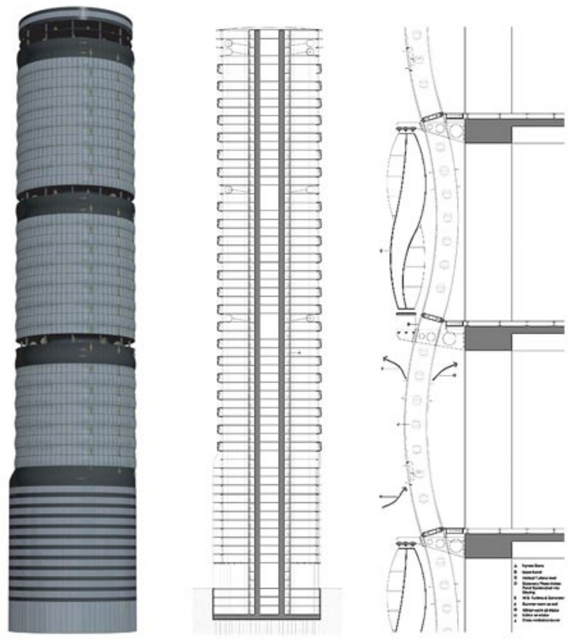


Figure 6. Wind turbines on wave form skin for wind acceleration

Wind-flow accelerates on tower sides parallel to the wind-flow and gains further velocity in the troughs of the wave profile, exterior glass skin. At these points are located, on the upper two thirds of the tower, the helical rotors of vertical axis wind turbines. About six turbines are placed around the circumference of the circular plan form. The glass skin on the bottom one third of the tower is placed off-center to form a solarium on the south side.

oped in some projects to shift warm or cool air from one side to another side of the building, as required. This may also be linked to a raised floor or floor/ceiling cavity acting as a plenum.

Wind-turbines

Electrical power generation from wind turbines employ horizontal and vertical axis types (HAWT and VAWT) and other types with newer rotor designs. Turbines may be mounted on top, the sides, or between components of a building cluster. Arrays of photoelectric cells can be mounted likewise. In the several types of natural energy systems, the building(s) must be shaped and orientated to work with the overall concept.

New studies reveal the loss of electrical energy from transmission over long distances, high cost of transmission infrastructure and growing opposition to visual pollution in landscapes of natural beauty by transmission lines and pylons. Some of these issues are intensified where wind turbines are concentrated in off-shore or in on-shore wind farms generally located a long way from industrial and residential areas where the energy is required. Over time this reality will probably have some impact on where people live in regions.

These and other factors are encouraging the development not only of energy efficiency and conservation in tall buildings, but also development of a new generation of buildings. These must be efficient not only in the use and conservation of energy, but also have the ability to generate energy using non-polluting natural renewable resources, including wind and sun for their own needs and possibly for export. The new development objectives also include interior climate modification by airflow and planting to be self cooling and self warming as far as possible.

Wind was an important source of mechanical energy and technical progress in a wide range of applications from ancient times up to the invention of steam and internal combustion engines. Regretfully, the important and interesting role of wind power in history is not completely understood and appreciated. The new applications of modern technology to harness the power of the wind has resulted in extraordinary recent progress in turbine design with the use of new and robust, lightweight materials and manufacturing. Refinements, advancement in efficiency and cost reductions appears frequently. Most of this progress and thrust has been focused on wind farms, with the larger and most advanced developments in Europe. Wind farms employ almost exclusively, at the moment, the horizontal axis type turbine (HAWT) on single, freestanding masts. Undoubtfully, important advances remain to be made in turbine design and will appear as international pressure intensifies for the reduction of pollution and employment and development of renewable resources. Though most attention has been focussed on the HAWT concept, the VAWT type is receiving increased attention and many new experimental designs are emerging in both categories. In HAWT, VAWT and hybrid concepts new designs with more efficient rotors are appearing.

