



CTBUH Research Paper

ctbuh.org/papers

Title: **Case Study: Capital Gate, Abu Dhabi**

Author: Jeff Schofield, Associate, RMJM

Subjects: Architectural/Design
Building Case Study

Keywords: Core
Design Process
Façade
Sustainability

Publication Date: 2012

Original Publication: CTBUH Journal, 2012 Issue II

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 Unpublished conference paper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 Unpublished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 / Jeff Schofield

CTBUH Journal

International Journal on Tall Buildings and Urban Habitat

Tall buildings: design, construction and operation | 2012 Issue II

Capital Gate, Abu Dhabi

Securing Iconic Structures

Environmental Performance of the TTDI

Developing Rotterdam's Skyline

Talking Tall: The Skyscraper Index

Debating Tall: Is UNESCO Going Too Far?

Tall Buildings in Numbers: Occupiable
Telecommunication & Observation Towers

Case Study: Capital Gate, Abu Dhabi



Jeff Schofield

Author

Jeff Schofield, Associate

RMJM
Floor 27, Monarch Office Tower
PO Box 6126
Dubai
UAE

t: +971 4 702 7626
f: +971 4 329 6444
e: j.schofield@rmjm.com
www.rmjm.com

Jeff Schofield

Since moving to RMJM Dubai in 2005, Jeff Schofield has lent his design expertise to a variety of large scale building developments, including mixed use, hospitality and high-rise projects.

As an Associate at RMJM, Jeff leads the effort in providing sustainable solutions to all design projects in the office. He has developed a holistic approach to design that integrates sustainability, structure and architectural expression with the built form, in order to provide meaningful solutions for high-quality building designs. Jeff seeks to design in a contemporary yet contextual manner, to create modern sustainable buildings using the latest technology.

Jeff currently lives and works in Dubai. He began his career in New York City and pursued his professional practice for more than 15 years in Paris, France. He has project management and design experience on a range of high profile projects and has specific experience in sustainable design and project management of large-scale public projects throughout Europe, United States and the Middle East.

“It is the first building in the world to use a pre-cambered core with a built-in lean of 350 millimeters that has been engineered to straighten with the addition of the upper floors. It is also the first building in the world to use vertical post-tensioning of the core to counter movement and support stresses created by the building’s overhang.”

Throughout history, a strong link has existed between iconic architecture and exhibitions. One of the best known examples is Paris’ Eiffel Tower, which was built as a visual symbol of the Exposition Universelle, World’s Fair of 1889. More recently, cities like Seville have used powerful and innovative architecture as a way to highlight the cultural significance of their exhibitions.

