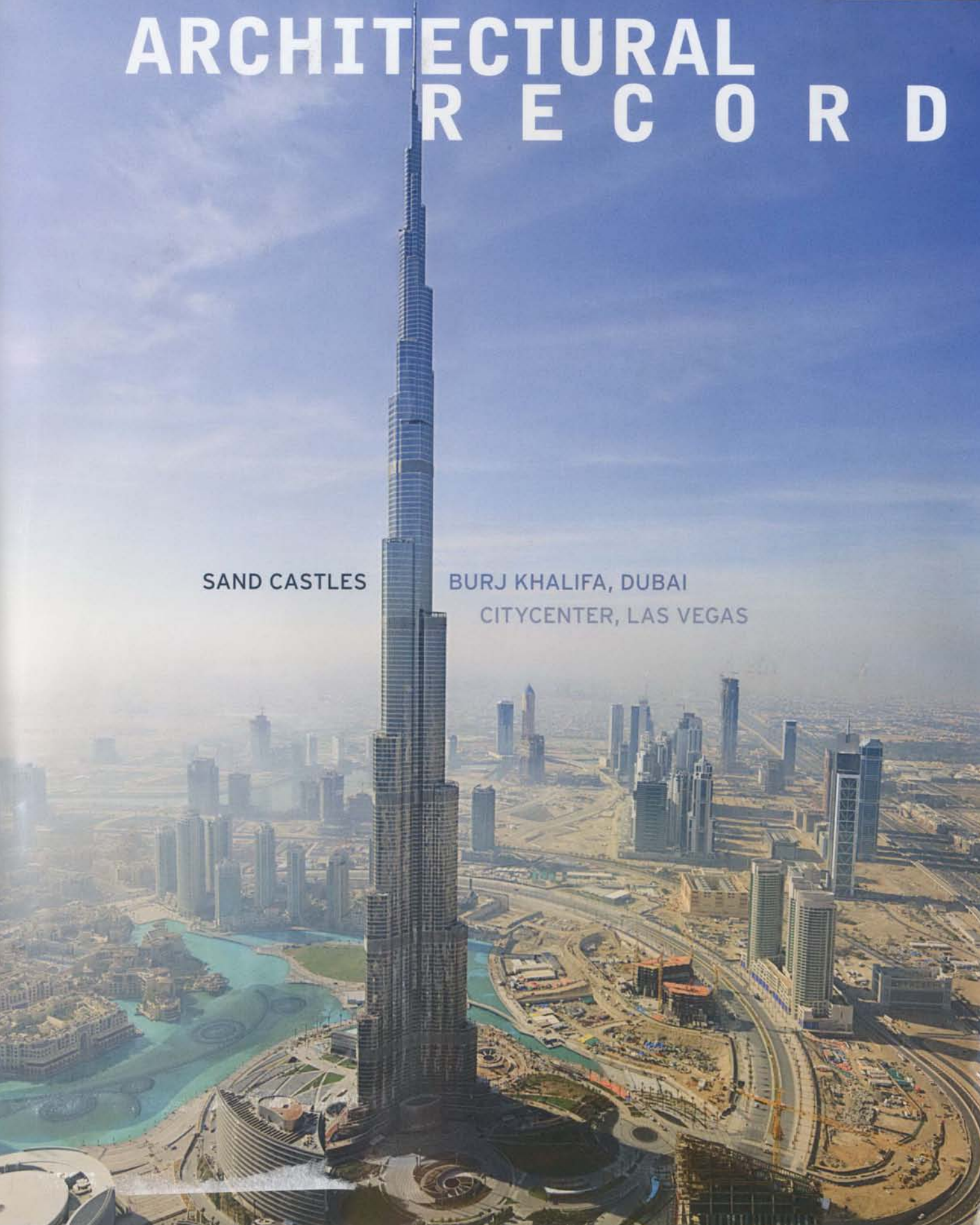
ARCHITECTURAL RECORD



SAND CASTLES

BURJ KHALIFA, DUBAI

CITYCENTER, LAS VEGAS

PRODUCT FOCUS

This month's product roundup takes a closer look at two iconic (and large-scale) projects featured in the issue: the Burj Khalifa in Dubai and CityCenter in Las Vegas. BY JEN RENZI

1

1 | PRODUCT **SunGuard Solar Silver 20 and ClimaGuard NLT Low-E Glass**
MANUFACTURER **Guardian Industries**
guardian.com

