Title: **South Beach Towers, Singapore**

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Subjects: Architectural/Design
Building Case Study

Keywords: Parametric Design
Redevelopment
Sky Garden
Vertical Urbanism

Publication Date: 2017

Original Publication: CTBUH Journal 2017 Issue II

Paper Type:
1. Book chapter/Part chapter
2. **Journal paper**
3. Conference proceeding
4. Unpublished conference paper
5. Magazine article
6. Unpublished

Canting Towers and a Cooling Canopy

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Abstract

After more than 100 years, an area of Singapore formerly off-limits to the public has been transformed into a new mixed-use development that combines two landmark towers, historic preservation of colonial military buildings, and a flowing canopy at the ground level. The result, called South Beach, is an integrated and vibrant space in central Singapore, maximizing the critical assets of innovative design, warm weather, connectivity, and history. Highlighting three key aspects of the project, this case study unpacks the design team's integrated approach, illustrating the complexity of the design process, and exemplifying how a tall building may make a positive contribution to its surrounding urban realm.

Keywords: Redevelopment, Sky Garden, Vertical Urbanism, Parametric Design

Introduction

The South Beach development covers an entire city block between the Marina and Civic District in the heart of downtown Singapore. Combining new construction with the restoration of existing buildings, the new mixed-use, energy efficient urban quarter brings together places to live and work with shops, cafes, restaurants, a hotel, and public spaces.

Rising up towards the north and south of the site are two inclined towers – 35 and 45 stories respectively – the South Tower is divided between a hotel and apartments, while the North Tower contains offices. A wide landscaped pedestrian avenue – a green spine – weaves through the site, connecting the towers, retail areas, and the MRT station, and is protected by a large innovative canopy, which shelters the light-filled public spaces beneath from the extremes of the tropical climate (see Figure 1).

From the outset, the design team's vision included the public spaces as well – the undulating canopy covering the green spine forms a key part of the sustainability strategy for South Beach. Due to its tropical climate, the use of outdoor spaces in Singapore is limited to certain times of day. The creation of the green spine and the canopy was an attempt to introduce a new kind of public space that would provide a comfortable microclimate even during the hottest hours of the day.

Figure 1. The innovative canopy shades the walkways and public spaces below.

The two towers are also defined by an environmental screen that rises out of the canopy to mitigate the harsh Singaporean sun. These eastern and western façades contain cascading sky gardens and balconies, while the north and south façades provide solar shading from oblique sun angles (see Figure 2).

The structural approach complemented and augmented the environmental features of the project, with the design team using parametric modeling to integrate all design aspects. This was particularly pertinent in the design of the canopy, where changes in the structural system impacted the environmental performance of the structure and vice versa. What followed was an iterative process of design, in which a single parametric model was fed with multi-layered information to simulate the performance of the canopy and refine the form of its components. In addition, the two towers – with inclined columns in opposing directions – also presented a significant structural challenge.

South Beach is significant in urban terms as well, with the restoration of four historic buildings on the site forming an integral part of the mixed-use development. As a former military site, the entire city block was largely inaccessible to the public until redevelopment began in 2007. As such, one of the key success stories of the project is the transformation of this site into a public space, with a ground plane that is now entirely open, accessible and largely pedestrianized. For the first time since 1907, the links between the historic district and the Marina Bay area have been re-established, revitalizing an important connection in the city that had been lost over time.

Environmental Design Strategy

South Beach's design aimed for the highest environmental rating – BCA Green Mark Platinum – for both residential and commercial components by introducing holistic approaches to environmental design. The

Figure 2. South Beach Towers, Singapore – rising up from the green spine.

> “Rather than attempting to achieve integration through a totalizing approach to parametric modeling on a single software platform, the project exposed different interfaces and outputs based on the team members involved and their immediate goals: visualization, physical modeling, and construction documentation.”

Figure 3. The louvers help protect the interiors from solar gain while maintaining views out.

Figure 4. The shingle glazing on the north/south façades.

