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Biography

After completing the master course at Graduate School of Engineering, Kyoto University, Mr. Nakai joined Takenaka Corporation in 1984. Through his career to date, he has consistently been in charge of advanced structures such as large space structures, base isolation and vibration control. His extensive works have resulted in a number of landmark buildings including Fukuoka Dome, Odate Jukai Dome and Sapporo Dome. In 2004, he received JSCA Award, Gengo Matsui Prize and JSSI Award for the structural design of an iconic base-isolated building, PRADA Boutique Aoyama. He now leads a division called Advanced Structural Engineering and is responsible for structural scheme design, expert support for design/construction teams and R&D activities relevant to special structures including super-tall buildings. He also conducted researches on vibration control as a visiting researcher at State University of New York at Buffalo in 1988 and 1989.

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Abstract
There have recently emerged a number of urban problems in large cities developed in the past, in the form of soaring land prices, traffic congestion, low nighttime population, air and water pollution, overexploitation of natural resources, and many others. This now calls for a new concept on urban planning, or a vision on a future city.

Takenaka Corporation, Japan, has held an internal competition on urban concepts based on 1,600-meter high "vertical cities" suitable for the future cities and environments. In this paper, the outline of the competition and the ideas of the selected proposals are introduced.

Keywords: vertical city, Ultimate Sky Tower, urban problems, sustainability, water supply

1. Introduction

A number of urban and environmental problems have recently emerged in the past development of large cities, including traffic congestion and soaring land prices due to centralization, low nighttime populations and "hollow" urban centers, and air and water pollution, noise, and waste disposal issues.

Proposals contributing to new and sustainable cities (e.g. Fishman, 1982, Izawa, 1990 and Nishi, 1991) were made in the 1980s and 1990s, when these issues became serious in some cities. Takenaka Corporation, Japan, also proposed the concept of "vertical cities" including "Sky City 1000" (Group V1000, 1989). While most of the concepts are still valid, there has recently been a mood and need in the firm to consider again what a vertical city should be like. Takenaka Corporation, therefore, has held a competition within the firm to gather ideas for urban concepts based on 1,600-meter high "vertical cities" suitable for the future cities and environments. The competition has sited Middle East, where particular consideration on the importance of water is needed. The purpose was to promote the advancement of urban functions through vertical cities of ultra-high rise buildings and to indicate new directions for highly advantageous and environmentally friendly urban development, such as the following:

1) Compact vertical cities and preservation of traditional architecture and historical relics.
2) Barriers against disorderly sprawl.
3) Wide-area disaster safety bases.
4) Ecological cities in symbiosis with the natural environment.
5) Achieving cleaner air and preventing the heat island effect by preserving greenery and reducing automotive traffic.
6) Comfortable, environmentally controlled half-indoor public spaces.

In this paper, the outline of the competition and the ideas of these conceptual proposals are introduced, focusing particularly on three selected proposals.

2. Outline of the Internal Competition

The internal competition was titled "Ultimate Sky Tower" and ideas were called for that may solve diversified problems inherent in current urbanism by way of a vertical city with the height of 1,600 meters. The site for consideration was set in the Middle East where an additional issue of water supply should be taken into account. Technological feasibilities of the proposals were somewhat sunk to allow the applicants free and creative ideas, while they were asked to give some considerations.

The competition was announced in June 2007 and closed about a month later. A total of 146 in-house architects and engineers in 25 teams participated in the competition and submitted their proposals. An internal committee reviewed all the proposals in details and selected three proposals as excellent and gave honorable mentions to six others, which are introduced in the following sections.

3. Proposal A: Liquid Crystal Tower

Concept

The considered site is in a severe desert climate with the annual mean maximum temperature of over 30 degrees Celsius and the annual precipitation of no more than 100mm. People there have lived with limited amount of natural pure water.

The Liquid Crystal Tower is an ultimate oasis on an inshore island, a mile-high tower city utilizing the power of nature to the maximum as well as protecting people from its severity. It offers a total of 9 million square meters' living space to a working population of 188,200. The sea waters the tower and the tower returns the water to the sea. People from the coast and from the open sea are interlaced in the tower creating a city that no one has ever seen. The people in the desert might have escaped from the scorching ground and lived in the sky by the time people in other parts of the world face desert climate due to the global warming.