The Concept

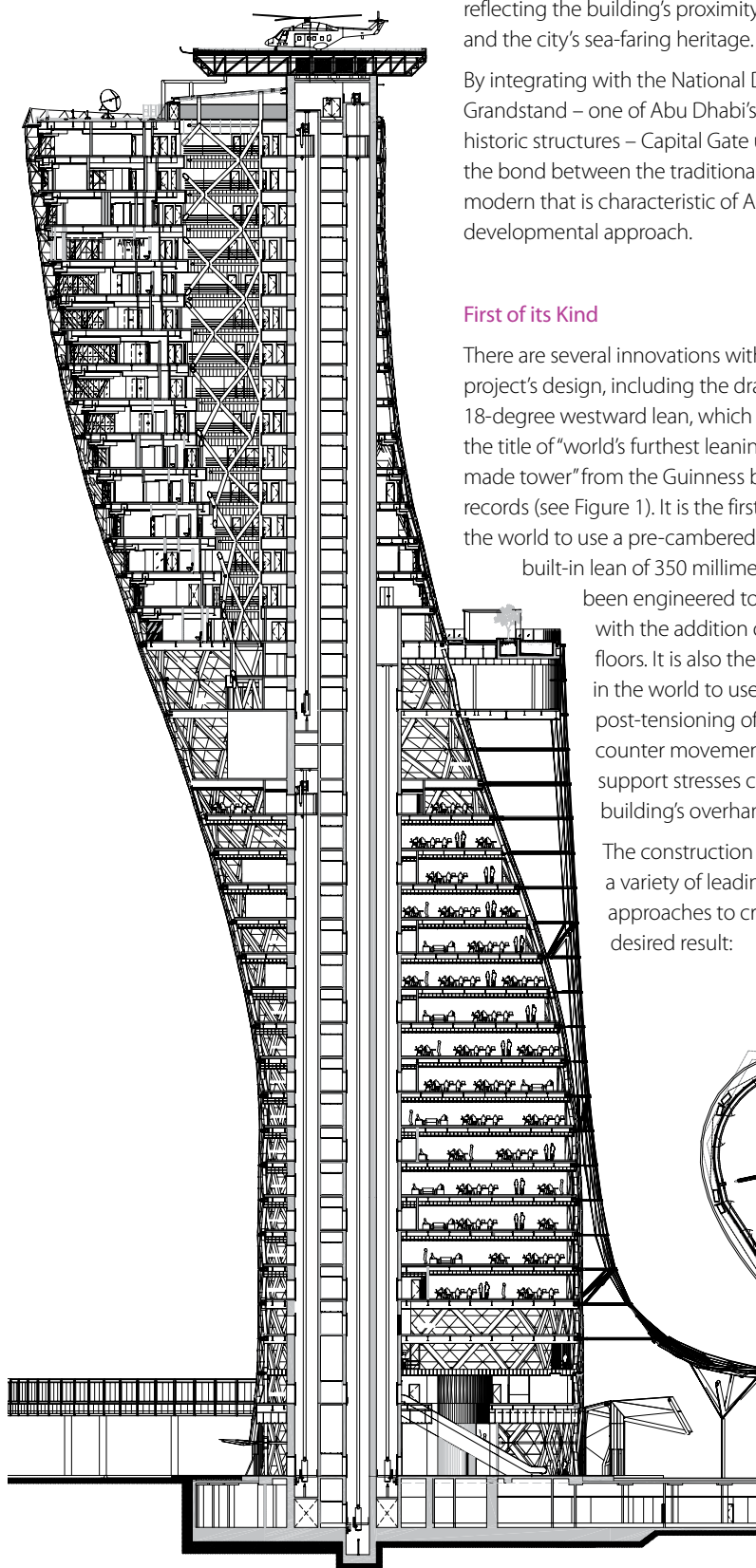
In 2005, the Abu Dhabi National Exhibitions Company (ADNEC) was created to drive forward the development of Abu Dhabi’s events sector. Plans were created with RMJM to build a state-of-the-art exhibition center which would be the largest in the Gulf region and provide world class facilities for live events to flourish in Abu Dhabi.

It was strongly felt that the entire development required a signature tower, a cutting-edge structure with a futuristic design,

aesthetic splendor and technical excellence to celebrate human achievement and reflect the dynamism of Abu Dhabi. Capital Gate is the result.

The tower’s curvaceous shape draws strongly on the sea and desert – two elements that have great resonance in Abu Dhabi. The building’s form is meant to represent a swirling spiral of sand, while the curved canopy, known as the “splash,” which runs over the adjoining grandstand and rises on one side of the building, creates a wave-like effect,





reflecting the building's proximity to the water and the city's sea-faring heritage.

By integrating with the National Day Grandstand – one of Abu Dhabi's most historic structures – Capital Gate underscores the bond between the traditional and modern that is characteristic of Abu Dhabi's developmental approach.

First of its Kind

There are several innovations within the project's design, including the dramatic 18-degree westward lean, which has earned it the title of "world's furthest leaning man-made tower" from the Guinness book of world records (see Figure 1). It is the first building in the world to use a pre-cambered core with a built-in lean of 350 millimeters that has

been engineered to straighten with the addition of the upper floors. It is also the first building in the world to use vertical post-tensioning of the core to counter movement and support stresses created by the building's overhang.