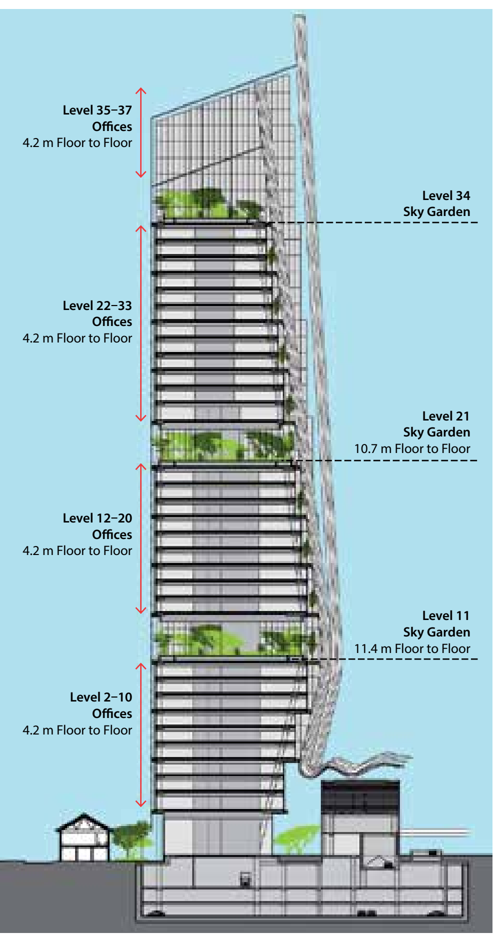

Figure 5. The north tower contains multi-tenant office space. © Foster + Partners.

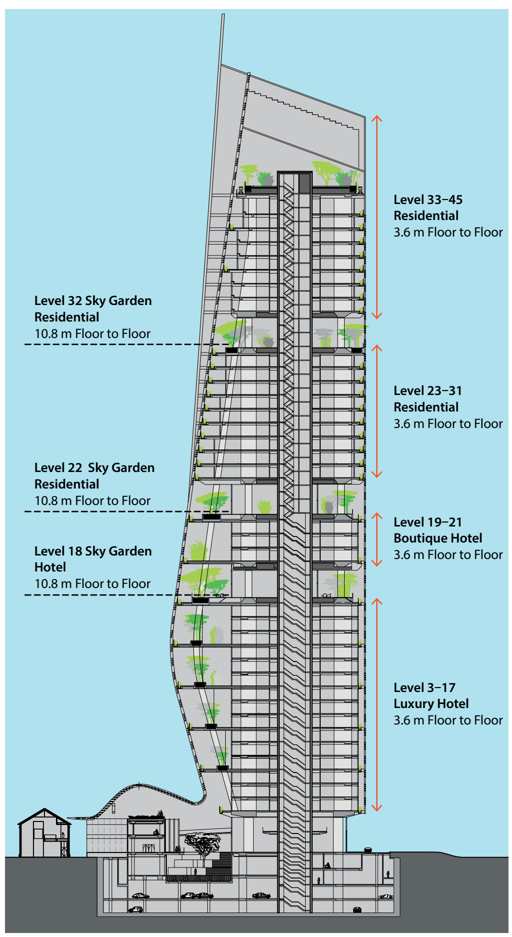

Figure 6. The south tower contains a hotel and residences. © Foster + Partners.

sustainability criteria driving the project were developed in three discrete strategic tiers: passive, active, and power generating.

Passive sustainable strategies were implemented in order to maximize the building's conservation of energy. This strategy integrated analysis of daylight, surface temperature, thermal comfort, rain protection, and air velocity to all the major public areas to inform an optimized solution. Form, massing, orientation, shading, and vegetation were then designed to correspond to the data provided for every stage of this analysis-driven investigation. Additionally, a series of structural studies for the canopy were undertaken, aiming to investigate ways of reducing the weight of the structure, directly reducing embodied energy.

Active sustainable strategies were developed to manage internal sources of energy efficiently. Lighting, waste treatment, and thermal comfort of residences were optimized to meet the local sustainability criteria. Rain water collected from the canopy roof is stored in a collection tank before being redistributed to several water features across the public space, as well as being used for irrigation.

Power generation strategies further improve the environmental performance of the design, supplying clean energy for the daily operations of the building's facilities. Accordingly, a sufficient portion of the design is covered by photovoltaic and solar thermal tubes to meet energy-generation goals. The parts of the canopy that should receive such elements were identified by solar radiation analysis, thus enabling the replacement of the necessary panels locally, without distracting from the continuity of the overall roof geometry.

