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Next Tokyo 2045: A Mile-High Tower Rooted in Intersecting Ecologies


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David Malott specializes in the design and planning of supertall buildings and large-scale mixed-use developments. With over 17 years of experience as an architectural designer and project director, he has contributed to KPF's strong presence in China, Japan, and Hong Kong.

Leslie E. Robertson has been at the forefront of structural engineering design for nearly 60 years, responsible for the structural design of some of the world's tallest buildings. In addition to the Shanghai World Financial Center, he is responsible for the structural design of the original World Trade Center, New York and the Bank of China Tower, Hong Kong.

Keisuke Hiei has been involved in a range of large-scale urban projects in the United States, Hong Kong, and mainland China. Specializing in supertall buildings and curtain wall systems, he contributed to the design of both the tower and podium for the Shanghai World Financial Center and the 490-meter International Commerce Centre in Hong Kong.

Heidi Werner specializes in software development that engages with contemporary issues impacting the future growth of global cities. She has been involved in the generation of performance evaluation tools that provide analytics for large-scale mixed-use projects negotiating complex urban issues.

"Next Tokyo" imagines a resurgent megacity, adapted to climate change through the realization of a high-density ecodistrict built on resilient infrastructure. The archipelago of reclaimed land supports transit-oriented development for a half-million occupants, while improving the resilience of Tokyo Bay against waterborne risks. Rising sea levels, seismic, and increased typhoon risk have raised consensus on the need for a strategy that offers protection to the low-elevation coastal zones surrounding Tokyo Bay. Next Tokyo addresses this city-wide vulnerability by providing coastal defense infrastructure that offers protection to the shoreline of upper Tokyo Bay. These resilient infrastructural elements function as the foundations for clusters of recreational open spaces and for high-density development across the bay, including the Sky Mile Tower, reaching over 1,600 meters in height. As a development strategy, a portion of the value generated from this new, desirable waterfront real estate would in return contribute to the cost of the municipal infrastructure needed to support it.

Urban-Scale Considerations

Coastal defense

Next Tokyo is a linear district strategically situated at a bottleneck in the bay, where multiple phases of land reclamation encroachment along the east side have reduced the waterway passage to only 14 kilometers across. By continuing this narrowing progression, Next Tokyo creates a protective border across the bay between the engineered edge of Kawasaki and the naturally protruding shoreline of Kisarazu.

Hexagonal infrastructural rings, ranging from 150 to 1,500 meters in width, are arrayed to disrupt wave action intensity in multiple layers, while still accommodating shipping routes. Faceted breakwater bars on the ocean-side of the district provide additional defense for the most vulnerable mid-bay portions (see Figure 1). Additional operable floodgates stitch the primary clusters together for the activation of a temporary flood barrier during extreme storm surges. Tokyo Bay is currently dominated by industrial use and shipping activity; the

Figure 1. Land use diagram of the proposed Next Tokyo district.

protection offered by Next Tokyo creates the potential to viably introduce more mixed-use development and recreational activity into its upper portion.

Transportation links

Next Tokyo serves as a mid-bay transit hub for the city by running parallel with the existing Aqua Line bridge-tunnel combination. Prior to the completion of this roadway connection in 1997, Kanagawa and Chiba Prefecture were only accessible by a 100-kilometer drive around the coast of Upper Tokyo Bay. To reinforce this crucial transit route for the city, Next Tokyo provides tunnels to accommodate additional forms of mass transit between the shores, including regional rail lines and a new "Hyperloop" Maglev/vacuum-tube transport system, using technology currently being developed by Elon Musk. These cross-bay linkages assist in completing regional transportation rings and further reduce travel times for the commuting population. The primary station services the Sky Mile Tower, four kilometers off the coast of Kisarazu and is adjacent to the existing junction of the Aqua Line bridge-tunnel. Secondary stations are proposed for both ends of the district to provide additional transfer connections to the Next Tokyo monorail system and water bus network.

Figure 2. Reclamation over time in Tokyo Bay, including proposed Next Tokyo in 2045[2]

High-density district

The coastline of Tokyo Bay has experienced radical modification since the sixteenth century. At present, nearly 250 square kilometers of reclaimed land has accumulated along the shores of the 1,300 square-kilometer bay (see Figure 2). In total, the Next Tokyo district occupies 12.5 square kilometers; however, artificial land accounts for only a quarter of this total area. The smallest hexagonal rings accommodate nearly all of the high-density development. These islands cluster around the major transit exchanges and provide waterfront open space for the predominantly residential Sky Mile Tower and a range of secondary mixed-use towers (see Figure 3). Occupancy for the new district would draw from both regional- and national-scale demand, by accommodating a half-million residents seeking to reduce their commute times or leave aging, at-risk suburban and coastal areas. The medium-sized rings remain water-filled to buffer the high-density zones from wave action and retain various shared water resources for the district, including freshwater reservoirs and public beach harbors. Terraced low-density development occupies the perimeter of these rings, with linear open spaces providing pedestrian routes safely above the flood line.