The construction also adopted a variety of leading-edge approaches to create the desired result:

- Four hundred and ninety foundation piles were driven 20 to 30 meters underground to support the structure and counter stresses. The piles, which were initially in compression during construction to support the lower floors of the building, are now in tension as the stresses caused by the overhang have been applied.
- The vertical and horizontal cross-sections of the tower are all unique.
- There is an asymmetric shape – no two rooms are the same (see Figure 2). Every one of the 12,500 panes of glass on the façade is a different size, although each pane is triangular.
- Floor plates change shape and orientation to create the distinctive "overhang" moving from "curved triangular" to "curved rectangular," while increasing in overall size and migrating from east to west as they progress up the tower.
- Capital Gate is one of the few buildings in the world that use a diagrid structure; it also features two diagrid systems, an external diagrid defining the tower's shape and an internal diagrid linked to the central core by eight unique pin-jointed structural members.
- All 8,250 steel diagrid members are different thicknesses, length and orientation. ➤

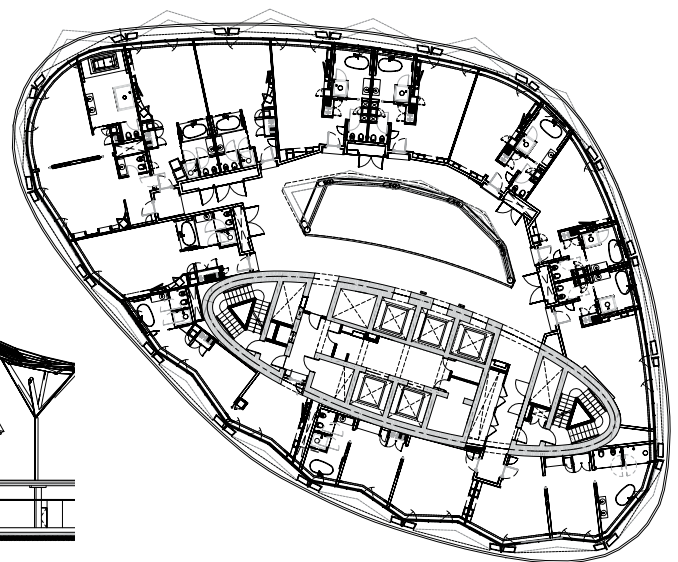


Figure 1. Typical section © ADNEC

Figure 2. Typical hotel floor plan © ADNEC

- Each of the 822 diagrid nodes (702 external and 120 internal nodes) is a different size and angular configuration.

Capital Gate forms the focal point of the Abu Dhabi National Exhibition Centre complex and the Capital Centre master development, a connected group of 23 towers including branded hotels, commercial buildings, residential and serviced apartment complexes and developments for mixed use. These facilities are built overlooking an urban highway along the south-western shore of Abu Dhabi. Capital Gate dominates this waterfront site from its position at the western edge of the ADNEC complex, adjacent to the exhibition halls and connected to the historic National Day Grandstand.

The tower stands out on the skyline; it is slightly removed from ADNEC's high-rise development on the eastern side of the site. Due to the location, views from Capital Gate are extensive in all directions. The preferred views are out to sea and along the coastline. Views towards the city are becoming more impressive as Abu Dhabi grows around it. Capital Gate cuts a strong profile against this emerging skyline.

Architectural Expression

The ground-breaking form of Capital Gate is due not only to its lean, but also to its funnel shape. It widens as it spirals upwards and outwards. This gesture creates the dramatic sculptural form which is expressed architecturally in a variety of ways (see Figure

3). The façade glazing emphasizes the organic elements with diagonals spiraling up along the structural diagrid. This weaving pattern is further broken down with individual panes of glass in a complex mesh wrapping the entire building. The sheer skin is interrupted only by two entrances on the ground floor, the footbridge to the car park, and the terraces at the top of the "splash."

The potentially monumental scale of Capital Gate is tempered by this "splash" sun shading on the south façade. This metal mesh screen at the lower half of the tower adds complexity to the overall form as it highlights the different uses of the tower – offices in the lower half and hotel in the upper half.

Architecture is about space making, and the architects sought to express the drama of Capital Gate in its interior spaces. The hotel arrival is at the top of the splash on the 18th floor, where visitors discover a panoramic view of Abu Dhabi. The lobby lounge is a double-height space cantilevered beyond the tower diagrid (see Figure 4), providing a dramatic arrival for guests. The restaurant located on this floor is also a dramatic double-height space positioned where the tower form leans at the steepest angle.

