

Title: **Design Strategies for Environmentally Sustainable Residential Skyscrapers**

Author: Sabina Fazlic, Graduate Student, Cardiff University

Subjects: Architectural/Design
Sustainability/Green/Energy

Keywords: Climate
Environment
Residential
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 Unpublished conference paper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 Unpublished

© Council on Tall Buildings and Urban Habitat / Sabina Fazlic

Design Strategies for Environmentally Sustainable Residential Skyscrapers

Sabina Fazlic

Welsh School of Architecture, Cardiff University, United Kingdom, brkics@Cardiff.ac.uk, +44 796 0546176



sabina1130@yahoo.com

Biography

Sabina Fazlic was born Sarajevo , Bosnia-Herzegovina in 1981. She moved to Chicago in 1990, where she obtained a Bachelor of Arts in Architectural Studies at the University of Illinois at Chicago . She is currently completing a PhD at the Welsh School of Architecture, Cardiff University , entitled “Design Strategies for Environmentally Sustainable Residential Towers in the Cool Temperate Climate.” Her focus is on the creation of an accessible framework based on the principles of sustainable design, particularly in relation to the bioclimatic approach. She has applied this research to work undertaken at Broadway Malyan (Birmingham) and the School of the Built Environment, University of Nottingham.

Design Strategies for Environmentally Sustainable Residential Skyscrapers

Sabina Fazlic

Welsh School of Architecture, Cardiff University, United Kingdom, brkics@Cardiff.ac.uk, +44 796 0546176

Abstract

The development of residential tall buildings has been accompanied by an increasing interest in the application of sustainability to the building sector. Therefore, this paper will focus on environmentally sustainable residential towers, specifically ones situated in the cool temperate climates of Europe and North America. It will consider a range of completed and proposed green high-rises and will examine in particular the theoretical and practical work of Dr. Ken Yeang. A new framework for ecological towers will be proposed, one designed for adaptability and ease of use by architects.

Keywords: sustainability, skyscraper, residential, temperate climate

Introduction

Due to the negative effects of urban sprawl and rapidly increasing urbanization, residential towers provide an opportunity for a more sustainable future. Current studies of sustainable towers, however, focus on commercial buildings and are generally difficult to approach from a designer's perspective. Furthermore, a lack of information exists for design in the temperate climate. This study aims to contribute to the emerging research in environmental architecture and will focus on the creation of a framework for environmentally sustainable towers in the cool temperate climate, home to major urban centers. Originating from the study of Ken Yeang's approach, which has been applied predominantly in the tropical climate, it will provide a practical method that can be used in conjunction with contemporary design methods and software. While it will focus on environmentally sustainable towers, the framework will place particular emphasis on bioclimatic strategies, followed by renewable sources of energy, resource conservation and optimal building systems.

This paper is part of larger study, intended for a PhD degree at the Welsh School of Architecture, and will summarize the results achieved thus far. At a later point, the framework is intended to be tested on two sites, one in London and the other in New York, as these cities represent two variations of the climate and well as differing social, historical and cultural approaches to the inclusion of skyscrapers. These towers are designed to be 150 meters tall, and although the framework is applicable to both larger and smaller skyscrapers, it places particular attention on this typical height of a tower found in the cities of Europe and North America.

The paper will be organized to demonstrate the origin of the proposed framework. Definitions and discussions of terms will be followed by a review of current proposed and completed bioclimatic towers. A discussion on the work of Ken Yeang will then consider the applicability of his approach to the cool temperate

climate and will lead to an introduction to and an overview of the framework.

Residential Towers

Because of its broad applicability and relevance to the case studies, the high-rise definition employed in this paper is from Emporis, an extensive database on buildings and the real estate industry. It states that "a high-rise building is defined as a building 35 meters or greater in height, which is divided at regular intervals into occupiable levels" (Emporis, 2005). The terms skyscraper, tall building, tower, and high-rise are interchangeable in this text. As is the case with the skyscraper, there is no consensus on what makes a tower residential. In this text, a figure of fifty percent residential use will act as an indication of the tower's classification as a residential building. This does not include temporary accommodation, such as hotel space. To differentiate between types, the term residential high-rise will only refer to a building of that purpose.

Cool Temperate Climate

As defined by the most accepted method of classification, the Koppen System, the earth's climate can be divided up into five different regions: tropical moist climates, dry climates, moist mid-latitude climates with mild winters, moist mid-latitude climates with severe winters, and polar climates. Often the two moist mid-latitude climates are combined into the temperate climate or commonly referred to as the warm and cool temperate climates. They are found in matching latitudes, so they usually share comparable amounts of sunlight and precipitation and their wind speeds are often of a similar degree (*Survey of Meteorology*). The major differences are in their temperature ranges, particularly during the winter. The warm temperate climate is characterized by warm-to-hot summers and mild winters, where the coldest month is below 18°C and above -3°C; the cool temperate climate is typified by warm summers and cold

winters, where the average temperature in the coldest month drops below -3°C. This study will focus on two subsets of the temperate climate, which will be referred to as the cool temperate climate in general. These subsets can be defined as:

Marine (Cfb)

This major type, moist subtropical mid-latitude climate occupies western sides of continents from 40° to 60° latitude. Prevailing western winds moderate the climate near the coast. The winters are relatively mild and summers cool and there are many low clouds, fog and drizzle particularly during the non-summer seasons. There is little snow usually, except at higher mountain altitudes (*Survey of Meteorology*).

Humid continental with hot summers (Dfa) or cool summers (Dfb)

Found between 40° and 60° latitude, this major type has uniformly dispersed precipitation of twenty to forty inches throughout the year. The area with hot summers (Dfa) differentiates itself from the other (Dfb) because of the season's high temperatures and warm, humid evenings, as well as a growing season extended by about two months (*Survey of Meteorology*).

