

Integration of Sustainable Building Technology and Form Generation of Tall Building



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Summary

The paper is discussing form of sustainable tall buildings especially for those require significant efforts to integrated concerns of environmental impact and economic benefits from sustainable approaches to ensure low energy consumption and CO₂ emissions.

Form generation achieved through sustainable design approach is becoming increasingly important, as we think more about the environment and energy conservation. As we try to preserve the changing environment, energy conservation turns into a priority.

Because buildings account for a large proportion of energy use, architects and engineers must focus on energy efficient design. In addition to that, buildings are one of the heaviest consumers of natural resources and account for a significant portion of the greenhouse gas emissions that affect climate change.

It is important to design efficient structures and functional architectural forms. Integrating them with energy efficiency strategies is essential to achieve a sustainable building: a hybrid using the least amount of resources to create a healthy and environmentally friendly building. Such a sustainable form of tall building is only possible with close integration across different construction disciplines.

Therefore, it is more important to understand the energy strategies and try to integrate them into the building form to have great advantage of sustainable design. Thus, it is critical for a sustainable form generation to support building energy conservation by developing new ideas to enhance building energy efficiency.

In this paper, we review examples of sustainable tall building illustrating the interaction between architectural forms, energy efficiency and provide analytical survey of the significance of adaptable use of sustainable solutions on the current practice of tall building.

Keywords: Sustainable Building Design, Tall Building, Renewable Energy, Form Generation

5. Introduction

As we try to preserve the changing environment, energy conservation turns into a priority. Because buildings account for a large proportion of energy use, architects and engineers must focus on energy efficient design. According to US Green Building Council, buildings use 40% of raw materials globally, buildings use 13.6% of all potable water, buildings represent 72% of U.S. electricity consumption, and buildings represent 38.9% of U.S. primary energy use [3]. In addition to that, buildings are one of the heaviest consumers of natural resources and account for a significant portion of the greenhouse gas emissions that affect climate change. In the U.S., buildings account for 38% of all CO₂ emissions. It is important to design efficient structures and functional architectural forms. Integrating them with energy efficiency strategies is essential to achieve a sustainable building: a hybrid using the least amount of resources to create a healthy and environmentally friendly building. Such a sustainable form of tall building is only possible with

close integration across different construction disciplines.

Table 1 Energy Consumption in the office building (Electricity)

Energy Use	Electrical Loads (KWh/m ²)
Heating and Hot water	201
Cooling	41
Humidification	23
Fans, Pumps and Controls	67
Lighting	60
Office Equipment	32
Computer Rooms	105
Catering	24
Other Electrical	15

Source: Tall Buildings and Sustainability (W. Pank, 2002)

One of the difficulties to pursue sustainable design was the cost of the project. Experience suggested that ideal integration of systems to achieve maximum benefit of sustainable design with less long term premium although it requires marginal initial premium at initial stage. Sustainable design is not always be achieved by develop new system or relied largely on state of art technology. Sometimes, there is a tendency to overestimate the benefits of certain energy solutions that may not work as planned or that may become difficult to modify once the building is built. Therefore, it is more important to understand the energy strategies and try to integrate into the building form to have great advantage of sustainable design. At the same time, a structural system accounts for thirty percent of the total building cost and is of a primary design focus. Thus, it is critical for a sustainable form generation to support building energy conservation by developing new ideas to enhance building energy efficiency.

6. Review of Sustainable Buildings

The Chicago Spire, a 150 story tower designed by architect Santiago Calatrava, has an unusual building facade formed by its pointed floor plan which is twisted 360 degrees around its axis towards the top (see Figure 1). In this tower, the exterior skin doesn't express the structural system of the building. It was difficult to integrate an exterior structural system with the twisted building facade because structures tend to lose their stiffness and bearing capacity when excessively twisted. Therefore a conventional internal core structure was designed.