Due to Capital Gate's unique shape, the upper half of the tower widens to create an atrium at the hotel's guest room floors (see Figure 5 and 6). This space is perhaps the most surprising discovery the visitor finds inside the building. The atrium is funnel shaped and appears carved out of the solid form around it, spiraling and leaning along with the tower. It



Figure 3. Capital Gate's organic shape © Devita Villanueva

is also expressed with a diagrid structure, informing its organic shape. While vertical in proportion, the atrium is intimate in scale. Light filters down from the large skylight roof above to create a serene environment.

The Structure

Capital Gate's base structure is a vertical concrete core surrounded by a steel diagrid describing the external form of the tower. Steel beams span between the two, supporting metal deck and concrete



Figure 4. Double-height lobby lounge © Devita Villanueva



Figure 5. Hotel atrium, looking up © ADNEC



Figure 6. Model section showing the funnel-shaped atrium © Jeff Schofield

composite floor slabs. Above the base, the atrium is formed with an internal steel diagrid attached to the core. Steel girders span directly between the external and internal diagrids, creating column-free floor spaces with typical spans of about 12 meters.

The external diagrid is composed of hollow square sections 600 x 600 millimeters on a side. They carry floors four meters high. Each diagrid member is a different length, depending on the angle at which it leans. The external diagrid elements are made from welded steel plates, 80 millimeters thick at the bottom floors, and progressively lightening to 40 millimeters at the top floors. The internal diagrid around the atrium is made of round steel profiles 400 millimeters in diameter, which are also hollow.

The diagrid connections are nodes located at the floor slab levels where girders frame in. The external diagrid nodes are also designed for the façade panels to frame on the outside (see Figure 7). Designers studied these connection details extensively to optimize construction, as well as structural integrity.

The concrete core occupies the only vertical space available in the tower profile. It has high reinforcement levels, especially at the steel



Figure 7. External diagrid structure © ADNEC

framing connections. The core has two innovative features:

- During construction a pre-cambered core was poured slightly off vertical, so when the tower floors were framed in to the opposite side, the added load straightened the tower.
- A post-tensioned core was designed with vertical cables in one side tensioned to counteract the lean on the other side. These cables were installed in vertical segments that overlap each other every seven floors. Strung together, they span the entire height of the core to maintain it in a perfectly vertical position.



Figure 8. The "splash" © ADNEC

The Capital Gate's wind bracing is designed as a separate system. Abu Dhabi has light winds, which Capital Gate counteracts through a combination of a dense network of core walls and outriggers at the 17th floor mechanical level, connecting the core to the external diagrid. The tower's round form and diagrid structure provide inherent resistance to torsion. At the ground floor, a massive concrete ring beam transfers the thrust of the diagrid into the foundations. It is noteworthy that Abu Dhabi is in a low seismic hazard zone, and the appropriate factors of safety and stiffness were applied for structural integrity. ➤

...water feature

“Putting a water feature in a lobby gets you LEED points, but it doesn't save energy, doesn't improve the environment and it doesn't change the world.”

Anthony Malkin, President of Malkin Holdings, owner of the Empire State Building on the building's retrofit. From "An Interview With Empire State Building's Anthony Malkin: Bike Racks and Showers Won't Change the World," Huffington Post "The Blog," March 28, 2012.



Figure 9. Curtain wall diamond-shaped panels © Jeff Schofield

The sun shading for the tower is a lightweight metal mesh hung from the terraces on the 18th and 19th floors (see Figure 8). In turn, the terraces are cantilevered 12 meters from the tower. They are braced to the external diagrid with steel profiles reaching diagonally down to the plant floor level. At this same mechanical level, on the opposite side of the tower, the atrium internal diagrid framing is transferred to the core with steel profiles placed diagonally in sections. The plant floor at mid-height ties together all the primary structural elements of the tower.

Façade Design

Capital Gate's cladding consists of two distinct elements – a curtain wall glazing system and metal mesh sun shading system. Both were installed by the same manufacturer in order to ensure close coordination between these interlocking systems and the steel diagrid to which they are attached.