The Burj Khalifa's 2,650'-tall, 160-story facade is veiled in 26,000 glass panels – tallying more than 1.8 million square feet of glazing – supplied by Guardian Industries. The company's SunGuard Solar Silver 20 and ClimaGuard NLT Low-E glass series both offer strong solar and thermal performance, antiglare properties, and enhanced light reflectance to withstand the desert climate's extreme temperature swings, strong winds, and blazing sunshine. **CIRCLE 200**

4

4 | PRODUCT **TS 93 Door Closer**
MANUFACTURER **DORMA**
dorma-usa.com

More than 16,000 pieces of DORMA hardware – including the TS 93 door closer – equip the Burj Khalifa's 12,000-plus portals. The track-arm, surface-applied TS 93 has a cam-and-roller design that reduces the effort required to open doors and eliminates protruding double-lever arms to create a barrier-free, ADA-compliant environment. **CIRCLE 203**

2

2 | PRODUCT **Mega Blinds**
MANUFACTURER **Hunter Douglas Contract**
hunterdouglascontract.com

In addition to supplying motorized curtain tracks and Roman shades for the Armani Hotel's 160 guest rooms, Hunter Douglas also customized more than 30,000 square feet of motorized Venetian blinds for the Burj Khalifa entry pavilions. The sun-shading louvers, engineered by company subsidiary Limelight, are powered by rooftop solar panels. **CIRCLE 201**