Fig. 2 Chicago Spire, Chicago, USA (source: Chicago Spire LLC) and its floor plan

Sustainable structural systems often depend on the architectural forms of the building. Structural and architectural forms may be combined to reduce material use. For example, stiffened architectural forms will have good structural performance as well. This idea was used in a

research project at the College of Architecture, Illinois Institute of Technology (IIT) (see Figure 2). The structural validity of this particular form comes from maximizing the moment of inertia at the base of the building. In this project, the architecture and structure work together to reduce the gravity and lateral loads on the building. In addition to great structural performance, this architectural form could be used to enhance building energy performance. Some ideas are proposed later in this paper

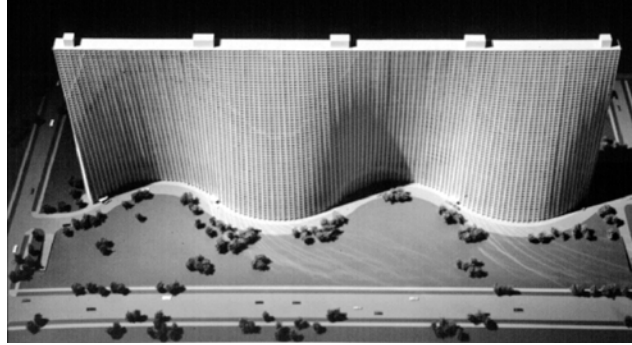


Fig. 3 Student thesis project (source: Master's Thesis Program, IIT)

Scale has a great impact on the selection of an architectural form, structure, and energy efficiency. To a great extent, scale determines the choice of a structural system and a form. Frequently, a building form can be perceived as an expression of the structural system. For example, a tall and slender building will require a structural system that responds well to the dynamic nature of wind. These requirements may restrict geometric forms, such as dramatic setbacks or excessive twisting, as they cannot withstand certain dynamic forces.

Some energy technologies in buildings can be very dependent on the structure that houses them. In 1997, the first author introduced an innovative structural system for a 600 meter high tower based on the solar chimney technology developed by Schlaich from Stuttgart, Germany, in the early 1980s (Figure 3). The tower structure was a very tall tube supported by multiple cables anchored to the ground. At the bottom of the tube, the air is heated by the sun in glazed collectors. The tube channels convective hot air from its bottom to the top which generates energy when it passes through small turbines. The taller the chimney, the more electrical energy can be produced. The structure for a solar chimney would have to be extremely tall, which is challenging from economic and construction perspective.



Fig. 4 Model of a 600 meter high solar chimney and its cross sectional plan representing a porous organic form (source: the M. Elnimeiri)

Sustainable structures may use nonconventional renewable materials such as bamboo. In the Tjibaou Cultural Centre in New Caledonia, by architect Renzo Piano, bamboo was successfully utilized as a primary structural material (Figure 4). Besides being a naturally renewable construction material, bamboo was an abundant local material, which significantly reduced embodied building energy. This form and structure can also be explored for tall building construction.



Fig. 5 Tjibaou Cultural Centre, Nouméa, New Caledonia (source: Renzo Piano Building Workshop)

Today, more efficient structures are being developed. Efficient structures, such as diagrid, have been used recently on two projects by architect Norman Foster: the Hearst Tower in New York (Figure 5) and the Swiss Re Tower in London (Figure 6). In both cases, the structural systems were located near the buildings' exterior and were expressed on the facades.

A good example of the combination of structure and architectural form highly responsive to its environment is The Met, a 69 story residential tower in Bangkok (Arch Daily 2009). The building structure consists of a series of closely spaced parallel shear walls (Figure 7). The shear walls form three clusters of residential units, separated by air gaps. Along the building height, the clusters are connected by sky bridges supporting gardens or community spaces. The air pathways between the three clusters of residences allow free air movement, thus providing the building with natural ventilation. The shear walls' layout also allows cross ventilation inside the residential units. In addition to ventilation, the air pathways between the shear walls reduce wind force impact on the structure. Recessed windows and hanging gardens also provide shade which helps avoid overheating in the hot and humid Bangkok climate.

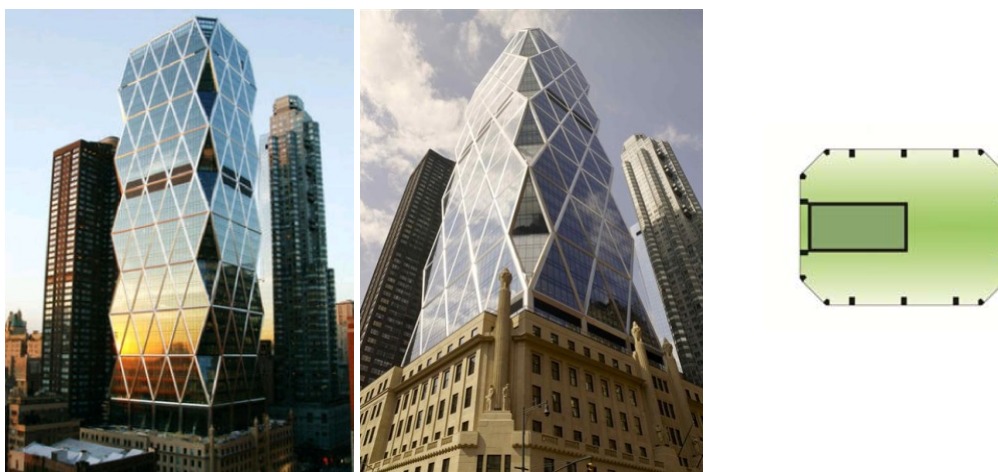


Fig. 6 Hearst Tower, New York, USA (source: Foster and Partners) and its floor plan