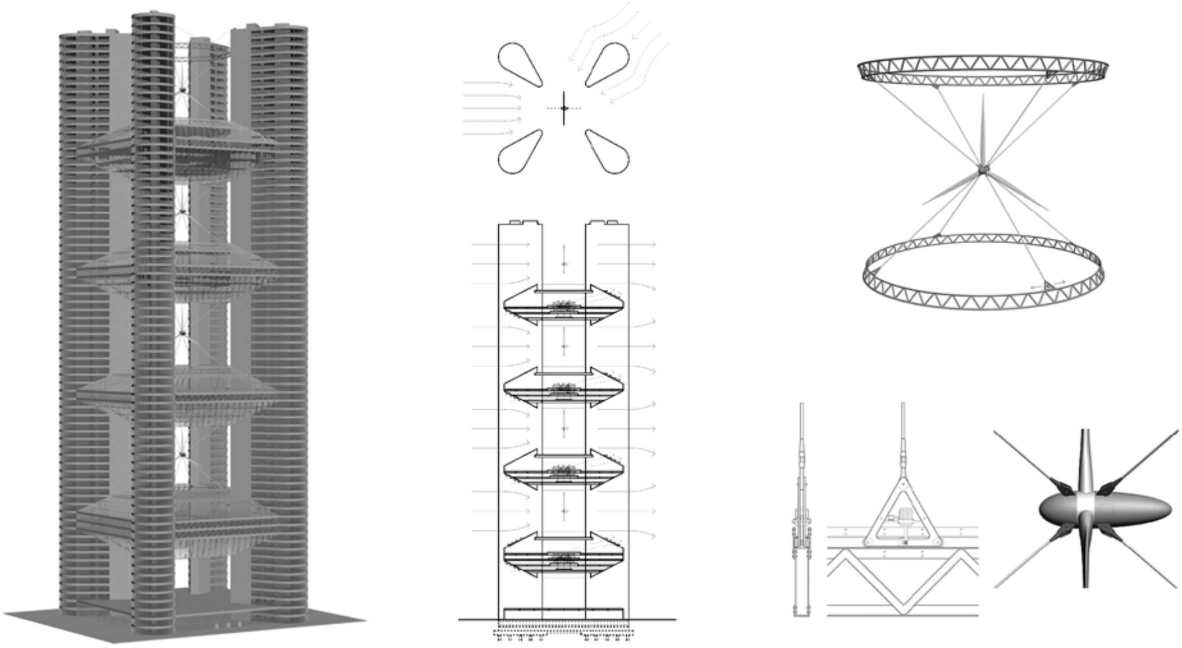


Figure 7. Four tower concept with Omni-directional wind turbines

Four corner towers support middle flying atria are shaped to focus and accelerate wind flow onto the rotors of centrally located, horizontal axis wind turbines. Side stays support each turbine with motorized end anchors on matching circular tracks. This arrangement permits the entire turbine housing to turn so that the blades of the rotor are always perpendicular to the incoming wind front.