The Two Towers

Located towards the northern and southern edges of the site, the two towers within the South Beach development make a distinctive addition to the Singaporean skyline. Each of the façades has been articulated differently in response to its orientation and the use of

Figure 7. The open-air sky gardens at intermediate levels take full advantage of Singapore's balmy climate.

internal spaces it encloses. The eastern and western façades feature an external screen with a louver system that provides horizontal shading while maintaining sight lines; while the north and south façades have alternating upward and downward-facing glazing panels that create a shingle pattern (see Figures 3 and 4). The upward-facing glazing reflects the sunlight by day, and the downward-facing glazing reflects the city by night, creating a dynamic composition in the heart of the city.

The two towers also comprise a series of vertical sky gardens, planters, and balconies that help protect the building from the sun and filter sunlight to reduce glare. These sky gardens improve the microclimate by enhancing natural air movement, while also minimizing energy consumption by optimizing heat exchange. They are irrigated using stored rainwater, and their ceilings – along with some other internal partitions within the towers – are made with local bamboo, a highly sustainable product. Apart from the benefits for the building and the internal spaces, these vertical gardens also continue the "city in a garden" ideal for Singapore and boost the aesthetic appeal of the building.

The north tower is a multi-tenant office building, currently occupied by international companies such as Facebook, Instagram, Expedia, Sanofi, and Lego, among many others. Sky gardens, located at levels 11, 21, and 34, break up the building's façade and also serve as communal break-out spaces and places to host special events for office workers (see Figure 5).

The south tower consists of a hotel topped by residential units on the upper floors (see Figure 6). It also has several sky gardens, located on levels 18, 22, and 32, with the former serving hotel guests and the other two meant exclusively for tower residents (see Figure 7). The 654-room hotel also features triple-volume sky terraces on levels 6, 9, 12, and 15, which are surrounded by clusters of hotel rooms. Above, there are 190 residential units, which include a mixture of two-, three- and four-bedroom units along with penthouses with private roof gardens.

The south tower also features a split core, i.e., the lifts serving the hotel and residences travel through different vertical shafts, enabling the residential units to be naturally ventilated through an air-well located above the hotel lift shaft. This has ensured that all units can meet or exceed the natural ventilation targets required to achieve Green Mark Platinum rating.

The Canopy – Design Predictions and Closing the Loop

The design of the canopy is the central focus of the project's sustainable approach. Its form was driven by solar and wind studies and is orientated to protect the avenue and retail areas from direct sun and rain, while allowing daylight to filter through to the space below. The structure is made up of ribbons of steel and aluminum louvers, which flex above the primary circulation routes and public spaces and dip near the edges to meet the existing buildings along Beach Road. The entrance to the canopy rises up to form an arc, which acts as a wind scoop, drawing the prevailing breezes through the space and promoting natural ventilation (see Figure 8).

The use of solar panels and optimally angled louvers means that natural sunlight at once can be harnessed to offset energy demand and be deflected to reduce heat gain. Average shading with the canopy is 57%, compared to 4.7% without. This rainproof "umbrella" also channels breezes, encouraging ventilation flow, presenting no

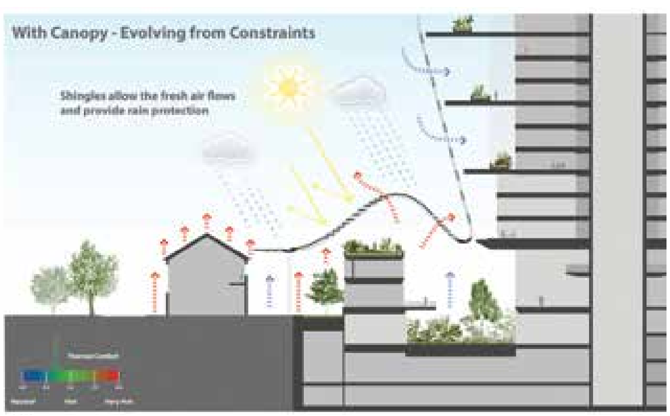

Figure 8. The canopy draws prevailing breezes while filtering out the harsh summer sun. © Foster + Partners.