Renewable resource strategies

Energy will be generated on-site through a

Figure 3. Aerial view of proposed Next Tokyo district.

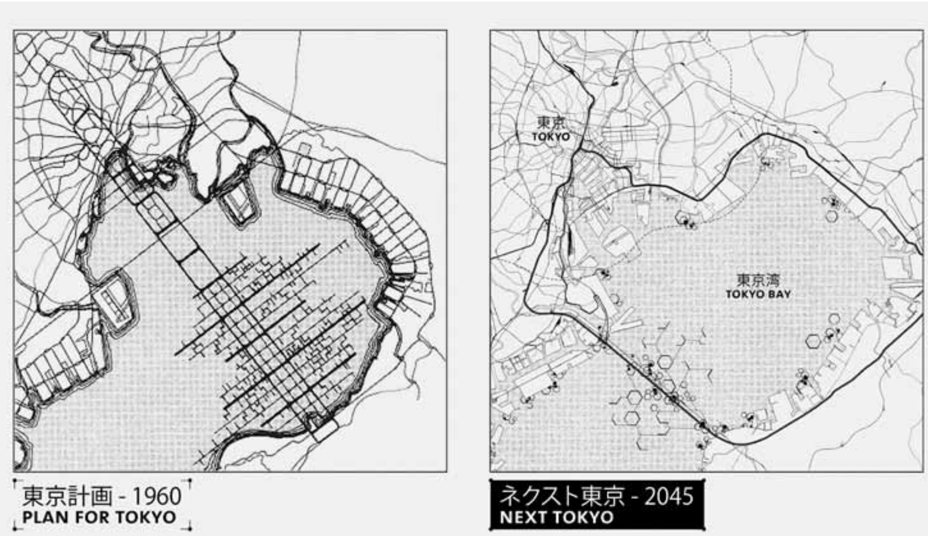

Figure 4. Comparison of Kenzo Tange's Plan for Tokyo Bay 1960 and the Next Tokyo 2045 Plan. © Kenzo Tange (L), the authors (R).

Figure 5. Sky Mile Tower.

number of different mechanical systems, including the capture of kinetic energy from the trains running across the bay, the use of solar electricity from photovoltaic cells, and the use of wind power, harnessed through small-scale microturbines integrated at high elevations in the mile-high tower. Urban farming exists at multiple scales in the district, and the largest infrastructural rings collect saline bay water to grow algae, which can provide a clean fuel source that is both rapidly renewable and extremely efficient. Industrial-scale agriculture is also integrated into the tall tower façades, while more localized community gardens and rooftop farms are introduced as added amenity. By providing local crop production on a variety of scales, a more secure food distribution system is created. This will significantly reduce the amount of food that is lost or destroyed during inclement weather and reduces the energy wasted for food storage.

Metabolist influence

Next Tokyo aligns with a long history of interest in Tokyo Bay as an underutilized resource. Over 50 years ago, Kenzo Tange envisioned a megastructure connecting the shores of Tokyo Bay during a post-war period of accelerated population growth, land shortage, and an absence of urban master planning. In his Tokyo Bay Plan of 1960, an urban spine of looping transportation routes and clusters of reclaimed land plots spanned 31 kilometers across the widest section of the bay to connect central Tokyo with Chiba Prefecture. The plan embodied several core principles of the Metabolist movement, by harnessing construction- and transportation-based technological advancements, and by proposing the creation of "artificial ground" to centrally densify the city. Next Tokyo introduces the spirit of Tange's unrealized plan to the year 2045 by merging it with new engineering technologies and a strategy for high-density vertical development (see Figure 4). Occupying the bay, but in a far smaller footprint, Next Tokyo explores future urban growth moving upward, rather than outward.

> "Although both of the tapered forms incorporated positive aerodynamic features, the one with vertical slots allowed the wind to flow through and yield a superior aerodynamic performance, simply due to its more efficient wind disruption."

Figure 6. Open-air sky decks at the top of Sky Mile Tower.