The curtain wall consists of diamond shaped panels stacked up floor by floor (see Figure 9). Each unit is two-floors high and one diagrid wide, about 8 x 8 meters on average. They follow the geometry of the structural diagrid, which carries their weight vertically. The panels are braced for wind resistance at the middle floor slab, which carries the horizontal load.

The curtain wall units are made of two components: steel and glass. The steel framing was manufactured in Austria. The frame profile is triangular to take loads in all directions. The glass was made in the United Arab Emirates. It is a low-emissivity glass, very transparent, yet provides good thermal insulation and glare reduction.

These components were assembled in Abu Dhabi into panels, which were transported to the site on over-sized flatbed trucks custom-made to accommodate the large units.

The metal mesh sun shading is made of light-weight metal framing with stainless steel wire mesh, 90% open. The "splash" is a flexible system designed to follow Capital Gate's curving forms. It is braced to the tower every five floors with round steel profiles. There are cross-bracing rods every floor. The connections for these elements are located at each diagrid node and extend through the curtain wall joints to reach the steel structure. Above the ground floor, as the geometry turns from vertical to horizontal, steel tree structures reach up to hold the splash form in place.

Façade maintenance is performed in various ways. The curtain wall elements are repaired and replaced from the inside, cleaning is from the outside via abseiling, and lightweight sun shading elements are repaired via abseiling. It is common in the Middle East to use abseiling, a form of rappelling for external building maintenance (see Figure 10). Capital Gate has eye-hooks in the curtain wall joints at every node, so the abseilers can hoist themselves close to the overhanging surfaces. Inside the splash, abseilers maneuver between the braces and rods to clean both glass and mesh at the same time.

Sustainable strategies

ADNEC is committed to being one of Abu Dhabi's leaders in sustainable development. From the beginning of concept design, the

architects and engineers integrated many passive and active sustainable systems into Capital Gate, including metal mesh sun shading, a double skin façade, high-performance glazing, reduced amount of materials, vegetated roof on the basement, low-flow water fixtures, district cooling, variable speed air conditioning, heat exchange for ventilation, and energy monitoring and controls.

Capital Gate's most visible feature is the "splash," which twists around the building towards the south to shield Capital Gate as much as possible from direct sunlight. The metal mesh eliminates 30% of the sun's heat before it reaches the building, reducing the air conditioning load on the protected floors. It also provides outdoor shade to the main entrance on the ground floor.

The upper half of the tower has a double skin façade to reduce the solar heat gain at the hotel levels. This is a modified double façade, which recycles interior air from the guest rooms into the façade cavity. Here it creates an insulating buffer between the hot outside air and the cool inside air (see Figure 11). The air is re-used in the room rather than exhausted and replaced with outside air.

The glass used on Capital Gate's façade is a low emissivity glass never before used in the United Arab Emirates. It's designed to keep the inside of the building cool and eliminate glare, while maintaining the transparency of the façade.

Capital Gate's organic shape also lends itself to savings in construction materials, in several ways, despite the lean. Its rounded form is