> "The south tower features a split core. The lifts serving the hotel and residences travel through different vertical shafts, enabling the residential units to be naturally ventilated through an air-well located above the hotel lift shaft."

Figure 9. Microclimatic studies undertaken post-occupation. © Foster + Partners

need to install air-conditioning for visitor comfort. Rainwater, too, collects at the lower points of the canopy, which serve as reservoirs that recycle water and irrigate the development's lush greenery.

To achieve this, Foster + Partners and Arup embarked on an iterative design process, which identified comfort requirements before balancing the climatic elements. There were a number of predictions about the performance of the canopy that were made during the design process. These predictions were tested after the building was occupied to verify their validity.

It is relatively easy to analyze the performance of a building based on feedback from Building Management Systems, measuring the consumption of electricity and water, and other such data. However, this does not hold true for outdoor spaces, such as the green spine under the canopy at South Beach. The canopy was designed to create an outdoor space that was comfortable to use throughout the year by moderating five separate elements – air movement, light levels, radiant temperature, and felt temperature. The designers and engineers had made several predictions through simulations during the design stage, which needed to be validated by measurements on the ground after the building had been built to "close the loop" between design-stage predictions and delivered performance.

The open spaces under the canopy of South Beach were investigated by a team of architects and environmental scientists using specialized thermal imaging equipment and microclimatic weather stations. The on-site studies focused on the relations between the tropical urban microclimatic variables and thermal comfort criteria that were established for comparing the simulation results with on-site measurements (see Figure 9).

These field studies showed that the "felt temperature" under the canopy at South Beach was up to 13°C lower than other canopied spaces in Singapore, and up to 17°C lower than unsheltered spaces in the city. The ground surface temperatures also varied drastically from 55°C on the streets to 30°C at South Beach.

The main reason for the success of the canopy in keeping cool is that the solar gains associated with the daylight levels under the canopy are kept low. During design, the team evaluated the thermal gains and illumination from direct solar radiation, and from diffuse sources such as the sky dome and adjacent reflective surfaces, including the ground itself. It is important to consider aperture size of the louvers as a function of light transmission and its resultant thermal impacts under the canopy. Improperly designed apertures can result in overheating of the spaces under the canopy, visual discomfort from glare and unwanted deterioration and fading of furnishings and other materials.

One additional reason for the success of the canopy was also that it did not inhibit air movement to a great extent – the team measured a wind speed of 1.5 m/s in an unsheltered space, while beneath the canopy wind speed was on average 1.5 m/s.

In the end, the difference between the design predictions and the actual readings on-site was very minimal – a testament to the rigorous analysis and modeling carried out as part of the design process.

Parametric Modeling

The design of the canopy was refined in response to a variety of environmental and structural factors that were mediated through a multifunctional parametric model. The use of parametric design on this project was far more sophisticated than normal, so much so that the in-house Applied Research and Development team at Foster + Partners had to write its own software. The innovative digital design platform used to develop the canopy model integrated the work of the design team and consultants into a seamless and responsive workflow. This enabled the development of a shared model capable of providing a full range of drawings and data – from design intent to information sheets for detailed design documentation.

In the canopy design, the environmental strategies are closely related to the geometry of the roof. Structural beams define the massing form and orientation of the canopy as well as the green spine along the main public space. Columns and drainage panels are situated to satisfy structural constraints