Sky Mile Tower

Connected communities at height

Sky Mile Tower is envisioned as a leader in a new generation of megatall buildings with sustainability, efficiency, reliability, robustness, and safety as key features (see Figure 5). A vertical network of segmented residential communities, totaling 55,000 occupants, is linked together by multi-level sky lobbies, offering shared public amenities, including shopping, restaurants, hotels, gyms, libraries, and clinics. Elevated open-air spaces were determined to be viable for the safe enjoyment of the residents in these overlapping zones through the use of wind tunnel testing, which helped to identify protected pockets with lower wind speeds (see Figure 6).

The tower form is conceived as consisting of multiple sets of three building legs interconnected to fit within a hexagonally shaped footprint. One building leg set overlaps with another set rotated in plan from the first; the sequence continues moving up the building. The number of floors in each set of building legs varies from 60 to 90. Each building leg has its own service core within the set, so the number of floors is not consistent from leg to leg. The Overlap between sets occurs every 320 meters over several stories to accommodate the sky lobbies. At these overlaps, full floors extend across the central space to provide connections between the six building legs. Elevator transfers, stair transfers, and other life safety services also occur at these overlapping zones. Therefore, if elevators or stairs were disabled in one of the building legs, alternate paths would exist at these common floors (see Figures 7 and 8).

Aerodynamic shaping

Even in the most seismically active regions of the world, the design requirements for wind exceed those for earthquakes; for a megatall building, the lateral pressures from the wind are greater than the imposed vertical loads on the floors. The tower will naturally have long periods of vibration that will be more readily excited by the wind. In order to address this practical issue, exploratory wind tunnel tests were carried out on three primary tower types:

- an extruded square tube,
- a solid stepped and tapered form, and
- a similarly stepped and tapered form, with varied slotted openings to allow the wind to pass through (see Figure 9).

The wind tunnel results showed that the square tube had an enormously high across-wind dynamic response – approximately 10 times greater than the slotted-tapered form. It was so high that attempting to control the loads or motions by adding more structure would be impractical. The two stepped and tapered options had nearly equal overall base wind loads. However, the solid-tapered form had a 20% higher dynamic response on the upper portion of the tower, resulting from the excitation of higher modes of vibration. The benefit of both versions is that the incremental steps and tapers confuse the wind, ultimately preventing large vortices from shedding in a coherent pattern (see Figure 10).

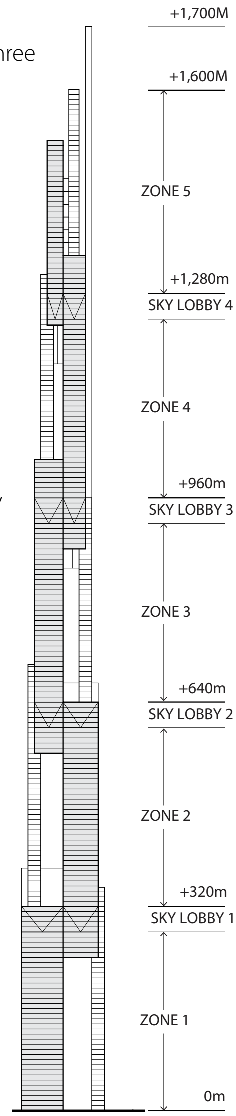

Figure 7. Sky Mile Tower – section.

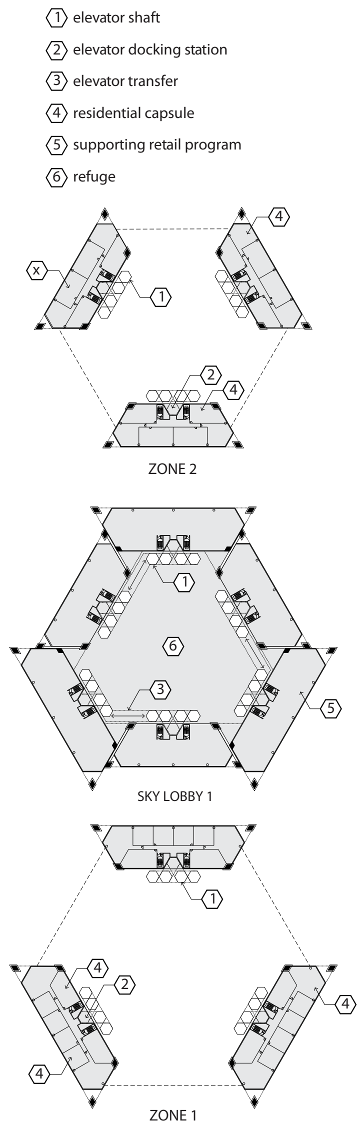

Figure 8. Sky Mile Tower – typical plans.