Fig. 6 Swiss Re Tower, London, UK (source: Foster and Partners) and its floor plan



Fig. 7 The Met, Bangkok, Thailand (source: Arch Daily) and its floor plan

Another example of sustainable structural and architectural integration is the Cocoon Tower in Tokyo by Tange Associates (Tange and Minami 2009). This 50 story tower is a vertical campus housing Tokyo high education institutions (Figure 8). The building structure consists of an inner core and three elliptical diagrid frames located at the perimeter. The diagrid frames are rigidly connected only at the base and at the top. Each of the three diagrid frames houses a classroom at every floor. The circular space between the exterior structures forms a series of three story atriums stacked on top of each other. The atriums serve as student lounges or enclosed school yards.

Masdar Headquarters is designed as the world's first large-scale, mixed-use "positive energy" building which produces more energy than it consumes (E-architect 2008). The structure of the building is composed of conical towers enclosed in diagrid (Figure 9).

Apart from supporting floor loads and providing lateral bracing, the towers serve as building atriums. The diagrid laced atriums create stack ventilation, and are reminiscent of such elements of Islamic architecture as wind towers and Arabic courtyards. The large roof is used for solar energy generation using photovoltaic arrays. The building will use sustainable materials,

integrated wind turbines, and additional systems to generate energy and reduce waste. Although the Masdar Headquarters is a mid rise building, the same ideas could be easily applied to the design of tall buildings.



Fig. 8 Cocoon Tower, Tokyo, Japan (source: Archicentral) and its floor plan

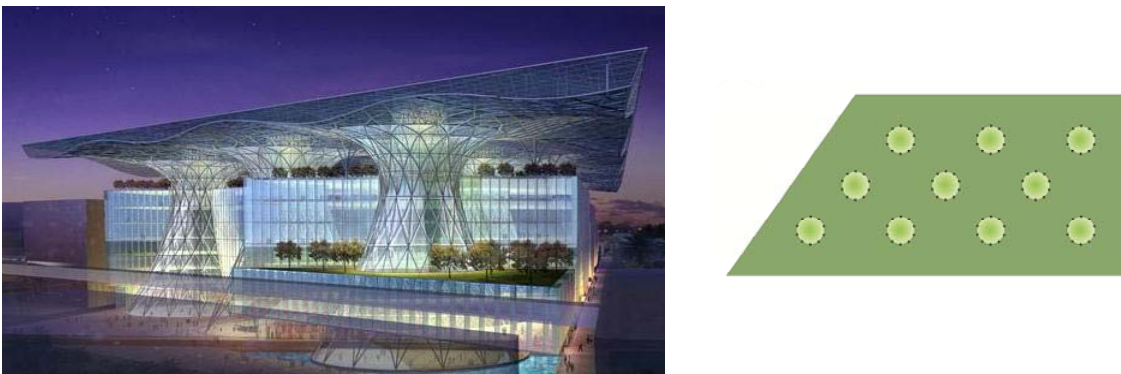


Fig. 9 Masdar Headquarters, Abu Dhabi, UAE (source: E-architect) and its floor plan

7. Integrated Form of Sustainable Tall Building and applied Technologies

Although the integration of many of technologies into tall buildings is still at the experimental stage, increasing numbers of designs and some completed projects utilize technologies such as building integrated wind turbines (BITW), photovoltaic cells (BIPV), co generation and tri generation systems, fuel cells and ground source heat pumps to reduce primary energy consumption. While current practice of tall building design integrating technology and building form, one must be understood that there are shifting from conventional building design to sustainable building design in regarding nature imposed to the building. Table 2 shows comparison between conventional and sustainable building design before state of art technologies applied to the building.

By concerning locality and climate seriously, system and solutions were provided by available resources.

Table 3 shows 6 design cases from recent practice in tall building design. Each design explained by types of resource and applied system to achieve enhanced energy performance and

sustainability.