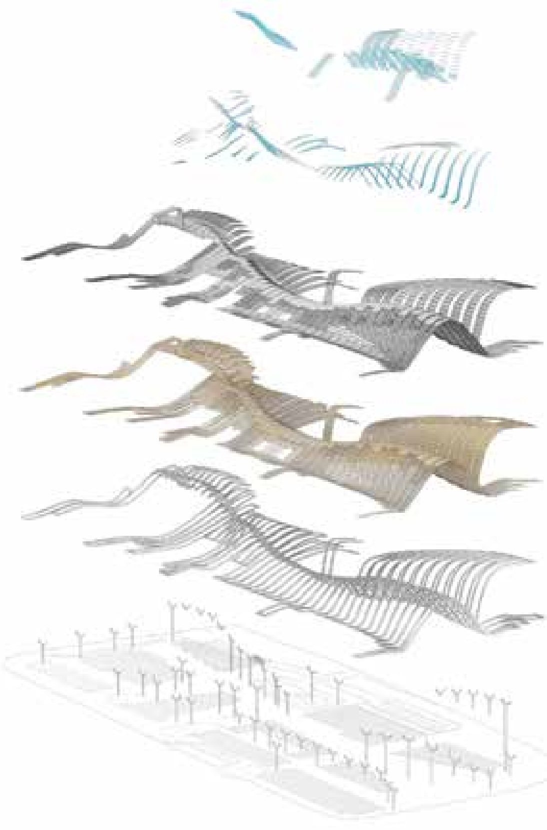

Figure 10. The canopy components. From top: glass louver infill, glass ribbon infill, louver structure, louver cladding, structural ribbons, and y-columns. © Foster + Partners

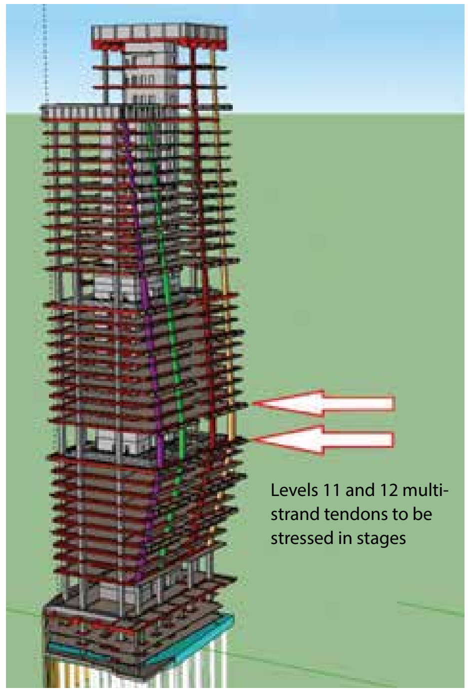

Figure 11. Staged post-tensioning. © Arup

and efficient water collection for each ribbon. Finally, louver panels are distributed to perform particular functions locally (see Figure 10).

However, unlike the hierarchical order of the environmental strategies, the digital model of canopy elements establishes many bi-directional relationships. When the structural system or drainage strategy changed, this alteration was reflected in updated canopy geometry and the location and types of louvers. Conversely, when louver properties changed due to structural or performance reasons, the beam depth was changed reciprocally. These interdependent relationships required significant changes even for relatively minor updates. The challenge in designing the South Beach canopy involved orchestrating this multi-layered information while maintaining the flexibility of design.

Rather than attempting to achieve integration through a totalizing approach to parametric modeling on a single software platform, the project exposed different interfaces and outputs based on the team members involved and their immediate goals: visualization, physical modeling, and construction documentation. The beams supporting the canopy and the louvers, which provide much of the structure's environmental mediation strategy, each exploited unique strategies for responding to the data provided by performance simulation. Thus, all aspects of the canopy were capable of rapid update cycles, while allowing the model to retain implicit connections with the initial principles from which it was derived. The solutions were tested by a series of analyses that monitored and informed the performance of the canopy's design at regular intervals during the project's development.

Building Structure

Soaring above – the two towers

South Beach features two technically challenging high-rise buildings with inclined columns tilting outwards at lower floors and back inwards at the higher floors. The resultant forces of these perimeter column inclinations under gravity forces are resolved into vertical as well as significant horizontal forces.

Unlike most high-rise towers, the inclined columns on one half of each tower create large horizontal forces due to gravity loads alone. This is in addition to the horizontal forces that are derived from wind or notional loads. To overcome this, the engineers designed the slabs at critical floors to transfer these forces to the core by staged post-tensioning (see Figure 11). As the forces in post-tensioning are very high, the tendons were cast within a thick concrete slab. The horizontal transfer tendons were planned for the sky garden levels where there was large headroom, allowing for structural slabs to be up to 600 millimeters thick without affecting the architectural intent.

The core walls, which range from 700 millimeters thick at the base to 400 millimeters at the top, are designed to resist these transferred horizontal forces. The basement slabs also act as rigid horizontal diaphragms to transfer these forces to the rigid diaphragm walls, which are partially offset by the lateral earth pressures. This is unlike a conventional high-rise building, in which the core is treated as a cantilever shaft encastred solely to the pile cap.