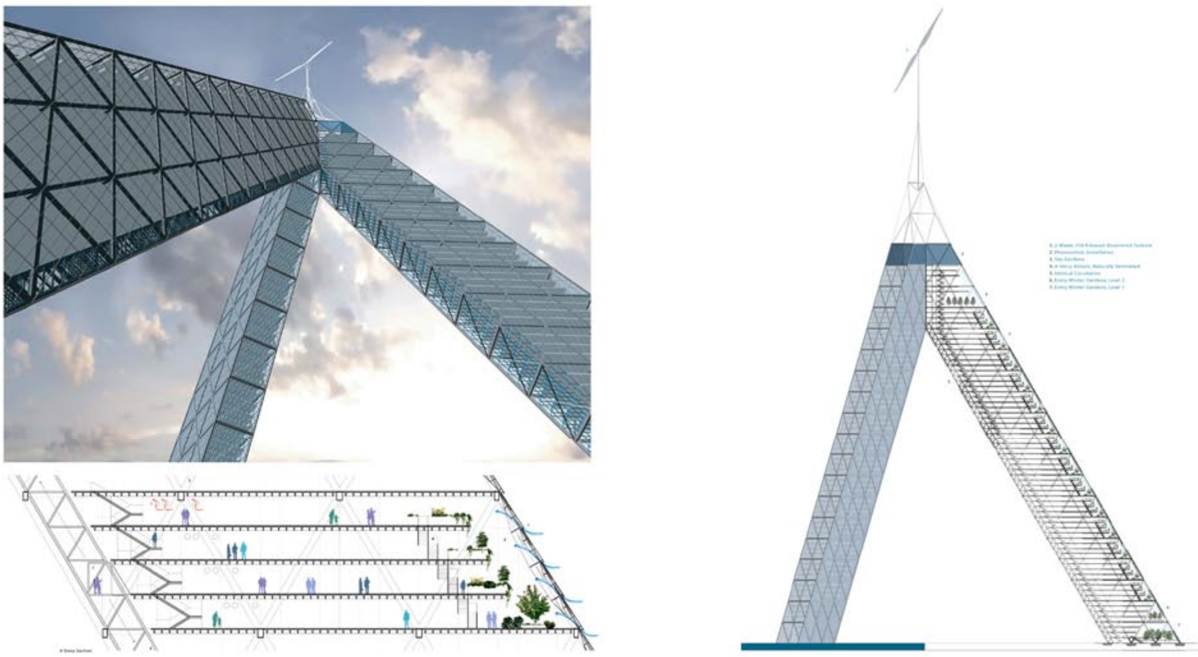


Figure 8. Tripod tower with down wind turbine

Triple, inclined towers with diagonally braced, side mega trusses supporting cross-floors and inclined elevators. Entering and circulating air passes through planting cascading down from outer ends of each floor in four story atria sections behind inclined glass. Triple column structure concept supports an experimental downwind, self-yawing horizontal axis wind turbine with a single, two bladed rotor.

In the entire field of wind turbine design very little attention has been given, however, to turbines on tall buildings. Conceptually, a tall building is a mast, which may penetrate undisturbed airflow of relatively high velocity. More important is that wind velocity increases with height. In the simplest form, wind turbines can be mounted on the exterior vertical surface or on the top of a tower building to harness the energy in wind-flow over