Each project indicated its sustainable solution by resources, differ from conventional building, all designed with both active and passive way of energy conscious design solution.

Table 2 Comparison of Conventional and Sustainable Building Design

Conventional Building	Sustainable Building
Reflect light	Absorb light
Cuts into the wind	Capture the wind
Insulate from solar energy	Absorb and use solar energy
Shed Rain water	Capture and use Rain water
Produce waste water	Store, treat and re-use waste water

Mixed-use district, Beach Road, Foster + Partners, Singapore

The scheme incorporates commercial, residential, retail and two high end hotels, as well as a direct 'green' link to an MRT station. Offering a light and comfortable environment, the canopy is articulated by ribbon forms that flex above the primary circulation routes and public spaces and dip near the edges reflecting the changes of use beneath it. The ribbons rise up the exposed east and west elevations of the developments where they form a series of vertical louvres. These filter the sun and provide a framework for the planting which will transform the developments into a series of vertically linked green spaces. The buildings forms and slanted facades are oriented to catch the prevailing winds and direct air flow down to cool the ground level spaces.

60-70 St Mary's Axe, Foggo Associates, U.K

One of the latest buildings proposed to be built in london's business district is 60 70 st mary's axe designed by foggo associates. already dubbed the 'can of ham' the building has been designed as an asset to its local surroundings rather than london at large. the 18 storey design will be used mainly as offices covering 17,843 sq m with some retail space at ground level. planning permission This distinctive semi elliptical new 90 metre, 24 storey office building will provide good natural light penetration whilst minimizing solar gain and delivering an impressive low carbon solution and BREEAM excellence.

Iris Bay tower, Atkins, Dubai

A 170m high, 32-storey tower comprises two identical double curved shells, rotated and cantilevered over the podium. The tower is elevated above a four-story perforated podium which floats over a double height arcade.

4 times Square, Fox & Fowle, USA

The 4 times Square Building is an environmentally responsible building. All building systems and construction technology have been evaluated for their impact on occupant health, environmental sensitivity, and energy reduction, making Four Times Square the first project of its size to adopt state of the art standards for energy conservation, indoor air quality, recycling systems, and the use of sustainable manufacturing processes. The building features environmentally efficient gas fired absorption chillers and a state of the art curtain wall with excellent shading and insulating performance. The air delivery system will provide 50% more fresh air than industry codes, and a network of recycling chutes will serve the entire building

Pearl River Tower, SOM, China

By reducing the building's energy consumption through a combination of the building's site orientation, a high performance building envelope, day lighting, and building control systems. By rotating to the east, the tower takes advantage of midday sun while the effects of late day sun on the larger, southern horizontal exposure are minimized. The south facade's low E glass, double layer curtain wall system reduces heat gain, which leads to less demand on the HVAC systems.

Anara Tower, Atkins, Dubai

The design combined with its orientation, the 100 storey plus mixed use project is spanning almost five million square feet. The design of Anara Tower will answer the environmental challenges posed to modern day skyscrapers by maximizing water and energy efficiency; and potentially including renewable sources of energy, in addition to conforming to the internationally recognized LEED certification requirements.

8. Conclusions

Tall building is still important icon of the city. However, to be more attractive to the future, tall building design should be overcome its limitation and minimize negative aspect on environment. In the past, tall buildings always develop with new materials, structural system and innovative architectural ideas. Those technological innovations impose great impact on tall building industry for both positive and negative aspect. By nature of tall building, it is very difficult to achieve low energy building. And currently, we are facing with serious environmental issues including global warming caused by CO₂ emission. It is strongly required to use sustainable concept and applicable technology for reducing energy consumption and CO₂ emission those consequently affect the form of tall building.

Recent practice shows possible adapt use of sustainable design concept for tall buildings. Although 6 projects shown in this paper were still immature stage, however, it indicated significant to aware the problems in tall building design.

The paper suggests some building concepts to enhance architectural form design development regards to energy efficiency strategies integrated with sustainable technology. A successful sustainable tall building can only be achieved by collaborative design process during the design process with other discipline. It is time to integrate energy strategies with architectural form generation through sustainable design strategies.

For the future tall building, new sustainable building form will provide innovations and enhanced creativity to the building design while it contributes to our clean environment.

Acknowledgments

This work was supported by Sustainable Building Research Centre of Hanyang University which was supported by ERC program of Ministry of Education, Science Technology (#R11-2005-056-04003-0). The authors also recognize the college of architecture at IIT and graduate students of PhD Program

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