Just passing through – the canopy

The intent for the canopy was to achieve a lightweight, single-layer structural system, rather than a truss structure, ultimately taking the form of six-meter-wide ribbons running in the east–west direction. The primary ribbon beams are a pair of fabricated steel hollow sections, with secondary members bracing the beams, resulting in a Vierendeel truss system. These ribbons support the aluminum and glass louver infill panels, which were distributed according to functional requirements beneath. Certain canopy areas employ solid louvers or louvers with shaded-glass infill panels to protect a dry route beneath, while other areas are configured to enhance cross-ventilation by employing a series of overlapping but open louvers.

Structural beams linking the ribbons are hidden within the louvers. A combination of these louver beams and arching ribbons achieves various pitch heights, giving the canopy much more rigidity vertically and

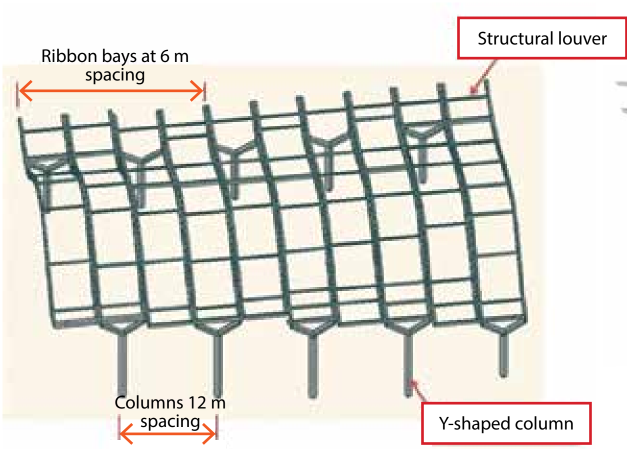

Figure 12. The beams of the canopy form a Vierendeel truss system. © Arup

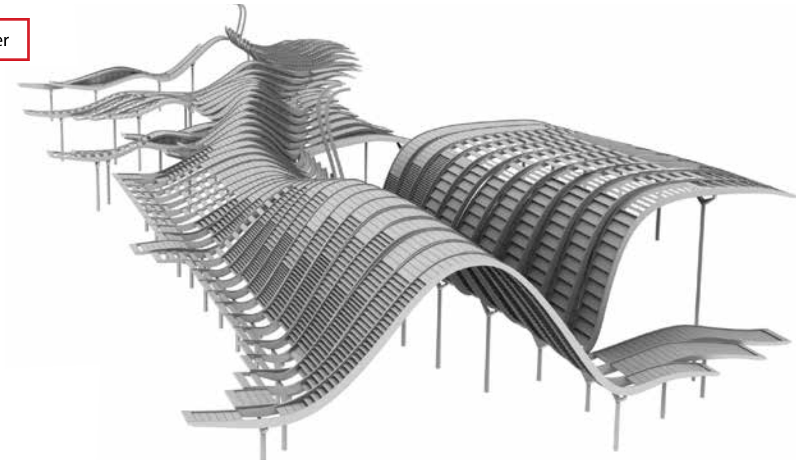

Figure 13. Louvers vary in opacity and orientation to aid ventilation, drainage, and shade. © Foster + Partners

laterally than can be visually perceived (see Figure 12). Rainwater down-pipes are optimized and hidden within arching ribbons and Y-columns.

A full-service 3D BIM model was developed to coordinate all services that are hidden within the louvers and ribbons (see Figure 13). The openings and stiffener plates in the ribbons for these services were optimized with this visual tool. Abortive work resulting from the clash of services with structural elements or architectural louvers were hence eliminated before fabrication.

The canopy's undulating form introduces structural complexities due to the varying stress levels along the span of the canopy. To address this, the design team included welded box sections side-by-side, allowing for the two adjacent ribbons to follow the different arch forms, while maintaining the rigidity. All plates of the boxes are of the same thickness, with varying depths to match the different stress levels, allowing for quick material procurement and easy fabrication. As opposed to using a series of off-the-shelf rectangular hollow sections, the bespoke wave-like ribbons allow for sections to be larger in size where forces are higher and smaller in size where forces are lower. This is represented by the tapering profile of the cantilever section.