Sustainability

In the most common definition, sustainability is referred to as "meeting the needs of the present without compromising the ability of future generations to meet their own needs," as defined during the Rio de Janeiro Earth Summit of 1992. A definition more specific to the field of architecture is that of the Royal Institute of British Architects (RIBA), which states:

Sustainable development is that which raises the quality of life and serves the goal of achieving global equity in the distribution of the Earth's resource whilst conserving its natural capital and achieving significant and sustained reductions in all forms of pollution, especially emissions of greenhouse gases.

In such general definitions, sustainability has an economic and social aspect as well as an environmental one, but due to the aims of this paper, only the environmental one applies. This will be referred to as environmental sustainability.

Also included in this paper is the term "bioclimatic." As defined by Ken Yeang the objectives of this approach are to "seek by design a *low-energy, passive building and better occupant comfort*" (Yeang, 1996). He compares this approach to the ecological one, whose aims are identical with the environmentally sustainable method. The bioclimatic approach is not however equivalent to the ecological approach mentioned, even though the two share most qualities (see *Figure 1*). Bioclimatic design uses the energies of the local climate, whereas ecological design considers the building's effects on the natural environment in its entirety. Ecological, or

"green," design's essential characteristic is the interconnectedness between all manmade and natural activities, while bioclimatic design, as an intermediate step, focuses on the building and its immediate surroundings. The bioclimatic approach here is of

	Design mode		
	Others	Bioclimatic	Ecological
Built form configuration	Other influences	Climate influenced	Environment influenced
Building orientation	Relatively unimportant	Crucial	Crucial
Facade and windows	Other influences	Climate responsive	Environment responsive
Energy source	Generated	Generated / ambient	Generated / ambient / local
Energy loss	Relatively unimportant	Crucial	Crucial / reused
Environmental control	Electro-mech	Electro-mech / manual	Electro-mech / manual
	Artificial	Artificial / natural	Artificial / natural
Comfort level	Consistent	Variable / consistent	Variable / consistent
Low-energy response	Electro-mech	Passive / electro-mech	Passive / electro-mech
Energy consumption	Generally high energy	Low energy	Low energy
Materials source	Relatively unimportant	Relatively unimportant	Low environmental impact
Materials output	Relatively unimportant	Relatively unimportant	Reuse / recycle / reintegrate
Site ecology	Relatively unimportant	Important	Crucial

Figure 1. Yeang's design modes (Yeang, 1996).

importance both because it is the least energy-intensive and most overlooked method applied to skyscraper design.

Finally, the terms passive and active are used to describe the two main approaches to sustainable design. Passive design is often referred to as the "natural" approach whereas active design is more mechanical and technological, as is illustrated by photovoltaic panels and wind turbines. Bioclimatic design is inherently a passive approach. It focuses on the built-form's configuration and orientation. It uses façade design, solar-control devices, envelope color, vertical landscaping, wind and natural ventilation as its tools (Yeang, 1999).

Need for Sustainable Residential Towers

As the continuing influx of people from rural areas has paved the way towards the creation of megacities worldwide, many emerging and traditional cities have adopted "tall building policies" that highlight possible skyscraper locations and functions in order to meet the commercial and housing demand. The exponential growth of skyscrapers, especially those for residential purposes, in Asian cities, is visual proof of the future endurance of the building type. Western cities, once with a somewhat hesitant attitude towards residential high-rises, are now reevaluating the positive role of urban living on the city. When combined with the technologies that allow for working from home and a decrease in typical household size, these urban residences are essential in the regeneration and growth of Western cities.

The western hemisphere is the focus here because of its infamous reputation as a polluter and energy-consumer. When compared to Africa, which is exceeding the carrying capacity of natural systems by a factor of one or one and a half, the West is scandalously disproportionate with its levels of consumption with a factor of six (Edwards, 2000). The United States, in

particular, is notorious for its sustainability record, as it produces more than twenty-five percent of the world's greenhouse trace gases and twenty-three percent of global carbon dioxide emissions (Scott, 1998). Europe as well, like the rest of the developed world, produces high levels of emissions. These alarming facts call for a rapid change of design priorities on the two continents, and hence this paper will focus on them.

As to the choice of the cool temperate climate specifically, what is of interest here is that it traverses the locations where the majority of skyscrapers are to be found, including New York, Chicago, Toronto, Frankfurt, and London. Just as crucially, it is in this climate that sustainable strategies are some of the least developed and applied. Moreover, it is the climate, not continent or country, that determines the effectiveness of a sustainable strategy, for, as Ken Yeang states:

As the location's most endemic factor, climate provides the designer with a legitimate starting point for architectural expression in the endeavour to design in relation to place, because climate is one of the dominant determinants of the local inhabitant's lifestyle and the landscape ecology"

(Yeang, 1996).

Examples of Sustainable Residential High-Rise

Although no entirely environmentally sustainable towers have been completed to date, there are a number of skyscrapers that have taken steps to bring high-rise design closer to this ideal. This section will investigate a number of such completed and proposed residential buildings in three of the cool temperate climate's most active cities.

In Chicago, two residential high-rise proposals stand out. 340 on the Park (see *Figure 2*), by Solomon, Cordwell, Buenz and Associates, is a sixty-four story tower designed to be the first residential high-rise in the city to meet the U.S. Green Building Council's LEED certification standards. Its most distinct passive design



Figure 2. 340 on the Park
(340 on the Park, 2007)

feature includes a two-and-a-half story winter garden at the twenty-fifth floor (Emporis, 2005), which is complemented by fully insulated windows and ventilation systems and energy-efficient heating and cooling systems. Rainwater will be collected for landscaping purposes and the materials used are understood to be eco-friendly (340 on the Park, 2007).