City Planning / Architecture

The tower is shaped like a horn allowing larger floor areas in the upper prestigious layers. (See Figure 1) Urban functions such as offices, retails, residences, educational facilities and administration are allocated along the height of the tower. Located at every 100m height is "The Sky Oasis", a mega slab creating a huge atrium with plenty of water and trees. Light wells with half mirrors draw sunlight into the tower as well as function as vertical shafts for lifts and air ventilation. Cylinder modules of diversified scales and functions soar from the mega slabs, and they are open to the atrium so as to gain indirect natural light and air. The center core supports the Sky Oases as well as serves as a chimney for the steam boiled by natural energies for use in the tower. A vast surface of solar panels envelops the foot of the tower and the surrounding area to provide energies as well as to accommodate a port.

Ocean highways are connected from the nearby coast to the tower and are merged into three-dimensional main lines continuing up to 200 meters in height, while lifts along the light wells provide the main vertical transport, bringing people and materials from the ground and the port to their destinations.

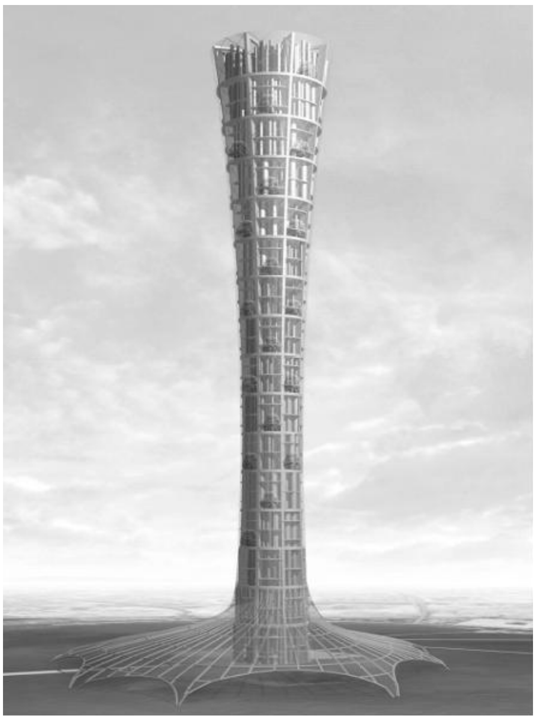

Figure 1. Liquid Crystal Tower (Nishimura et al.)

Energy

A circulation system of seawater using natural energies is intended for an effective supply of water and electricity throughout the tower thus creating a comfortable environment.

Figure 2 illustrates the proposed circulation system. *1) Energy collection*: Solar panels and a geothermal system are used to collect electric powers at the foot of the tower. One and half million square meters of solar panels would be required to supply half of the energy for the next process, 2 x 10^6 kW. *2) Steam generation*: The collected power is used to boil seawater and provide necessary potential for the steam to rise up by a chimney effect in the center core to the 1,600 meters' height. *3) Intermediate power generation*: Steam turbine generates 50,000 kW to provide 5% of the energy to be consumed in the tower. *4) Generation of distilled water*: The steam is naturally cooled down and condensed to distilled water at the top of the tower. *5) Water usage and return to the sea*: The distilled water is stored and supplied to each part of the tower along the light wells by the potential energy and finally returned to the sea.