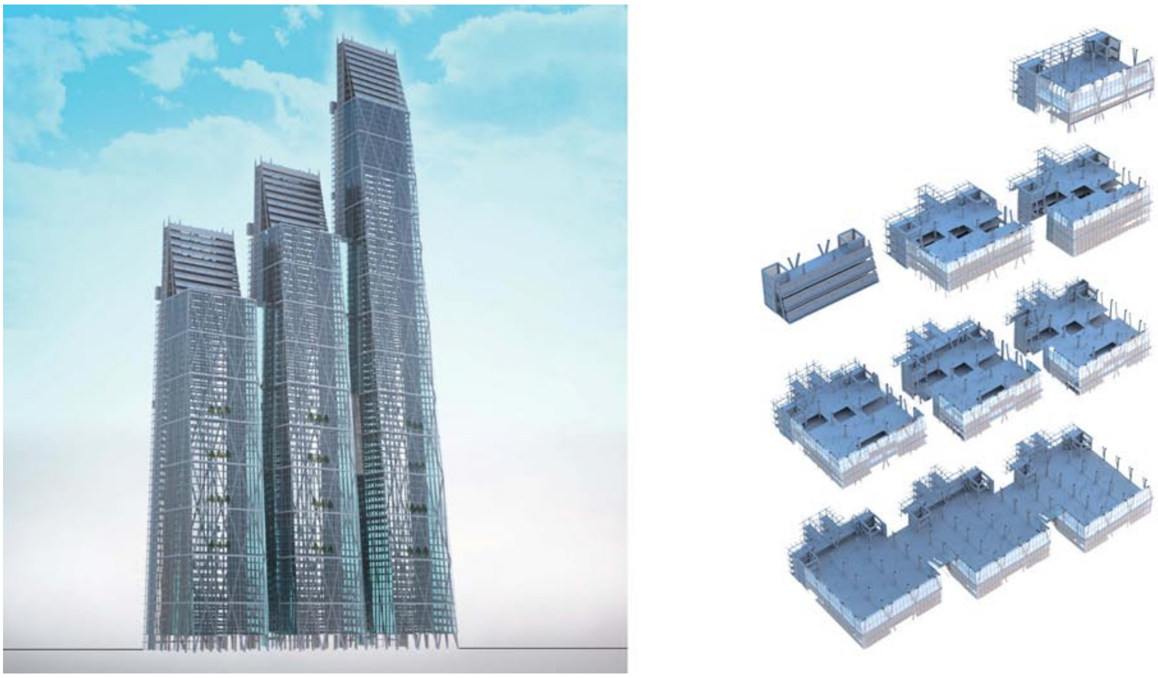


Figure 9. Inclined interconnected towers with top solar power concentrator.

Three-separated, in-line towers with inclined south fronts have vertical circulation on the north. Towers are linked by east west through walkways and bridges connecting interior atria on four levels. Additional atria are placed on the south inclined fronts as part of the energy system. The diagrid exterior structure with operable glass skin extends across the façade and atria. Concentrated solar power plants are installed on the upper levels of each tower with the appropriate thermal energy conversion, co-generation plants.

the top or/and around the sides of a single tower. Experiments and studies indicate that this basic arrangement possesses considerable potential for electrical power generation. Theoretical designs which have been proposed on these lines, generally use existing turbine technology and conventional building forms. To fully utilize the energy potential of wind power from tall buildings equipped with turbines, development of new forms and technologies is needed specifically for this task. Several are proposed in this paper.

Single towers may be in congested urban situations or free standing in new developments, outside the dense urban core of a city. In both cases the tower should be shaped accordingly and equipped with the appropriate turbine. Multiple or clustered towers can be interconnected and also be different heights. The main building form determinant is to increase wind flow velocity by shaping the building and its external surface to focus and compress wind flow thereby increasing velocity and energy harnessing potential.

The most challenging factor in the design of towers equipped with turbines is wind-flow direction. In some locations wind flow may have one or two predominant directions. In other locations there may be none. Even in locations with strong main wind direction(s) there will be variation at times of seasonal change. Predominant or omnidirectional wind patterns require different approaches to tower and cluster form, the selection of turbine type and placement of equipment.

Tower or cluster design for non-predominant or omnidirectional wind pattern locations requires that the HAWT must be able to yaw, possibly through 360°, so that its rotor blades can always be perpendicular to the varying direction of the incoming wind front. In this way, one or a group of turbines can maintain continuous optimum energy generation, irrespective of incoming wind-flow direction.

Yawing ability is a standard feature of the single freestanding unit on its mast. However, a single or cluster of yawing HAWT's integrated into a building presents challenging new design and technical problems. The turbine hub must be supported in such a way, which will permit the entire turbine to orientate by rotating horizontally on a middle column support (5) or by bottom and top side-stays with motorized end anchors on circular tracks (7). Top mounted weather sensors will register wind direction, send data to a computer, which will command the turbine to orientate accordingly and perform other operations. The structural and mechanical challenge of these configurations will depend upon the complexity of the supporting building form. Turbines with vertical rotors VAWT's do not have a preferred orientation, which potentially simplifies the overall structural and mechanical configuration. Wind turbines of both types can be top or side mounted on towers in combination with devices and building form to accelerate and focus wind flow.