Urban Context and Conservation

The site overlooks the Padang (formerly the Padang Cricket Ground), home to many of Singapore's leading institutions and landmarks, including the National Gallery of Singapore, The Old and New Supreme Court, St Andrew's Cathedral, Victoria Theatre, The Esplanade, and the famed Raffles Hotel (see Figure 14).

South Beach sensitively addresses the adjacent Raffles Hotel by carefully restoring the four former military buildings along Beach Road and interspersing them with conserved mature trees. The towers are then set back from Beach Road, with only the recessed upper levels visible above. Designed to be a natural extension of the adjacent historic district, the key old buildings on-site were also used to define the pedestrian routes through the development. The presence of the historic buildings, together with the overarching canopy, give the entire development a distinctly low-rise pedestrian character.

Figure 14. Historic buildings along Beach Road, including the NCO Club in the corner and the Raffles Hotel across the street.

Figure 15. The canopy forms part of the integrative tissue between the old military buildings and the new towers.

There are four conservation buildings along Beach Road – Blocks 1, 9 (also known as the Straits Settlements Volunteer Force (SSVF) Drill Hall), and 14 of the former Beach Road Camp, together with the neighboring Singapore Armed Forces Non-Commissioned Officer (SAF NCO) Club. These buildings straddle the pre- and post-WWII eras, embodying varied forms, technology, materials, and climatic design responses to the tropical context. They are synonymous with Singapore's nation-building and defense history, being a Remembrance Day memorial site for Volunteer Corps veterans, as well as the birthplace of the SAF. The group also carries conservation significance as the first Modernist buildings to be gazetted for conservation in Singapore, in 2002. The Urban Redevelopment Authority (URA) technical conditions required that these structures be sensitively restored and adapted for new use, as an integral part of the new mixed development.

From an urban conservation viewpoint, the transformation of a former high-security and publicly inaccessible military site into a commercial mixed-use development presents both great opportunities as well as challenges. A key conservation priority was the preservation of the street frontage of Beach Road, long characterized by the low-rise forms and heterogeneous façade designs of the four historic buildings. Their fine urban grain in turn informed the massing design of the new podium blocks behind, successfully integrating the new urban form of the development with the character and scale of the surrounding neighborhood across the street. The introduction of a sinuous microclimatic canopy that runs the entire length of the site also helped to mediate the stark contrast of scale between the heritage structures and the new-built towers (see Figure 15).

Conclusion

The South Beach project represents a critical opportunity to realize a highly functional mixed-use development that meets contemporary standards of environmental performance and preserves important historical buildings. Its intensively modeled design process resulted in an addition to the neighborhood that fits well into Singapore's emerging high-rise vernacular and actually improves the thermal dynamics of its site. In this way, it embodies the "vertical city in a garden" concept that distinguishes Singapore.

- Some extracts relating to the conservation aspects of the project within this article first appeared in an essay by Ho Weng Hin published in The Singapore Architect Journal, October 2016.
- Portions of this paper about the environmental strategy and parametric design were previously published in the Conference Proceedings of ***Acadia 2011: Integration through Computation,*** edited by Jason S. Johnson, Branko Kolarevic, Vera Parlac, and Joshua M. Taron. ■

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Project Data

Completion Date: November 2015
Height: 218 meters
Stories: South Tower: 45; North Tower: 35
Total Area: 153,067 square meters
Use: South Tower: Residential/Hotel; North Tower: Office
Owner: South Beach Consortium
Developers: City Developments Limited; IOI Group; South Beach Consortium
Architects: Foster + Partners (design); Aedas (architect of record)
Structural Engineer: Arup (design)
MEP Engineer: Parsons Brinckerhoff Consultants Private Limited (design)
Main Contractor: Hyundai Engineering & Construction
Other CTBUH Member Consultants: Arup (façade, geotechnical, sustainability); BMT Fluid Mechanics Ltd. (wind); Davis Langdon (quantity surveyor)
Other CTBUH Member Suppliers: Hilti AG (cladding); KONE (elevator)