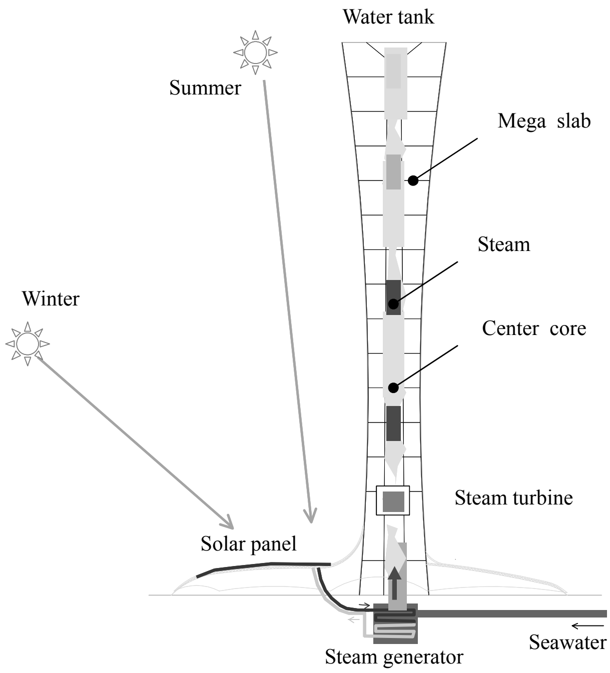

Figure 2. Water circulation system

Structure

The mega structures are composite sections with steel profiles as re-bars and concrete of up to 300 N/mm^2 in cylinder strength. (NB: Takenaka Corporation's current maximum is 150 N/mm^2 in actual use and over 200 N/mm^2 in laboratory testing.) Radially located mega columns, 20 meters by 5 to 9 meters, and the center core support the mega slabs at every 100 meters in height. The circular mega slabs, void slabs with a total depth of 7 meters, provide artificial grounds to the cylinder modules. Mega beams are also embedded circumferentially in the mega slabs. TLD (Tuned Liquid Damper) systems are planned using the distilled water to reduce vibrations due to wind for human comfort. The TLDs, accommodating a total of 3 million cubic meters of water, reside on the upper mega slabs (the Sky Oases) and also allow the occupancies' close contact with water.

The solar panels around the foot of tower are supported by mega space truss with the maximum depth of 20 meters. The surface is deliberately inclined and shifted to one side so as to gain as much solar energy.

4. Proposal B: Spiral Sky City

Since ancient times, man has sought to construct cities on green belt along mighty rivers. In the Middle East, an abundance of parched land has made people aware of the preciousness even more and cultivated diversified means of living with the nature.

On this occasion, a high-rise city abundant in water and greenery is proposed, extending skywards for 1,600m around the integration of a 30km spirally coiled river and foliage promenade. This is named "Spiral Sky City". (See Figure 3)

A city is created through insertion of both artificial base sections (skeleton) housing commercial facilities and functional units (infill) into the spiral. (See Figure 4) Unit alteration and addition can occur as is required. Both their density and the direction from which they are viewed will greatly affect the image of the city. To preserve a rank as the world's tallest building, the height of the spiral and artificial base sections can be extended to compete with other high-rise projects.

Figure 3. Spiral Sky City (Ueda et al.)

Artificial base sections are laid every 100m and supported by additional units as necessary. High-speed vertical elevator transportation and spiral sky tram transportation run throughout the city. Energy gain via solar and wind power generation units as well as effective water usage through subterranean desalinization and recycling units, orients the spiral toward an entirely self-sufficient city. Creation of a Spiral Sky City would effectively promote the expansion of surrounding greenery. Through manifold Spiral Sky City installation, parched earth could be converted into fertile land.

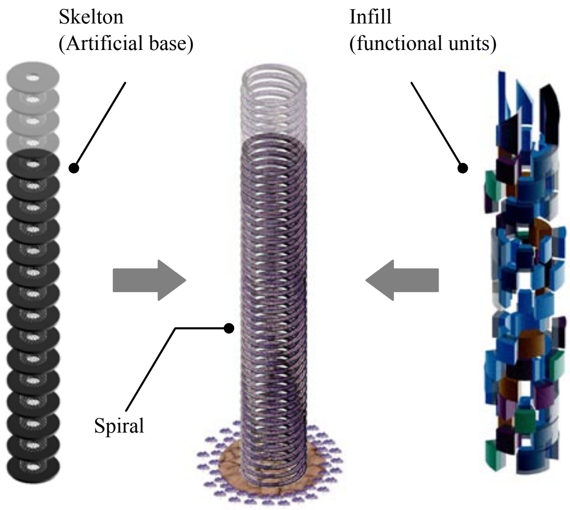

Figure 4. Skelton and infill

5. Proposal C: Tower of Life

With worldwide explosion of population and improvement in the standards of life, securing water resources has become more and more crucial for many cities. This is especially true to the Middle East, where water purification plants play even more important role to the people's living due to the desert environment.

Proposed here is a permanent source of clean water, "Tower of Life", a water tank for a city. It is not any ordinary water tank, but a 1,600 meters tall "city within a city", where people live and work. The tower will constantly supply pure water not only for the inhabitants within, but also for the nearby areas. In order for this tower to continue operating far into the future, it is intended to consume minimum amount of energy, and to produce energy by itself. Gravity, wind power, solar power, and evaporating energy are all utilized by means of a high-efficiency energy conversion technology, for maximum self-efficiency.

The features of the tower include: (See Figures 5 and 6)

1) A huge water tank always with its full capacity at the top. The water is carried from underground in a vapor state and condensed here.
2) A mega-structure system consisting of metal-tube mesh. A double-layered exterior skin with built-in solar cells for power generation.
3) Interior spaces naturally ventilated through the

"punctures" opened through the outer skin.