Photovoltaics

The generation of electric energy directly from the sun employs arrays of photoelectric cells. These can be top or side mounted on the building skin and form, which

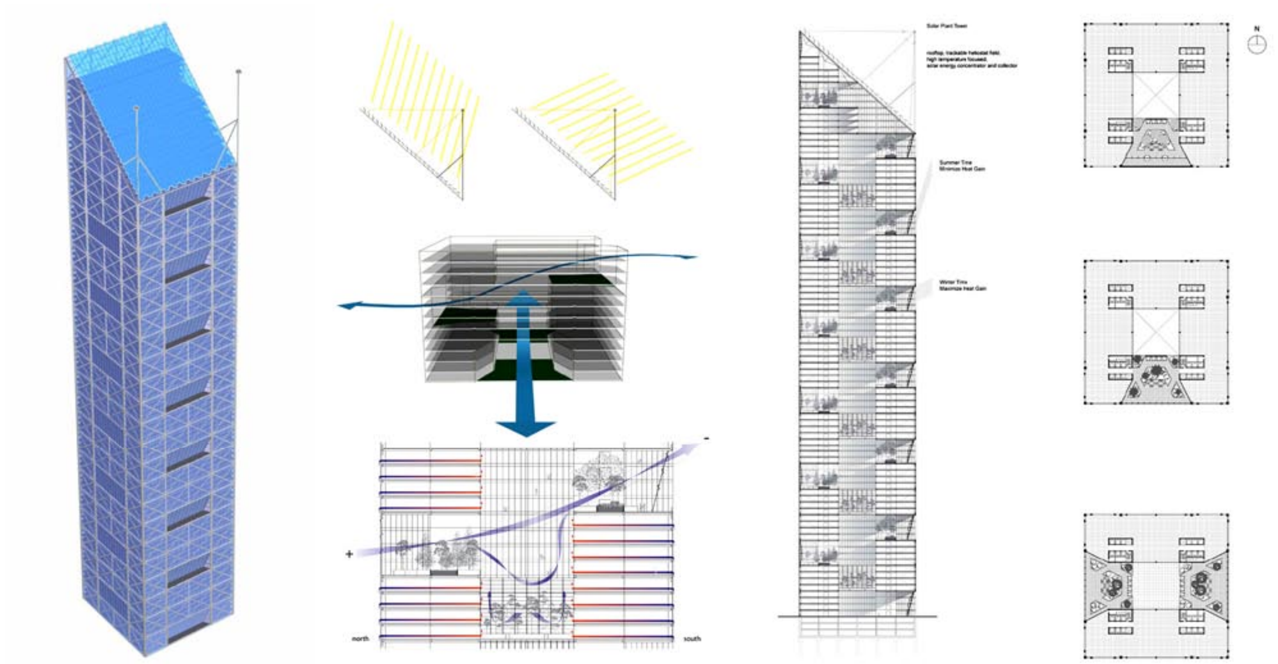


Figure 10. Omni-directional through ventilating tower

Openings every eight floors on each tower side channel air, light and interior gardens to the middle atrium and through to the opposite side. Remote controlled openings and louvers in glass skins across openings control airflow and solar gain. A concentrated solar power plant with a heliostatic reflector field installation is placed on the inclined upper level with two collectors and related equipment.

should be shaped to facilitate optimum and accurate solar orientation. Arrays may be stationary, integrated into the glass skin, or on heliostatic mounts, moving through one or more planes on horizontal, vertical or inclined building surfaces. Their movements would be computer controlled by data from top mounted weather sensors to maintain optimum angle and efficiency from sunrise to sunset throughout the year.

Concentrated solar power

One project (9) is shown with concentrated solar power (CSP) installation on its upper section. In this proposal the parabolic concentrators can change angle in the vertical plane and function efficiently for most of the solar day and year. Limited angle change in the horizontal plane minimizes over shadowing from adjacent sections of the installation to thereby function during early morning and late afternoon in the summer solstice.