The second Chicago proposal, this time consisting

of a number of towers, also considers the provision of green space. The Kennedy Expressway is a barrier between the west and east sides of the city and is characterized by congestion and a lack of green space. The firm Perkins and Will was commissioned by the city to come up with a solution to the forgotten area, resulting in the "Green Corridor" proposal (see *Figure 3*). It is designed as a prototypical "Green" community, with four blocks forming a mixed-use neighborhood, all connected at the roof and by bridges with public paths and retail spaces. The east portion of the plan is reserved for office developments, while the west is kept residential. Eight buildings are suggested, and each top is equipped with large curved structures that act as windshields or scoops. They direct the wind to "flush" the expressway cavity of carbon dioxide and bring fresh air to the park areas. New green spaces are also created within the bridges and sky gardens in the towers (Shaw, 2007). Even though this proposal currently will not be built, the project has created a twofold effect: to demonstrate the possibilities of the city's new Central Area Plan and to create a dialogue for architects to propose sustainable solutions for city design (Chicago Architecture Foundation).

New York, with a stronger tradition of residential towers, is also home to two completed sustainable residential towers, the Solaire and the Helena. Although the two are less renowned than its sustainable commercial skyscrapers, including the Conde Nast Building (4 Times Square) and the Hearst Magazine Tower, these residential buildings are nonetheless notable as they are among the first residential high-rises to consider the environment in their designs.

The Solaire (see *Figure 4*) employs both active and passive design methods. In terms of active methods, daylight is maximized through the use of high ceilings and large windows, which are generally floor-to-ceiling height. The lobby as well has large windows, facing the surrounding park area. The most distinct passive design feature of the building is its use of vegetation and stormwater. About 75 percent of the



Figure 3. Kennedy Expressway
Corridor (Shaw, 2007).



Figure 4. The Solaire
(Solaire homepage, 2007)

open roof area, and 57 percent of the site area, is vegetated by plants chosen for their visual interest, drought tolerance, wind resistance, and adaptability to shallow soil. These shrubs, perennials and bamboo utilize a water retention layer underneath them, which captures nearly 70 percent of rainwater for their use. The water that is not needed then flows down to the stormwater retention system, designed to retain 10,000 gallons, located in a tank in the basement. A sediment basin and treatment system is within this tank, and water retained there is reused for irrigation of the roof and park. The principle behind this roof structure is the reduction of the urban heat island effect (*Solaire homepage*, 2007).

In terms of active methods, it has a centralized HVAC system fuelled by natural gas, free of ozone-depleting refrigerants and chosen for its energy efficiency. A gas-fired chiller is used to reduce the electric load, especially during peak demand periods when the New York City power grid cannot meet requirements and users generally rely on supplemental power provided by highly polluting generators. Photovoltaic panels are placed on the tower's west façade and clipped to the roof. Consisting of 3,400 square feet, they exploit the intensity and position of the sun in the summer months. Overall, they are expected to generate 5 percent of the building's energy at peak loading performance and estimated to have a payback period of about four years (*Solaire homepage*, 2007).

Additionally, more than two-thirds of the building materials were manufactured within a 500-mile radius of the building and 50 percent of these materials were meant to contain raw resources from the local area. Furthermore, 19 percent of used materials contain recycled content and contain no formaldehyde and low or no VOCs. The photovoltaic cells were prepared from 100 percent recycled material and low-emission, low-VOC materials were specified for indoor objects and finishes. Less than 20 percent of residential units are provided with basement parking spaces, and the building owners have contracted with ZipCar to offer on-demand access to hybrid-technology vehicles. Provisions have been made



Figure 5. The Helena
(The Helena homepage, 2007)

for electric vehicle charging and storage has been granted for bicycles. All in all, the Solaire consumes 35 percent less energy, reduces peak demand for electricity by 65 percent and requires 50 percent less potable water than expected of its type (Zukowski, 2000).

The Helena (see Figure 5), designed by Fox and Fowle Architects completed in 2005, is the most recent addition to the city's growing number of residential towers. The

122-meter, 37-story tall tower represents itself as "environmentally 'green'" and emphasizes five approaches that make it so. The first is "reduced energy use" through solar panels, Energy Star-rated appliances, occupancy sensors, high-performance windows, etc., and stresses that 50 percent of its purchased energy is generated by wind power and that waste heat provides all the building's hot water needs. Its "reduced pollution" objective results from the reduction of material transportation distances, containment of pollutants, use of co-generation micro turbines, and promotion of alternative forms of transportation. "Reduced water use" includes rooftop vegetation and recycled water use for cooling towers and "reduced waste" is the effect of recycling of materials, specification of renewable material sources and recycling of construction debris. The final approach is "healthier living," which is achieved by the reduction of pollutants and increase of ventilation (*The Helena homepage*, 2007).

As is the case in New York, London's most famous sustainable tower, 30 St. Mary Axe (Swiss Re) is for a commercial purpose. However, the city is home to the greatest number of environmentally sustainable residential high-rises, although none of them have been completed.

The most anticipated is in fact a mixed-use tower. Known as "the shard of glass" because of its spire-like shape, the sixty-six story London Bridge Tower (see Figure 6) is to become the tallest tower in Europe in the next five years as it has already undergone approval. It is



Figure 6. London Bridge Tower
(London Bridge Tower, 2006)

also to be located nearby a major transportation point of the city, and will incorporate office (lower level) and residential space (upper stories), as well as a hotel and public space. Much like the St. Mary Axe building, it faced opposition when first proposed, but unlike it, its shape responds to the context of church spires and ships mast that defined the skyline, rather than any environmental criteria.

Next to the enormity of ten thousand people inhabiting the building and its visual presence in London, the London Bridge Tower's approach is "ecology, sustainability and environmental design (Finch, 2000). Its architect, Renzo Piano, envisions winter gardens on each floor, equipped with operable louver windows, even though their function is not necessarily for ventilation. Its ventilated double skin façade will instead reduce heat gain and increase comfort in close proximity while the excess heat from the offices is to be used to heat the spaces above (*London Bridge Tower*, 2006). Excess heat

will naturally disperse through a hundred meter tall radiator at the top and this radiator will also use the thirty-five mile-per-hour winds to cool the building when needed (*Emporis*, 2005). The tower will also consider new forms of air-conditioning, new recycling techniques and materials, and will not provide car parking in an effort to improve its green criteria. All of its features are expected to reduce energy consumption by thirty percent (*London Bridge Tower*, 2006). All in all, the tower presents a different approach towards sustainability than the other London towers: instead of determining its shape from environmental criterion, green principles are made to fit into its pre-defined form.