4) Shuttle elevators with 5 stories and capacity of 180 people.
5) An open-air "garden-in-the-sky" with a "station" for shuttle elevators at every 100 meters in height
6) An underground vapor plant where seawater is taken in, evaporated and desalinated so that pure water is carried to the top of the tower in a vapor state.

From ancient times, and in many cultures and ethnicities, towers have possessed a special meaning to human civilization. This "Tower of Life" adds another meaning and role to what people would expect from a tower.

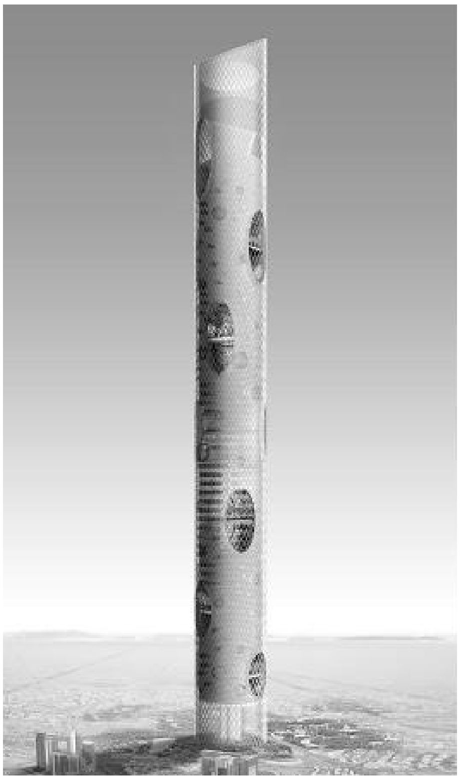

Figure 5. Tower of Life (Yoshimoto et

Figure 6. "Puncture" in outer skin

6. Other Proposals

In this section, the proposals with the honorable mentions are shown. Although not selected as the excellent ones, they also showed creative insights into the future of the vertical cities.

Paradise @ Mile High (Figure 7)

The aim of this design is to secure a large floor area in the high-rise section of the tower with a high real-estate value by shaping the high-rise section into a horn, departing from the traditional towers with pointed top. The horn-shaped top of the tower is not only highly rational in terms of structural mechanics but is also expected to have an effect of bringing the wind environment in the habitable area inside the horn to the same level as on the ground. In addition, a cooling system that utilizes a day/night temperature variation is made possible by using the large surface area of outer side of the horn.

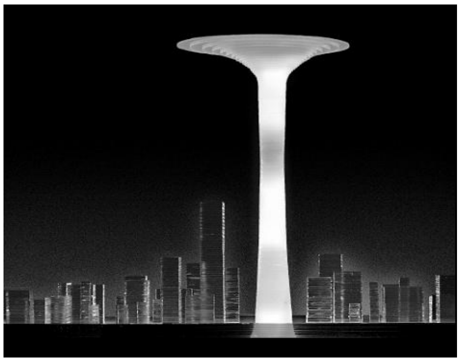

Figure 7. Paradise @ Mile High (Suga et

Air Tube City (Figure 8)

Huge triangular trusses stacked in layers on top of each other to form a spiral comprise this tower that rises high into the sky. Wind is used for power generation – the rising air from natural ventilation and stack air effect by taking outside air (fresh air) into the void in each layer. A pool laid out every 50 floors is used not only for daily life water but also functions as a passive vibration control unit.

Figure 8. Air Tube City (Bouda et al.)

Standing Creek (Figure 9)

Three triangular poles are erected in a spiral design and laterally connected one another to form a stable structure. The residential spaces in the three triangular poles are open inward to protect against direct sunlight and wind pressure. The seawater pumped up from the foot of the poles flows in the outer skin of the poles and the residential spaces in the poles to adjust the air temperature in the residential spaces.