Another project (10) is shown with a CSP installation on the inclined upper levels of a square tower. This arrangement consists of an inclined heliostatic field of reflectors, which are programmed and linked to track and simultaneously focus the reflected sun onto collectors located at two braced masts in the south-west and south-east corners of the tower. The high temperature energy achieved in the collectors is conveyed in liquid form to a plant room at the base of the masts for steam conversion to drive turbines and a co-generation installation.

The advantages of CSP are well known and interest in this technology is expanding. However, there are challenging technical problems in fitting reflectors on vertical or inclining surfaces on towers and maintaining optimum orientation for intercepting incoming solar radiation. Mounting devices may be stationary or moving and computer controlled by data from top mounted weather sensors. Efficient orientation and performance of devices is dependent upon building form. The collection and transport of high temperature energy in fluid form from concentrators to conversion plant must be carefully planned.

Light

Light penetration in the floors of tall buildings is a primary determinant of plan form and dimensions. The possibilities of 'light-pipe' technology are well known and have been applied in the diagrid tower (11). In this tower, light is gathered from the exterior every sixth floor at the landscaped atria levels and reflected downward through the center in the 'light-pipe'. Light is re-directed horizontally at every floor from the 'light-pipe' at each floor by prismatic reflectors. Accumulated thermal energy at each sixth floor primary reflector is used by the general energy system.

Landscape

The purpose of interior planting is to reduce glare from direct sunlight by leaf filtering of solar radiation, reduce temperatures by creating full or partial shade and by trans-evaporation from plant leaves. Generous interior planting efficiently improves the interior climate by absorbing CO_2 emitted by humans and producing oxygen