Another proposed London tower is Broadway Malyan's Vauxhall Tower (see *Figure 7*). The building would be the tallest residential tower in the United Kingdom, and one of the tallest in Europe, with forty-eight residential floors. In terms of sustainability, the achievements would be just as unprecedented. Its most prominent element will be an 11.4 meter wind turbine that would generate enough electricity to power the tower's common lighting (*Emporis*, 2005). When combined with the low 'e' triple glazing with ventilated blinds, it will require only thirty percent of the gas and electricity of a conventional building (Smith, 2001) and CO₂ emissions will be between one half and two thirds of the usual tower. At the base, it will draw water from the London Aquifer and use

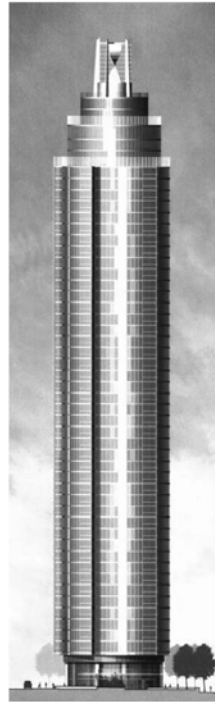


Figure 7. Vauxhall Tower
(*Emporis*, 2005)



Figure 8. Skyhouse
(*Skyhouse*, 2007)

heat pump technology to remove warmth from the water in order to heat the apartments in the winter (*Emporis*, 2005). Unlike all but St. Mary Axe, sustainability plays an important role in the building's original form, bringing it closer to the bioclimatic ideal.

A third London skyscraper, Skyhouse (see *Figure 8*), by Marks Barfield Architects, was designed as a prototype residential bioclimatic tower for no specific site. Even though the shape

does not then result from the microclimate, its form evolves from its energy-saving aim. The three oval components meet at an open center that incorporates helical wind turbines to generate power (Pearman, 2004). The glass includes photovoltaic cells to add to the power supply (Pearman, 2004) and when combined, the energy would be provided to communal areas such as the heated swimming pool (*Sustaining*, 2006). Furthermore, recycling systems, high insulation and a low heat demand add to its environmental credentials.

However, unlike most new residential towers of London, a quarter of the apartments would be reserved for key workers in the city such as nurses and teachers (Finch, 2000). The apartments and penthouses on the higher levels would be set aside for people who can afford them (Finch, 2000), but the very tops of the buildings would be turned into gardens or other open places for all to share. Alongside the rooftops, because of the compact three hundred square meter size, the tower would leave sixty five percent of a one hectare urban plot for green space (Pearman, 2004). Research was prepared into what people wanted in high-rise residences; the results stated space, light, security, concierge, health club, access to transport links, laundry, shops, modern design and excellent views. Parking was included, which goes against the trend of building at public transport intersections (*Skyhouse*, 2006). Other provisions include crèches and libraries at ground and top levels (Pearman, 2004). It is meant to appeal mostly to the younger market, but the elderly are expected to benefit from the design and its urban location.



Figure 9. SkyZED
(*SkyZED*, 2006)

Architect of the BedZED project, Bill Dunster has also turned to the large-scale mixed-use skyscraper as a model of a "Zero Energy Development" that emits no carbon dioxide and increases energy efficiency. Like Skyhouse, SkyZED (see *Figure 9*), also known as the Flower Tower, is a response to the need for affordable homes and high density (*Sustainable Towers*,

2006) and will include work and community areas such as school, nurseries, and a car-pool, all on the first six floor. Likewise, in the 'shade zone' of the tower, parks and sports facilities will be provided. Above the two hundred square meters of commercial and leisure space there will be one-, two-, and three-bed maisonettes to allow for a large variety of users. These residences will have private balconies at the edge of each panel where wind velocities are lowest and will be connected through communal, lawn-covered sky gardens at every fourth floor (*Sustaining*, 2006).

Environmentally, this tower applies most contemporary green design methods. The four-petal shape maximizes views, privacy and daylight. This shape also magnifies ambient wind speed four times, allowing for vertical axis drag type turbines designed with self-lubricating bearings, a five year maintenance cycle, and nearly no sound projection. Photovoltaic cells, mounted in the cladding and roof, are used in conjunction with the turbine to meet annual electric demand. Heat would be produced through either woodchip boilers for smaller schemes or through biomass fuelled heat and a power plant on larger sites (SkyZED, 2006).

This 'living machine' in Dunster's term will also reclaim all grey and black water for the entire block and minimize downdrafts through its permeability. It will be constructed from reclaimed, renewable, and composite materials. Its windows will be triple glazed and walls contain up to three hundred millimeters of insulation that would provide thermal protection during both summer and winter periods. This would also allow for acoustic isolation (Sustaining, 2006). Furthermore it would recycle its own waste and use an environmental sewage treatment (Bill Dunster Architects, 2006). This tower considers all factors of bioclimatic design, and is one of the few proposed thus far that can be considered wholly ecologically designed.

Two other proposals, the Bishopsgate Towers and the Elephant and Castle Eco-Towers, are also worth noting, but, because Ken Yeang designed them, will be discussed in the next section.

Ken Yeang

One cannot examine the bioclimatic skyscraper without studying the work of Dr. Ken Yeang. This Malaysian architect, trained in the UK, is considered to be the father of the bioclimatic skyscraper. His first bioclimatic high-rises were located in, or nearby, Malaysia, and his novel approach has been referred to as an expression of Malaysian independence and economic aspirations. He uses modernism without symbolic abstraction, showing an understanding of traditional values without the use of traditional forms and materials (Yeang, 1994). The application of native vegetation and the linking of building form and orientation with location replace the internationalist tendencies of the majority of skyscrapers. They instead serve as moves towards an independent architectural style specific to one people and one locality.