Figure 9. Wind response was tested on models for three primary tower types. © RWDI

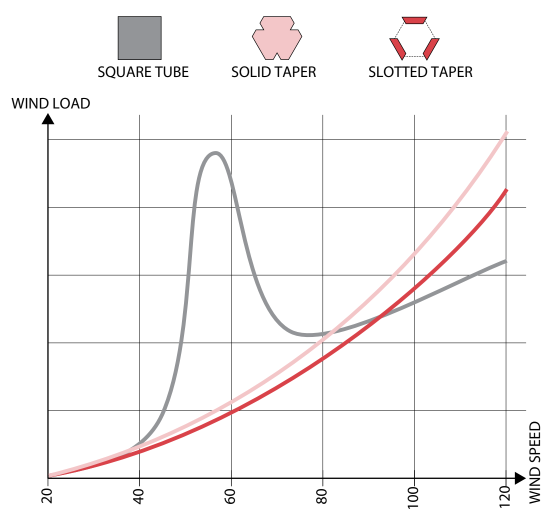

Figure 10. Wind response of three primary tower types. © RWDI

> “Pumping the water directly from the ground would be very costly and time-consuming. To overcome this, an articulated façade around the tower’s legs would increase surface area as part of a strategy to allow for cloud harvesting as a water source.”

Well-correlated vortices can produce a high dynamic response, resulting in both high inertial wind loads and elevated motions that tower occupants would perceive. Although both of the tapered forms incorporated positive aerodynamic features, the one with vertical slots allowed the wind to flow through and yield a superior aerodynamic performance, simply due to its more efficient wind disruption.

Structural design

The primary concern of the structural engineering team was to ameliorate the structure motions and stresses imposed by the wind. Megabracing on the inner face of each of the building legs, combined with concrete shear walls at the sides, provides the basic lateral force system for each of the three building legs in each set. Concrete is used to carry the larger loads – essentially, the entire weight of the building – and does so with small levels of bending moment. This becomes possible because of the high level of stiffness of the perimeter walls (see Figure 11).

At the overlapping common floors, large-scale steel trusses connect the two sets of building legs into a unified structure. These are plane frames in structural steel, bound into a space structure by the concrete work. In this way, the steelwork is not required to be molded into three-dimensional connections, thus eliminating cross-grain stress in the steelwork. Steel-to-steel connections, whether welded or bolted, are robust and redundant, two-dimensional, uncomplicated, constructible, and economical. At the perimeter, small columns support the concrete floor framing. These perimeter columns are supported on belt trusses spaced at 30- or 40-story intervals; these trusses transfer all the perimeter column loads to concrete shear walls. Concepts of robustness and redundancy permeate the approach to the structural design of this tower. All systems are organized such that any perimeter column, belt truss, or transfer truss could be disabled without an ensuing disproportionate collapse.

Wind loads were taken from analysis performed by the structural engineering team and consulting wind engineers. The studies show that the building performance and the building strength provide more than ample margins against the imposed loads. Further, as established by the International Standards Organization (ISO) and by the design team’s experience, wind-induced lateral oscillations are contained well within acceptance criteria. Earthquake loads were derived from Japanese building codes. A geotechnical engineer would be retained to develop earthquake time histories and site-specific criteria for the site. Preliminary assessment indicates that foundation conditions are suitable for the safe support of the tower structure; however, a comprehensive geotechnical report would be required. Basement depths remain under study, though it is likely that the tower would be best supported on a piled mat. Because of the high water table, the surrounding low-rise construction would likely be founded on tension piles.

Vertical (and horizontal) transportation

In crafting the transportation systems for the Sky Mile Tower, the design team approached ThyssenKrupp to brainstorm how technological advancements could address some of the unique logistical demands. The engineering challenge of transporting 55,000 residents through a slotted-tapered form became more feasible by leveraging the new MULTI magnetic-levitation elevator technology. A MULTI system was proposed for the tower as a series of unidirectional staggered loops, linking five residential zones