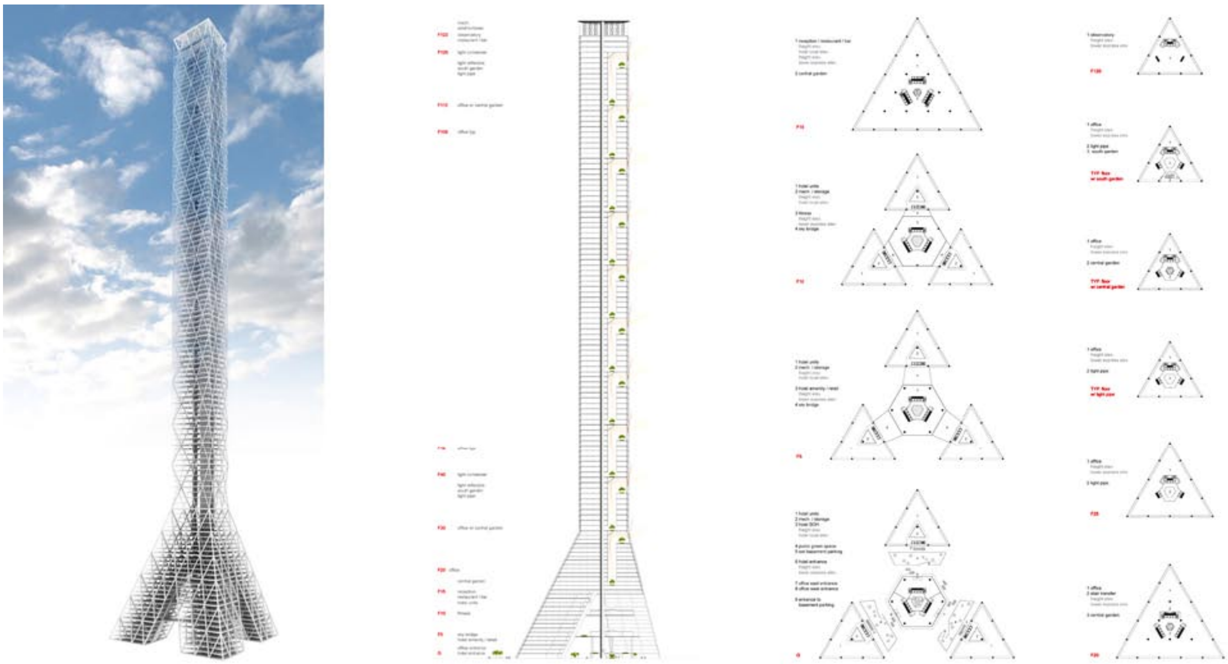


Figure 11. Diagrid tower with light pipe

Triple column support structure with triangulated floors and diagrid exterior. Light enters each tower floor from the exterior and from the interior 'light pipe'. Light is gathered into the 'pipe' every sixth floor landscaped atria level and reflected downward through the plan center and re-directed horizontally at each floor by prismatic reflectors. Accumulated energy at each sixth floor primary concentrator reflector is utilized by the energy system.

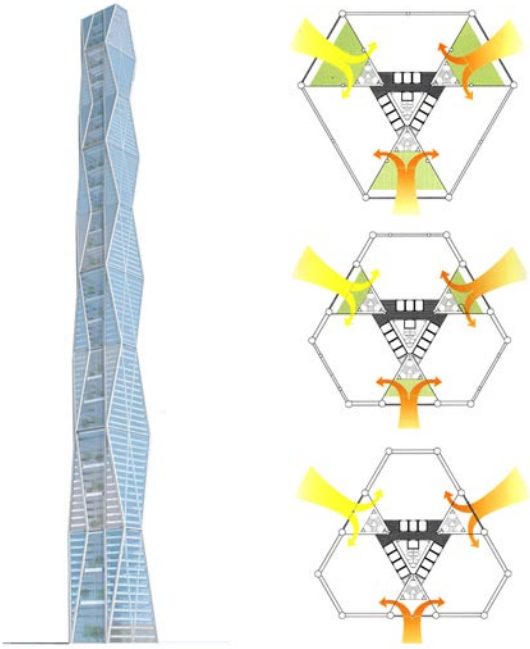


Figure 12. Mega-frame tower with corner atria

Triangulated, tubular mega-frame, articulating multi-story atria located at extremities of floor plan, three per level. Entering and circulating air flows through landscaped atria. Air flow moves from north to south and vice versa through the cavity of the double exterior skin and atria planting as part of the energy system.

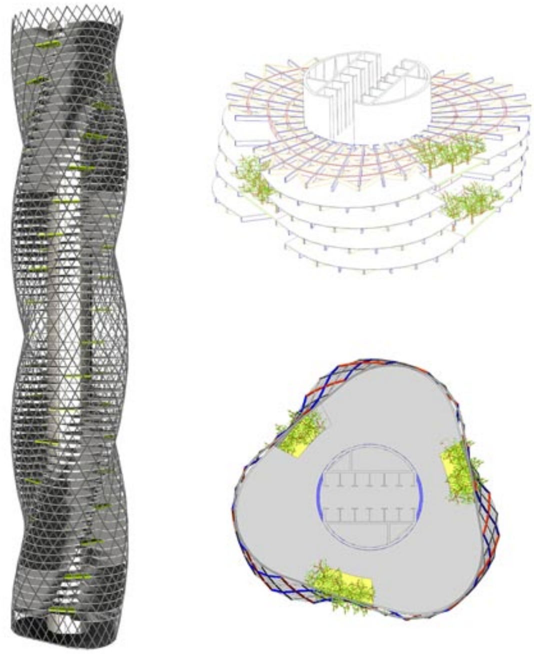
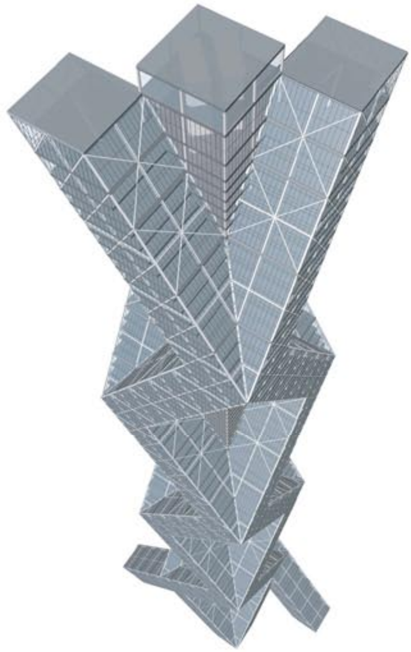