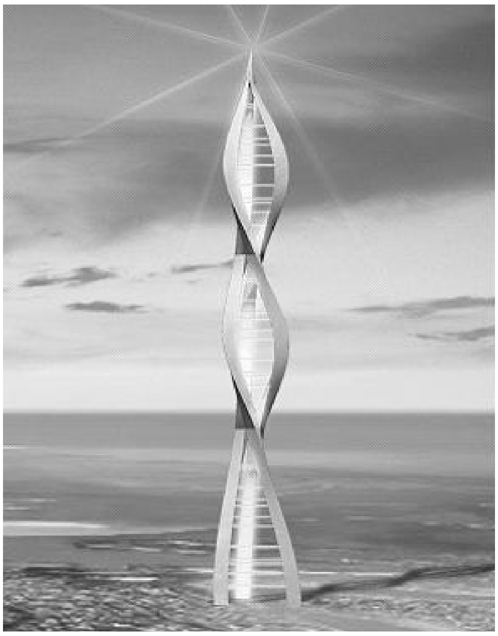

Figure 9. Standing Creek (Inoue)

Sky-Enveloper (Figure 10)

This design branches one arch into two towers that comprises the arch to form a stable structural body and envelop a town at the foot of the arch. The arch evokes the symbolism of a gate that receives the visitors from the sea and creates a new value instead of height.

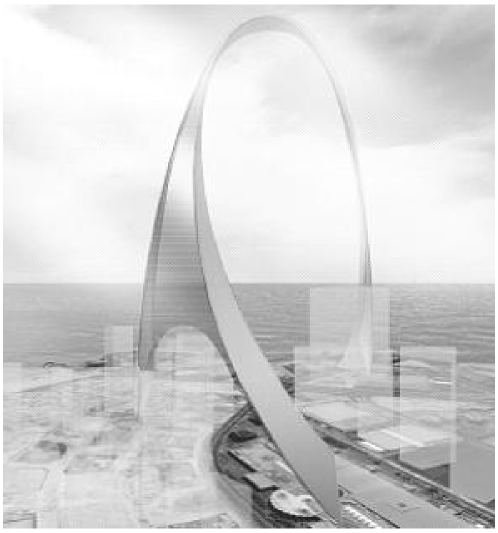

Figure 10. Sky-Enveloper (Ohno et al.)

One Mile Camel Hump (Figure 11)

This design is a photosynthetic oasis dome. The panel units comprising the dome are provided with many functions, including solar power generation, power generation by the difference between inside temperature and outside the dome, wind power generation, heat ray and ultraviolet protection, and absorption of carbon dioxide and generation of oxygen by growing algae. The units work in response to climates (changes in the world outside the dome) to ensure the comfortable environment inside the dome and produce energy with efficiency.

Figure 11. One Mile Camel Hump (Takamuku et al.)

Yggdrasill Tower (Figure 12)

Yggdrasill is formed by consolidating core functions of a city into convoluting tubes, i.e. roots of the mythical tree. This design incorporates various ingenious plans, including the wind power generation that utilizes the rising air created in the tubes, the water purification and heat exchange by the use of core strata, and the cloud seeding for rain by spraying seawater into the sky.

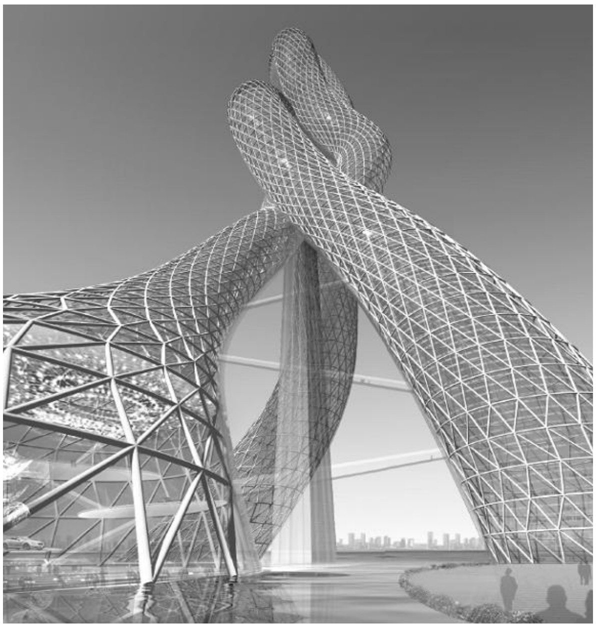

Figure 12. Yggdrasill Tower (Hori et al.)

7. Conclusion

Proposals on urban development concepts for new vertical cities, obtained through a private and internal competition, have been introduced. Many proposals have shown deep insights into the current problems of the past development and importance of water, and architectural excellence. While the authors are fully aware, and the readers should be aware, that these proposals are still at the conceptual stage and will surely need detailed studies and new research and development, the authors are anticipating the advent of vertical cities in the near future.

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