This adaptation of regionalism was later translated into his western skyscrapers, where he continues his pursuit towards buildings of minimal environmental impact and with optimization of passive systems of operation. His designs are strongly linked to his research, which includes the use of wind power and biodegradable materials. His numerous works demonstrate his insistence on applying urban design principles vertically through such measures as skycourts as verandas. Yet his most memorable contribution to skyscraper design is the building's close ties with the local climate. Yeang's

search for a coherent bioclimatic process began in the 1970s with a thesis that would later be published as *Designing with Nature: the Ecological Basis for Architectural Design* (Yeang, 1995). Aware of the lack of an agreement to the ecological approach, he attempts to develop "a unifying theoretical basis and frame of reference for design." In it, he provides a framework for integrating buildings with nature. A cyclical pattern of material use is promoted, one that encourages designers to minimize the adverse ecological effects of their concepts. To obtain the framework, he grouped the fundamental interactions of the natural and built environments. The four resulting sets are:

1. external interdependencies of the design system (system's relations to external environment)
2. internal interdependencies of the design system (system's internal relations)
3. external/internal exchanges of energy and materials (system inputs)
4. internal/external exchanges of energy and materials (system outputs)

There are two ways to obtain these sets, either through the "General Systems Theory" (see Figure 10), which is more diagrammatic, or through a "Partitioned Matrix" (see Figures 11 and 12). He emphasizes that all four sets must be taken into account if the design is to be ecologically holistic. This framework, relevant to the building's entire lifetime, provides linkages between ecological elements. It can be used by various professionals in the design state as well as during research, a fact that further highlights its unifying and comprehensive function.

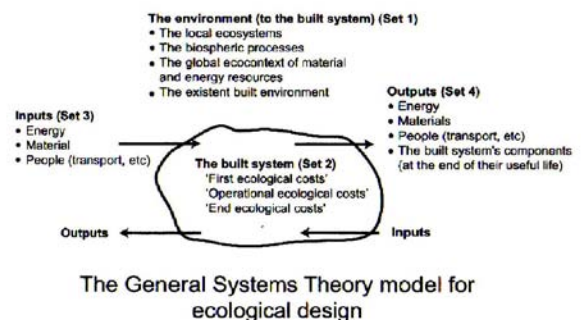


Figure 10. General Systems Theory (Yeang, 1995)

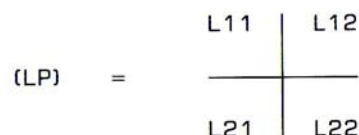


Figure 11. Partitioned Matrix (Yeang, 1995)

Yeang then applied the framework to projects in TR Hamzah & Yeang Sdn. Bhd., a practice set up with a fellow student from the Architectural Association School of Architecture, Tengku Robert. Leo van Schaik describes

four periods of his work, which resulted in a range and number of skyscrapers, but it is the last period that is of most concern to this paper it is the period most related to his London proposals (Castle, 2000).

Interactions	Symbol	Description
The external inter-dependencies of the designed system (its external relations)	L22	This refers to the totality of the ecological processes of the surrounding ecosystems, which intersect with others which interact with other ecosystems elsewhere within the biosphere, and the totality of the earth's resources. It also includes the slow biospheric processes involved in the formation of fossil fuels and other non-renewable resources. These may influence the built environment's functioning and are in turn also influenced by the built environment. It is these elements that are either altered, depleted or added to by the built environment.
The internal inter-dependencies of the designed system (its internal relations)	L11	This refers to the sum of the activities and actions that take place in or are related to and associated with the built environment and its users. They include the operational functions of the built environment. These will directly affect the ecosystems of the location in which they take place spatially and the ecosystem elsewhere (systemically), as well as the earth's totality of resources. These can be considered in the pattern of a life cycle of the built environment.
The external/ internal exchanges of energy and matter (the system's inputs)	L21	This refers to the total inputs into the built environment. These consist of both the stock and the flow components of the built environment (or the energy and matter needed for the physical substance and form of the built environment and its attendant processes). The efforts taken to obtain these inputs from the earth's resources often result in considerable consequences to the ecosystems.
The internal/ external exchanges of energy and matter (the system's outputs)	L12	This refers to the total outputs of energy and matter that are discharged from the built environment into the ecosystems and into the earth. These outputs may include the built environment's own physical substance and form, which also may need to be disposed of at the end of its useful life. These outputs, if they are not assimilated by the ecosystems, result in environmental impairment.

Figure 12. Description of Environmental Interactions (Yeang, 1995)

There are four aspects of this last period worth noting. The first is his attempts to combine his “research, design and development” approach into a format accessible to other designers. This is best demonstrated by the 1997 publication *The Skyscraper Bioclimatically Considered: a Design Primer* and the 1998 publication of *The Green Skyscraper: a Primer for Designing Ecologically Sustainable Large Buildings*. The second aspect is the shift from a purely “bioclimatic approach” to a “green” or “ecological” approach that includes provisions for material and equipment. Here he also begins a more in-depth application of “active approach” elements, such as wind turbines. Third, he begins to think on a larger scale, particularly about masterplans and landscapes. This is echoed in his skyscrapers, which are no longer merely buildings, but “cities in the sky.” He emphasizes the importance of mixed-uses, public spaces

and pedestrian linkages. Finally, he had by this time changed from using the term “tropical skyscraper” to “bioclimatic skyscraper.” This shift was the result of his discomfort with the boundaries of the regionalist position as well as his realization that the ecological approach had universal applications (Powell, 1999). This would lead to the globalization of his work, which is demonstrated by his most recent designs for buildings in the temperate climate. He again faces some of the same difficulties as he had in the beginning, particularly that of a local aesthetic and the translation of his tropical design principles for application in the temperate climate. He is currently based in London, as a partner in Llewelyn Davies Yeang, Ltd., and the two London proposals illustrate the advancement and emphasis of his ecological approach.