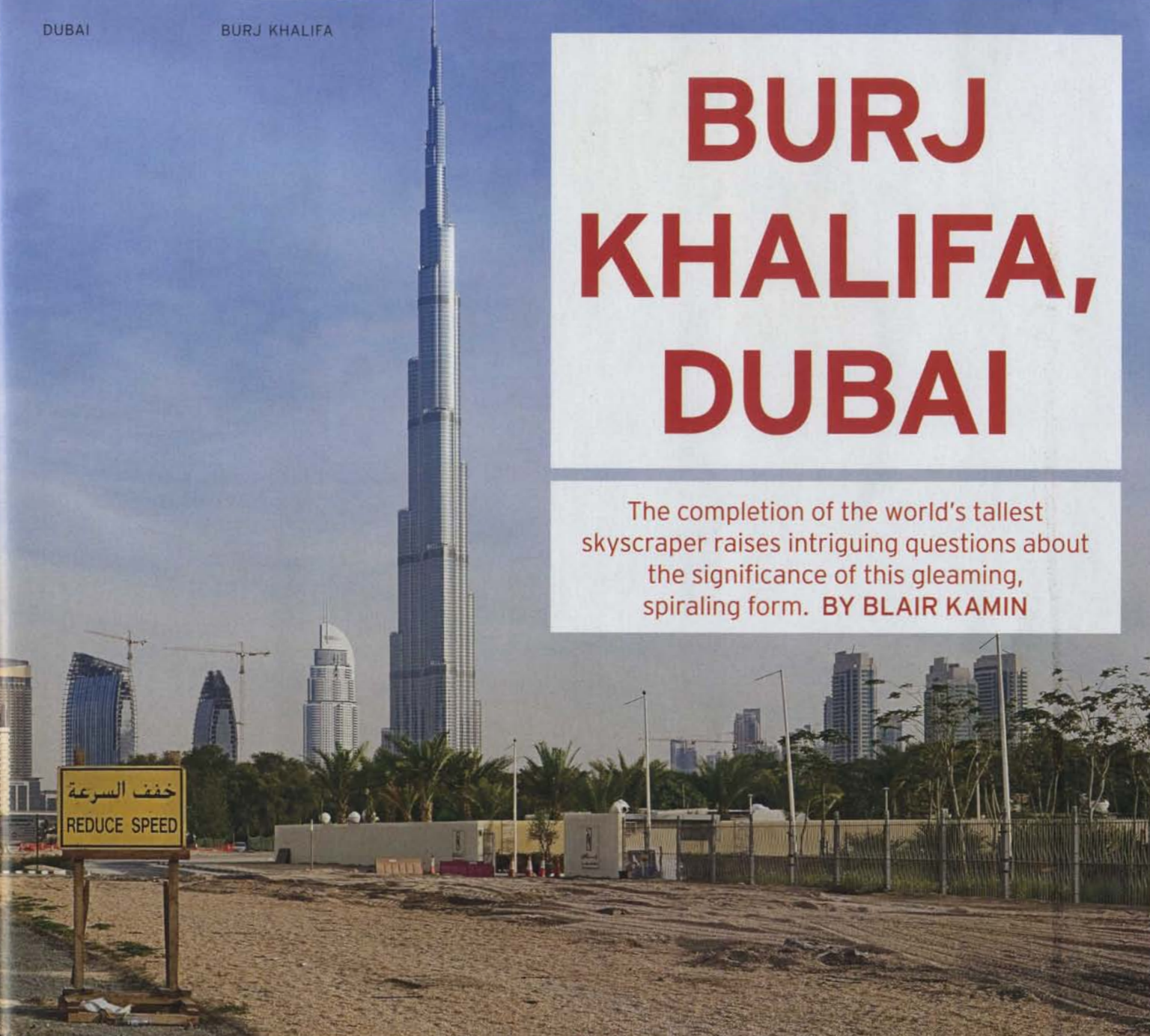
3

3 | PRODUCT **Varia EcoResin, Pure Gold Interlayer**
MANUFACTURER **3form**
3-form.com; 3form.eu

Varia EcoResin wall panels form a shimmery backdrop in the entrance lobby of the Burj Khalifa's Armani Hotel. The translucent resin panels, which incorporate 40% preconsumer recycled content, can be specified with custom interlayers or with items from 3form's vast portfolio of wood veneers, organic materials, and textiles – such as Pure Gold metallic fabric (above). **CIRCLE 202**

BURJ KHALIFA, DUBAI

The completion of the world's tallest skyscraper raises intriguing questions about the significance of this gleaming, spiraling form. **BY BLAIR KAMIN**



Iconic skyscrapers, especially those that strive for the fleeting title of "world's tallest building," are rarely the progeny of cold logic. Their backers invariably are motivated by ambition and ego. The architect does not control whether or where such behemoths are built. He or she can only ensure that they are proud and soaring things, not Frankenstein-esque, XXL-size monstrosities. Such is the considerable achievement of Adrian Smith, FAIA, and his former colleagues at the Chicago office of Skidmore, Owings & Merrill (SOM) in the gargantuan yet persuasive Burj Khalifa, which rises half a mile above the desert in the once-unstoppable, now-humbled Persian Gulf playground of Dubai.

THIS PAGE: **Stainless-steel spandrel panels and vertical fins articulate the gleaming glass-and-aluminum curtain wall of the tower.**

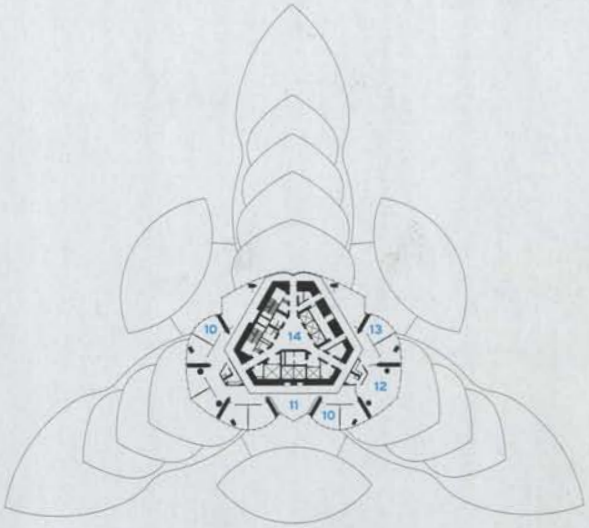
OPPOSITE: **The Burj Khalifa is surrounded by a 27-acre park designed by landscape architects SWA. The complex overlooks the Dubai Lake and Fountain and the Old Town Island, a new, low-rise mixed-use complex (foreground).**

At the staggering height of 2,717 feet (easily more than two Empire State Buildings), this shimmering, spiraling mixed-use tower inevitably raises the question: When is big too big? To some, this giant of giants – its spire alone is more than 700 feet tall – clearly overshoots the mark. Shortly after its spectacular January 4 opening ceremonies, critics pegged it the Hummer of skyscrapers. "Purely a vanity project," said the German urban planner Albert Speer, Jr., in *Spiegel*. "Completely unsustainable," jibed Britain's *Guardian*. Pundits also ridiculed the tower's abrupt name change – from Burj Dubai (Arabic for "Dubai Tower") to Burj Khalifa in honor of Sheik Khalifa-bin-Zayed al-Nahyan of Abu Dhabi, who bailed Dubai out of its 2009 debt crisis. In the Great Recession, when sustainability supposedly has supplanted spectacle as architecture's guiding principle, the bling of the Burj Khalifa offers a convenient target for those eager to consign the pre-Crash Age of Excess to the ash heap of history.