Figure 10. Façade maintenance via abseiling from the outside © ADNEC

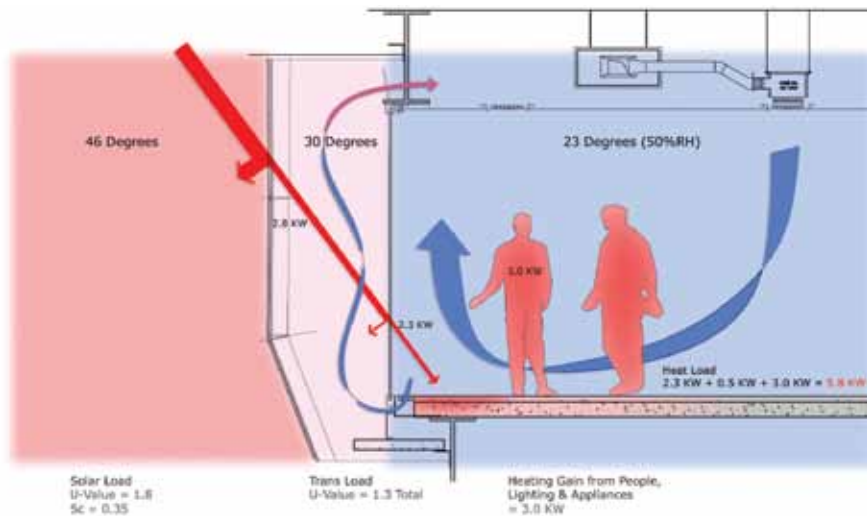


Figure 11. Double skin façade system © Jeff Schofield

aerodynamic, presenting less resistance to the wind than a rectangular building, thereby requiring less structure for lateral loads. The round perimeter encloses space more efficiently than a rectangle, so less façade surface is needed than for a conventional floor plate of identical area. The result is that fewer materials are required for structure and façades. This is a reduction in concrete, steel and glass, materials which all have high carbon content and embodied energy.

Landscaping around Capital Gate creates a vegetated roof over the basement, increasing the thermal insulation and reducing the need for air conditioning. Native plants are used, which require less irrigation than conventional landscaping. To further reduce potable water use in this desert context, low-flow water fixtures are installed in the public areas and washrooms, including WCs and faucets.

District cooling is provided by Abu Dhabi Municipality, a more energy-efficient means of obtaining chilled water than installing chillers on site. The chilled water is distributed by variable speed pumping, which reduces energy use in operating the air conditioning. Heat recovery wheels reduce energy use for ventilation by exchanging hot and cool air during the intake and exhaust process. Energy monitoring and controls in the Building Maintenance System further reduce energy use by implementing efficient operation of lighting, air conditioning and other power-consuming and heat-generating functions.

Partnering Solutions

The huge technical challenges that had to be confronted in bringing Capital Gate to life have been overcome through a structured partnering program. It is a fairly unusual technique in this part of the world, which ADNEC has employed with much success on all of its construction projects. Essentially, all the key organizations working on a project are located together in one location. The architect sits next to the project manager, who sits next to the quantity surveyor, who sits next to the contractor and the rest of the team. The objective is simple: to remove confrontation and create a single team mentality with one single goal – to get the project completed in the most effective way. JCP International, the partnering consultants who worked at a strategic level with the joint leadership team, worked from the project and construction management level to the front line supervisors and staff to instill a culture of collaborative working within and across organizational boundaries.

Conclusion

While clearly a unique structure was built using some of the world's most advanced construction techniques, ADNEC believes the tower's appeal goes far beyond an architectural and engineering marvel. Functionality and purpose have been a prime focus.

Capital Gate houses Abu Dhabi's first Hyatt Hotel, the five-star Hyatt Capital Gate, as well as approximately 15,000 square meters of office space.

The tower is also strategically important to Abu Dhabi and visually represents the emirate's progress and evolution. It is the focal point of a world class business district, and is inter-connected with the thriving Abu Dhabi National Exhibition Centre, which hosted more than 200 events in 2011, welcoming around one million visitors. Capital Gate's visitors or tenants have access to the world-class amenities within the building as well as elsewhere within the ADNEC development, including facilities such as a fully-operational airport check-in facility.

The Guinness world record for "world's furthest leaning manmade tower" has shone a spotlight on Capital Gate and Abu Dhabi, as has a "Megastructures" documentary on National Geographic Channel ("The Leaning Tower of Abu Dhabi"), broadcast in more than 166 countries to an estimated television audience of more than 200 million.

The people of Abu Dhabi feel a sense of honor in Capital Gate. They are confident Capital Gate's aesthetic splendor and technical achievement will generate admiration and discussions around the world for years. ■

Project Data

Completion Date: 2011
Height to Architectural Top: 165 meters
Stories: 35
Total Area: 53,100 square meters
Primary Uses: Hotel/Office
Project Developer: ADNEC Group
Architect: RMJM
Structural Engineer: RMJM
MEP Engineer: RMJM
Façade Consultant: Hyder Consulting
Landscape Consultant: Al Khatib Cracknell
Main Contractor: Al Habtoor Engineering
Steel Contractor: Eversendai
Façade Contractor: Waagner Biro
Project Manager: Mace