The first project proposed by Yeang in London, Bishopsgate Towers (see *Figure 13*), consists of two residential 65-story skyscrapers and a 50-story office and hotel with a convention center. The residential towers are made up of apartments forming a ‘fan’ shape on the northern and southern sides, while an internal atrium, surrounded by a continuous landscaped ramp, spirals through the building. The various residences are meant for both social/subsidized (35%) and market-rate (65%) accommodation, and each apartment is provided with a planted front and back garden. A vertical and horizontal zoning diagram acts as a vertical land use pattern, determining the location of mixed-use facilities, including communal gardens (Richards, 2001; 223).

Yeang’s ecological method is fully employed here, most notably his passive low energy responses. The sunpath of the site and the conditions of the summer and winter windrose determine the overall form of the building. Solar gain is maximized in winter and mid-seasons and solar shading is taken advantage of in summer months. Lift cores are placed on the northeast and west facades to provide a buffer of solar protection in the summer. During the winter months, the low-angle sun penetrates the atrium and southeast-orientated residences receive maximum solar gain. The façade utilizes a multi-layered external wall to control the individual gardens and apartments. A mesh-screen windbreaker element reduces the inflow of strong winds and

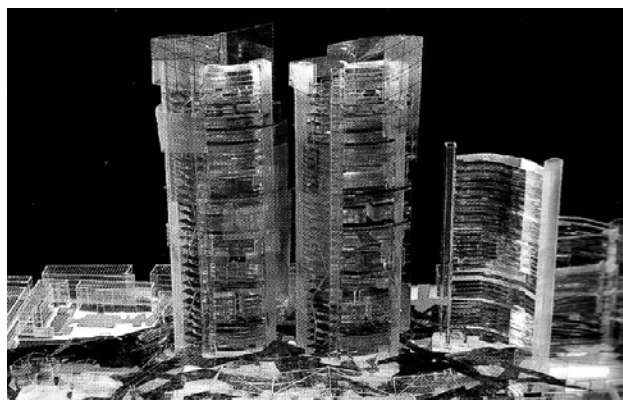


Figure 13. Bishopsgate Towers (Richards, 2001)

adjustable insulate shutter doors preserve the heat at night. Internal shutters and large double-glazed windows support the design, as does the landscaping and planting, which act as a wind buffer and summer-time protection against solar radiation. The ventilation strategy utilizes these elements to encourage natural ventilation in the summer and mid-season months and to minimize energy losses during the winter by changing to a mechanically assisted ventilation system. South-facing photovoltaic panels act also as a rain-screen. Rainwater catchment scallops and a “roof-catchment pan” are introduced and small wind turbines are considered (Richards, 2001).

All in all, the Bishopsgate Towers are unique in that orientation, not views or form, are the starting points, and, when combined with the comprehensive list of green features and mix of uses, present the most socially and ecologically sustainable proposal for London thus far.

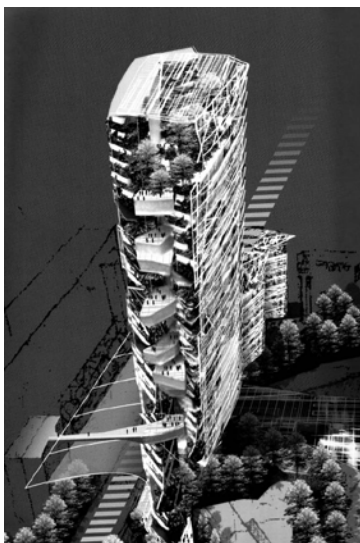


Figure 14. Elephant and Castle

Eco-Towers Yeang's second London proposal consists of three towers, one thirty stories tall and the others twelve, that contribute to a 180 acre regeneration project for Elephant and Castle (see Figure 14). In most ways, they do resemble the Bishopsgate Towers configuration, orientation, façade design and landscaping. Here as well the lifts and stairs are more compact, 'sky pods' have been added, and a major inward garden has been incorporated. The main difference is the lack of a spiralling ramp, which is replaced by regular floor intervals (Richards, 2001). These towers attempted to create a zero CO₂ emissions energy supply and use materials that have low embodied energy and come from sustainable resources" (Towers in Europe, 2007). The aim

of both projects is to resolve three major issues: Social Sustainability, Environmental Sustainability, and a Passive Low Energy Response (Richards, 2001).

Framework

The framework proposed for the design of environmentally sustainable residential towers originated from two concerns. First, there is a lack of application of primary, or bioclimatic, strategies in the early stages of design. While most towers in the cities discussed have a passive design feature, basic methods of energy reduction, such as a narrow floor plate and solar orientation, are often ignored. This is often due to commercial pressure to utilize all available land, but sometimes due to a lack of availability of basic design recommendations. Second, where basic information is available, there is nonetheless a lack of organization and hierarchy of the data. Although Yeang presents much data in his texts and proposes a matrix of interactions, he does not prioritize or recommend any specific plan of action. Furthermore, the matrix is not designed for the specific problems of the cool temperate climate and residential skyscrapers situated there.

The new framework proposed here (see Figure 15) relates to Yeang's external/internal exchanges, mainly the energy and matter required to create the tower, as it is the interaction where architects have the most influence. It consists of a table split into rows and columns and that incorporates all aspects of environmentally sustainable design, with a preference of application.

The rows represent the energy and materials flowing through the building and are split into inexhaustible and exhaustible resources, together referred to as environmental inputs. The inexhaustible resources include visible radiation, solar radiation and airflow. The designer is provided with a choice of either increasing or decreasing their effect according to the season. The exhaustible resources, consisting of water, materials and land are meant at best to be conserved or at worst to be recycled. The preferred order of application here is from top to bottom, with a clear distinction between inexhaustible and exhaustible.