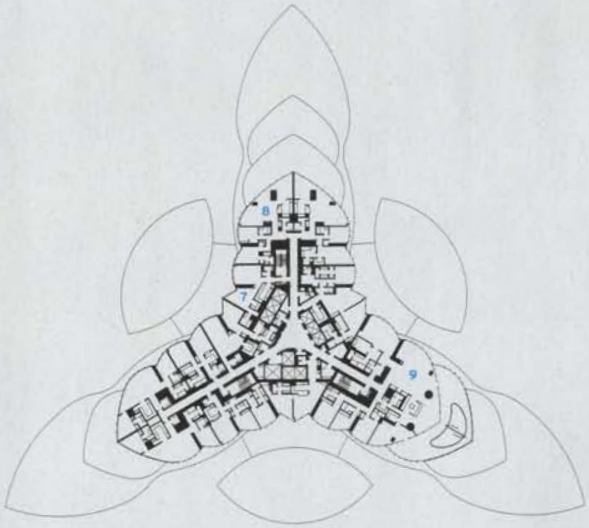
But it would be shortsighted to conflate the messy circumstances surrounding the Burj Khalifa's completion with the tower's exhilarating and surprisingly refined architecture. And such a dismissal would ignore previous supertall sagas. When the now-beloved Empire State Building opened in 1931, so few of its floors were rented out that it was labeled "the Empty State Building." Building booms and busts come and go, as do the temporary wearers of the world's-tallest-building crown. What matters, in the long haul, is the artistry that separates skyscrapers that are merely yardstick-tall from those that make of their tallness a smashing aesthetic virtue. And the Burj Khalifa easily meets – and exceeds – and exceeds – that standard, soaring in both height and design quality above Dubai's often-ludicrous collection of architectural cartoons.

The $1.5 billion skyscraper marks the first time since Egypt's Great Pyramid of Giza that the world's tallest building has been found in the Middle East. It also represents a great leap forward in height, rising higher than the previous record-holder, Taipei 101 in Taiwan, by more than 1,000 feet. Yet the tower is more than a mere feat of engineering, the product of mad scientists striving to achieve a listing at guinessworldrecords.com. The secret to its success is its integration of architecture and engineering, long a staple of the SOM Chicago office, responsible for five of the world's current 10 tallest buildings.

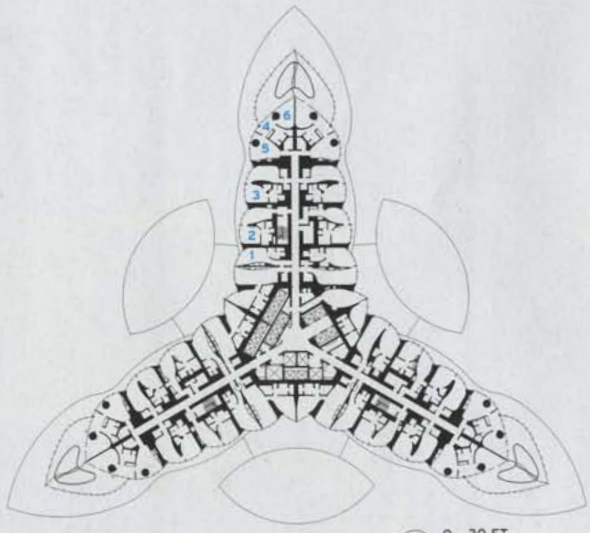
To be sure, the tower is no paragon of sustainability. But a little perspective is in order. When the tower's developer, the state-backed Emaar Properties, rounded up the usual supertall suspects – including SOM, Kohn Pedersen Fox, and Pelli Clarke Pelli – for an invited competition in 2002, green was not on its agenda; "Big" was. At that time, architects and the culture at large had yet to embrace sustainability as they have today. It is perhaps unfair to judge a building



TYPICAL OFFICE FLOOR



TYPICAL RESIDENTIAL FLOOR



TYPICAL HOTEL FLOOR

0 30 FT.
9 M.

SITE PLAN (OPPOSITE)

1 BURJ KHALIFA ARRIVAL COURT
2 ARMANI HOTEL ENTRY
3 RESIDENTIAL ENTRY
4 VIEWING DECK
5 LAKEFRONT PROMENADE
6 TOWER GARDEN
7 WATER FEATURE
8 CHILDREN'S PLAY AREA
9 RECREATION AREA
10 SERVICE YARD
11 OFFICE ENTRY

FLOOR PLANS

1 STUDIO
2 CLASSIC GUEST ROOM
3 SUITE
4 LIVING ROOM
5 DINING ROOM
6 BEDROOM
7 ONE-BEDROOM UNIT
8 TWO-BEDROOM UNIT
9 FOUR-BEDROOM UNIT
10 OFFICE
11 STAFF CAFÉ
12 EXECUTIVE SUITE
13 MEETING ROOM
14 RECEPTION

TO RECEIVE ONE AIA LEARNING UNIT, READ THIS ARTICLE ALONG WITH "BEYOND LIMITS," STARTING ON PAGE 89.