Figure 13. Triple spiral tower

Three interior gardens follow the triple spiral of the tower form around the center core. A diagrid exterior structure supports the floor circumference edge and a double glass skin façade with opening panels. Entering and re-circulating air flows through each of the three gardens. The cavity of the double skin, the atria gardens and a floor plenum are interconnected to form an overall airflow, computer controlled system.

needed by humans. A very important benefit of interior planting is a psychological one. Carefully placed plants and flowers offer an antidote to the stress inducing character of much modern urban activity.

The preferred location of planting is on the east, west and south faces for solar filtering and shading. In several projects cascading planting is located behind an inclined glass skin so that entering or re-circulating air is



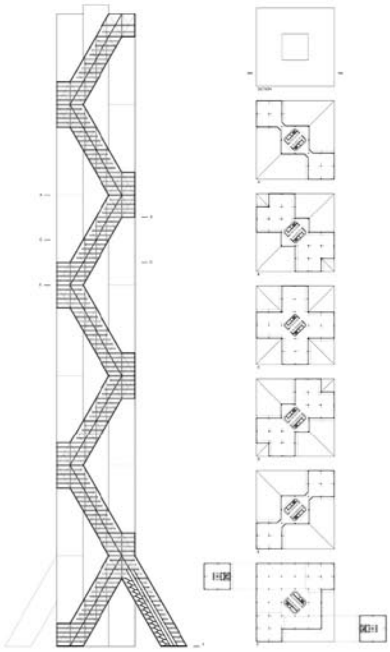


Figure 14. 'Zigzag' tower

The plan form maximizes the window area on each floor of the tower. The diagonal/spiral form configuration unites and braces the plan extremities with the core. Forward inclined horizontal glass skins offer glare mitigation. Cascading planting is placed on floor edges behind backward inclined glass to provide shade and to filter incoming or re-circulating air.

beneficially filtered and considerable solar gain in summer from inclined skins is reduced. In several projects (8, 9, 12, 13, 14) entering or re-circulating air is passed through single or multi-story landscaped atria as part of the overall environmental, air conditioning system.

Interior planting must be arranged and designed in relation to solar orientation and as part of the overall energy concept. Plant irrigation should be gravity driven and use rainwater or recycled water. The environmental benefits of planting are very well established but the technology of interior horticulture and gardens is less well understood. However, long and extensive experience from the great glasshouses, such as Kew Gardens, waits to be utilized.

Conclusion

The inexorable depletion of fossil fuels and approach of the beginning of the end of the petroleum age is now the subject of serious geo-political debate worldwide. Concomitantly and encouragingly, renewables is now receiving growing attention as an economic and feasible, non-polluting alternative to fossil fuels. Research is accelerating, new concepts are appearing and being developed and tested. Equally important is that sponsorship for research and development work is coming from governments and the private sector. But most important of all is that several bold international developers are financing visionary projects actually under construction. Amongst them are high-rise towers equipped with wind turbines and related technologies for energy independence. On going and speculative research and development is expanding, which is demonstrating that the potential of wind and solar power is much greater than thought ten years ago. Advances begin with ideas followed by development and evaluation, which then generate further advances. This process is gaining momentum in response to the international economics of petroleum depletion and global environmental pollution. Some of the promising new structural and energy possibilities and ideas being pursued by the IIT group are summarized in this article.

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