The columns are the design elements of a building. They consist of orientation, configuration, fabric, system

			Orientation	Configuration	Fabric	System	Renewables
Inexhaustible Resources	Visible Radiation	Increase					
		Decrease					
	Thermal Radiation	Increase					
		Decrease					
	Airflow	Increase					
		Decrease					
Exhaustible Resources	Water						
	Materials						
	Land						

Figure 15. Proposed framework for environmentally sustainable residential towers in the cool temperate climate.

and renewables. The preference of application here is from left to right, as orienting a tower design is much less energy intensive than applying an optimal building system. The application of the columns on their own leads to a design that lacks any coherent organization, and therefore they function together with the rows. Therefore, to achieve the greatest effect, the designer should consider the top left corner interaction, the orientation and visible radiation, apply as many principles as possible, before examining the next row down. In this way the bioclimatic approach is examined before any active mode approaches can be made. However, not every interaction will need to be considered, as certain environmental inputs are not affected by the building's design elements. For example, building orientation does not influence an input like visible radiation and so the interaction is omitted and shown black in the diagram. This omission also occurs when an input, such as the decrease of airflow, is counterproductive in a stage of design, here orientation, and better approached elsewhere, such as configuration. Orientation therefore applies the main considerations of the climate's design; the following rows then handle secondary and subsequent considerations. This makes this version of the framework

specific to the cool temperate climate, as a different set of interactions would be prioritized in other climates.

Renewable energy sources are unique in that they are not related to increasing or decreasing the environmental inputs, only transforming their power into energy; hence the input subcategories "increase" and "decrease" do not apply here. Relating to this category, because of its common dependence on early stage design, if the designer wanted to highlight, for example, a wind turbine, the renewable source could be considered first, but thereafter the priority would go back to the bioclimatic approach.

The interactions between the rows and columns are connected to a separate set of design principles, which consist of a series of simple, individual steps related to the combination. For example, one of the principles for the interaction between visible radiation and fabric includes the louvers, which are explained in a series with individual options for size, angle, etc. These principles are presented as annotated visual images to allow for ease of use and are linked with each other, both in the same interaction and with others. Due to their presentation as individual images, rather than as one large principle, the framework is designed to be adaptable and expandable,

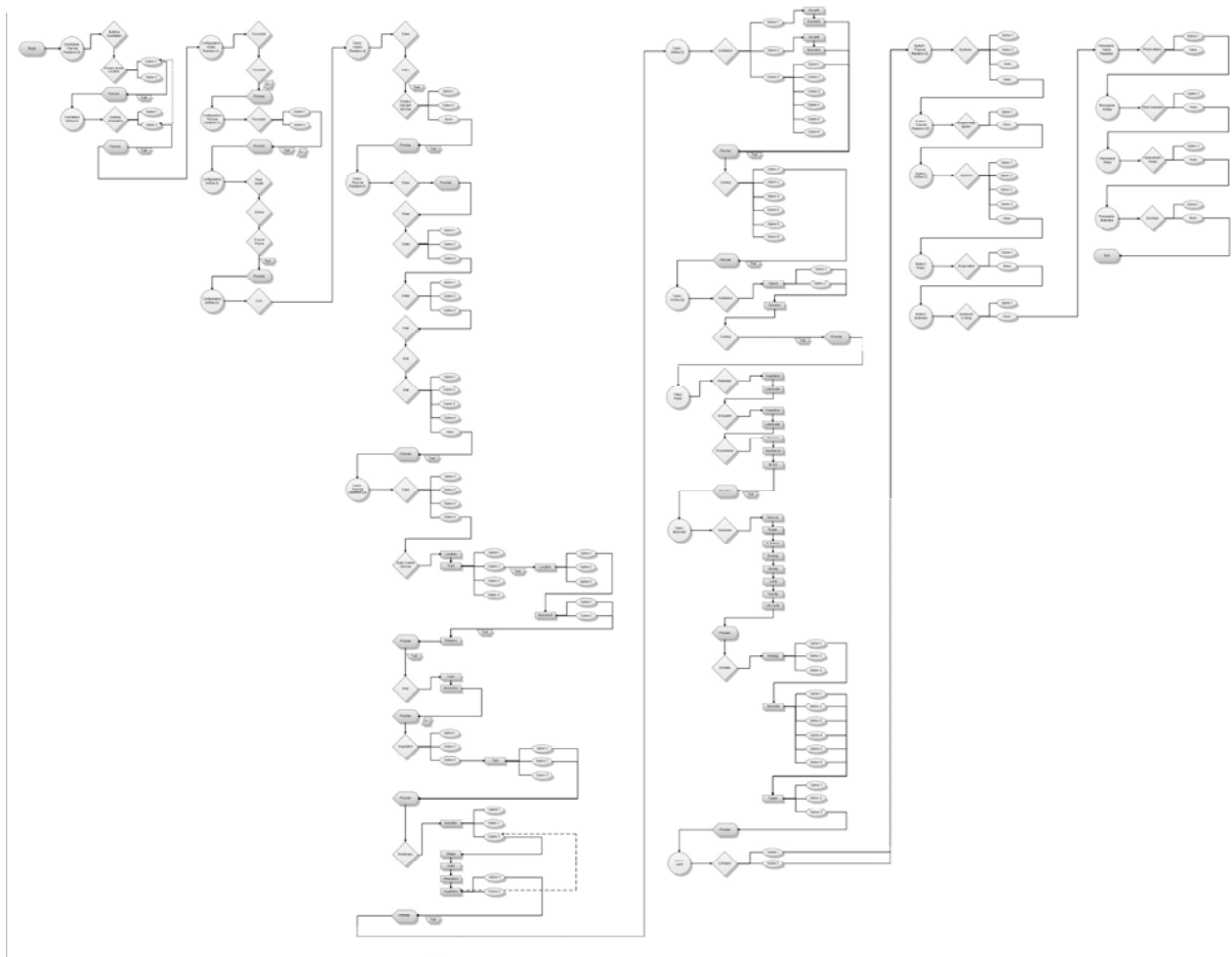


Figure 15. Proposed framework for environmentally sustainable residential towers in the cool temperate climate.

so that that any future additions or corrections can be included with ease and without changing the framework structure. Furthermore, the principles' simplicity aids in their memorization, so that the framework with each application becomes easier to use.