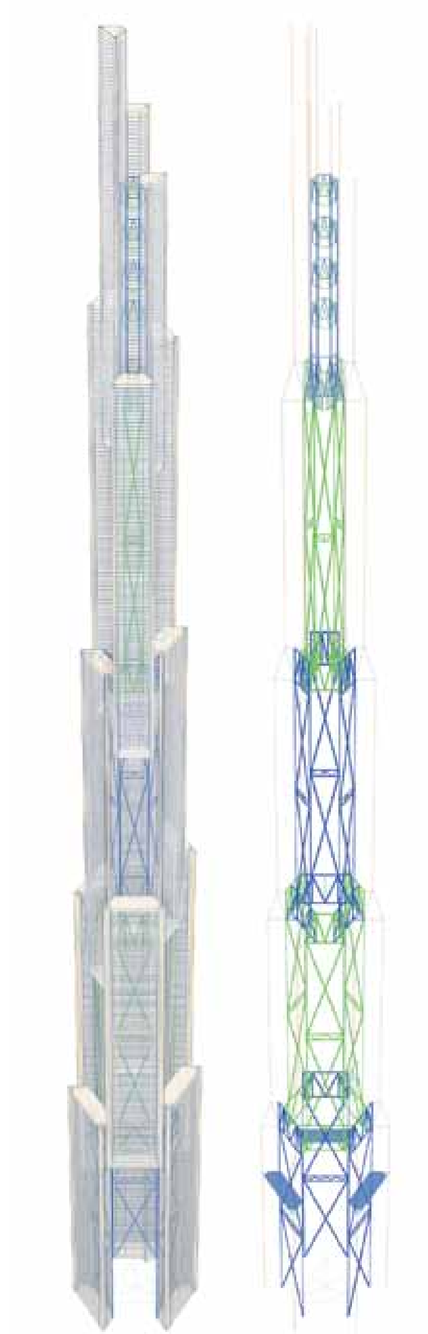

Figure 11. Sky Mile Tower structural system. © LERA

and four sky lobbies. With building legs ranging from 280 to 460 meters, local elevator cars run within a single residential zone along their interior faces in dedicated up- or down-shafts. At the top and bottom of a building leg, the cars reverse direction by running horizontally to an opposing directional shaft and maintain a continuous loop. Shuttles run on longer loops across multiple residential zones to provide direct service between the building entry and the sky lobbies. Shuttle cars run express through the building legs, parallel to the local car shafts. In the interlocking zone they transfer horizontally, aligning with a new building leg and vertical shaft to connect with the next sky lobby.


Figure 12. Overall view of proposed Next Tokyo development.

Services

The slotted-tapered form of the Sky Mile Tower provides a variety of benefits that would allow for it to work with its environment. This is a key philosophy that underpins the ability of a building to function in a way that can successfully provide the systems and resources required to support such a large number of people, while still minimizing its ecological impact. For example, the tower design takes advantage of upper atmospheric conditions by utilizing the stratified air and lower outdoor air temperatures to help meet cooling and water loads.

The distribution and organization of facilities throughout the tower will help to further optimize building efficiency by limiting the mechanical losses and additional electrical demands. One example of this is the distribution of water. Pumping the water directly from the ground would be very costly and time-consuming. To overcome this, an articulated façade around the tower's legs would increase surface area as part of a strategy to allow for cloud harvesting as a water source. The water can then be centrally collected, treated and stored at various levels throughout the tower, while utilizing gravity as a method of distribution, thereby eliminating pumping from the ground to upper floors. Additionally, the cooler air around the taller portions of the tower can be utilized to help reduce the building's heating load at a minimal energy or financial cost. Blackwater recycling systems can also occur both mechanically and via biofiltration methods, which, in combination with the cloud harvesting and rainwater catchment systems, can completely eliminate the need for an additional source of potable water.

Since Sky Mile Tower is constructed as a series of communities, waste heat from one zone will be reused by another zone to increase energy efficiency. This thermal micro-grid provides each community with access to additional mechanical capacity and provides redundancies in the case of emergency events or localized power outages. Organic waste management via an on-site anaerobic digester will both significantly reduce the amount of building waste, and provide natural gas that can be used to power tri-generation plants, which efficiently generate the electricity for providing hot and cold water.

Conclusion

The global population will likely continue to concentrate in urban areas, most of which are situated near major bodies of water. In the context of increasing environmental threat and sprawling urban migration trends, Next Tokyo presents a megatall building participating in the transformation of an existing coastal megacity, allowing it to become more resilient to contextual change. Next Tokyo occupies Tokyo Bay in the spirit of Metabolist urban planning while responding to contemporary desires to realize a symbolic mile-high tower; it creates a megastructure with a vertical height matching the base unit of distance for nearly all modes of horizontal transportation. The feasibility of this proposal is reinforced by the leveraging and integration of technological advancements.

The proposal was featured in NHK Japan's documentary series "Next World," which aired February 8, 2015, http://www.nhk.or.jp/nextworld/map/main.html#45. ■

Unless otherwise noted, all photography credits in this paper are to Kohn Pedersen Fox Associates.

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