Birmingham Case Study

To develop and test the effectiveness of the framework, a prototype tower was designed for a site in Birmingham, United Kingdom. The 150 meter tower had an allowable footprint of 25m X 25m, and an aim of 90% residential use. Other than this, the program was unspecified, as the focus was to create a tower guided by the framework. A very generic, orthogonal building was proposed in order to illustrate the visual differences of a typical tower as opposed to a tower using the same design style but one that applies sustainable principles as well.

The process of designing this tower was recorded in a flowchart (see *Figure 16*). The columns correlate to the framework's columns, but here, in order to conserve space, fabric has been split into two columns, situated in the middle. The flowchart also has visual symbols: circles represent interactions; diamonds, principles; ovals, options/steps; rectangles, considerations/subcategories. Furthermore, it indicates where the design could be tested using external tools (trapezoid), such as environmental software, as well as where a visual preview is preferred at point where choices may have a large aesthetic effect (rounded tag). Although the figure shown here has illegible text, these symbols help to show the route of this building's creation as well as an array of options available, in this example only from principles extracted from Ken Yeang's work. A visual representation of the building's morphosis, using SketchUp software, is included (see *Figure 17*) to demonstrate the graduate changes that lead to the final design. The final tower, although not designed to have a varying aesthetic, nevertheless demonstrates that environmental design necessarily leads to a building with an altered visual impact. Therefore, the sustainable approach, contrary to common misconceptions, does not lead to the standardization and monotony of architecture, but in fact allows for a great variety of design options while providing a building with local character and environmental sensitivity.

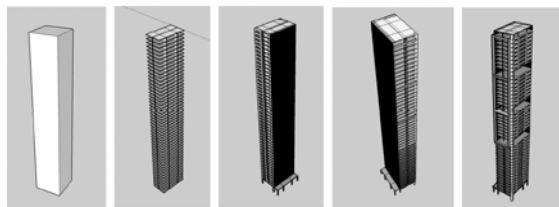


Figure 17. Development of Birmingham tower on various facades.

Conclusion

This paper examined the emergence and role of environmentally sustainable residential towers in the cool temperate climates of Europe and North America. It reviewed current examples of completed and proposed green towers in that region and assessed the work of Ken Yeang in order to evaluate the state of contemporary sustainable approaches. It then proposed a framework that would allow for improved organization, adaptability and expansion and tested it on a site in Birmingham. Considering the urgent need for sustainability in the built environment and the rapid growth of residential towers, it is hoped that the framework will allow for greater access to environmental design.

References

- 340 on the Park. Home page.* (January 2007). <http://www.340ontheparkchicago.com>.
- Bill Dunster Architects. (October 2006). *ZEDfactory. Towers in Europe.* Sustainable Towers.
- BOOTH, R. (2000). *Piano tower hits the right note with Livingstone.* The Architect's Journal. vol. 212. No. 18. (16 November 2000). p. 18.
- CASTLE, H. *Reconciling the Irreconcilable? The Architecture of Ken Yeang.* Architectural Design.
- Chicago Architecture Foundation. *Kennedy Expressway Green Corridor.* Archidose. <http://www.archidose.org/Jun03/061603.html>.
- Emporis.* (May 2005). <http://www.emporis.com>.
- SCOTT, A. ed (1998). *Dimensions of Sustainability: architecture, form, technology, environment, culture.* E&FN Spon. London.
- EDWARDS, B. and DU PLESSIS, C. (12 August 2000) *Green Architecture.* Architectural Design in 'Today,' BBC Radio 4. London.
- FINCH, P. (2000). *Renzo Piano goes sky high with Europe's tallest building.* The Architect's Journal. vol. 212. No. 3 (20 July 2000). p. 11.
- London Bridge Tower.* (October 2006). *Renzo Piano Building Workshop.* <http://www.rpbw.com>.
- PEARMAN, H. (2004) *The only way is up.* The Sunday Times Magazine. (2 May 2004). pp. 38-47.
- POWELL, R. (1999). *Rethinking the Skyscraper: the complete architecture of Ken Yeang.* Thames & Hudson. London.
- RICHARDS, I. (2001). *T.R. Hamzah & Yeang: ecology of the sky.* Victoria: Images. Mulgrave.
- SHAW, C. (January 2007). *Building the Greenest City in America.* *Newtopia Magazine.* <http://www.newtopiamagazine.net>.
- Skyhouse.* (October 2006). *Marks Barfield Architects.* <http://www.marksbarfield.com>.
- SkyZED: The Flower Tower.* (October 2006). Bill Dunster Architects.
- SMITH, J. (2001) *News: 49-storey 'ecotower' proposed for London.* (21 December 2001). *Emporis.* May 2005.
- Survey of Meteorology.* (January 2005). Lyndon State College. <http://apollo.lsc.vsc.edu/classes/met130/notes>.
- Sustaining: Tower Blocks.* (October 2006). <http://www.sustainingtowers.org/SOA-present.htm>.
- The Helena homepage.* (January 2007). <http://www.thehelena.com>.
- The Solaire homepage.* (January 2007). www.thesolaire.com.
- Towers in Europe.* (October 2006). Sustainable Towers. <http://www.battlemccarthy.com>.
- YEANG, K. (1994). *Bioclimatic Skyscrapers.* Artemis London. London.
- YEANG, K. (1995). *Designing with Nature: the ecological basis for architectural design.* McGraw-Hill. New York.
- YEANG, K. (1999). *The Green skyscraper.* Prestel Verlag. Munich.
- YEANG, K. (1996). *The Skyscraper Bioclimatically Considered: a design primer.* Academy Editions. London.
- ZUKOWSKI, J. and THORNE, M., ed. (2000). *Skyscrapers: The New Millennium.* Prestel. London.