SITE PLAN

The swirling park designed by SWA Group at the base of the Burj Khalifa echoes the tower's curves and supplies water features and planting for the hot, humid climate. The mix of plants (irrigated by graywater) includes date palms, olive trees, and the Hymenocallis (spider lily) that inspired the Burj's design.

PHOTOGRAPHY: © IWAN BAAN (FIRST SPREAD); NICK MERRICK/HEDRICH BLESSING (SECOND SPREAD); DAVID GAL/SWA GROUP (THIS PAGE)

birthed in one era by the standards of another, just as it is unrealistic to insist on passive solar cooling in a climate where summer temperatures hit 120 degrees Fahrenheit and even the bus shelters are air-conditioned. The Burj beats the heat with double-paned glass walls that combine a low-E outer layer with a reflective inner layer. Besides, by promoting urban density, the skyscraper has attributes of conceptual green rather than literal green.

Located a few miles inland from the azure waters of the Persian Gulf, the tower is the undisputed centerpiece of a 500-acre, master-planned city-within-a-city that has improbably risen on what was desert just six years ago. Its nearly occupied 160 floors house a chic Armani hotel, floor upon floor of sold-out but mostly unoccupied condominiums, an already-popular observatory, and still-under-construction boutique offices. Huddled around the tower, like Lilliputians to its Gulliver, are various residential and hotel towers, the sprawling Dubai Mall, and a new "old town" of traditional, Islamic-themed town houses and hotels. While the juxtaposition of heights may seem bizarre, Emaar shrewdly calculated that the presence of the world's tallest building would give the area cachet and allow the company to charge higher prices for units with prized "Burj views." Such a strategy paid off – at least until Dubai's real estate market collapsed in 2009.

Taking note of the Burj's superskinny, supertall silhouette, many critics have wrongly averred that the tower was inspired by Frank Lloyd Wright's unbuilt Mile-High Illinois scheme of 1956. In fact, as Smith and SOM have made clear, the actual forerunners were the suavely curved, three-pronged Lake Point Tower in Chicago of 1968, designed by Schipporeit & Heinrich, which has shallow floor plates to keep residents close to prized views; and another three-lobed, residential high-rise, SOM's Tower Palace III in Seoul, South Korea, completed in 2004. Such was the formal genesis of the Y-shaped Burj, whose organic forms subtly echo in plan the onion domes and pointed arches prevalent in Islamic architecture. In tandem, SOM's chief structural engineer, William Baker, designed a wind-resistant "buttressed core" of concrete that, at the 156th floor, gives way to an internal steel structure that carries the mostly unoccupied spire to the summit (see page 89).

This innovative structural solution allows the Burj to be remarkably tall and remarkably thin, with one-third less square footage than the steel-framed Willis (originally Sears) Tower even though it almost doubles Willis's height. As at Willis, floor plates simply drop off as the tower sets back, letting columns run continuously and avoiding costly structural transfers. Yet in lieu of Willis's boxy Miesian geometry, the setbacks whir upward in a dynamic, counterclockwise spiral. By sheathing the faceted, sculptural mass in a luminous,

1. **The residential entry pavilion contains a large sculpture by Jaume Plense, titled *World Voices*, comprising 196 cymbals and representing the number of countries in the world. The structure of bronze-and-brass alloy, plated with gold, rises from a pond that echoes the leaf-shaped form of the pavilion.**

2. **The upper level of the entrance pavilion for the corporate suites has a sculptural ceiling of English sycamore to give it an organic lift.**

3. **The escalator leads to a lower-level entrance for the offices that connects to parking for cars. Glass is held in a suspended cable-net structure.**

4. **In the upper floors for the corporate suites, walls are lined with dark Wenge wood.**

light-catching skin, accentuated with fin-shaped stainless-steel mullions, Smith creates a dazzling skyline object that mounts rhythmically to a thrilling climax. This skyscraper looks like a skyscraper, its elegant, exultant verticality providing Dubai's random clumps of high-rises with an unmistakable center of the tent.

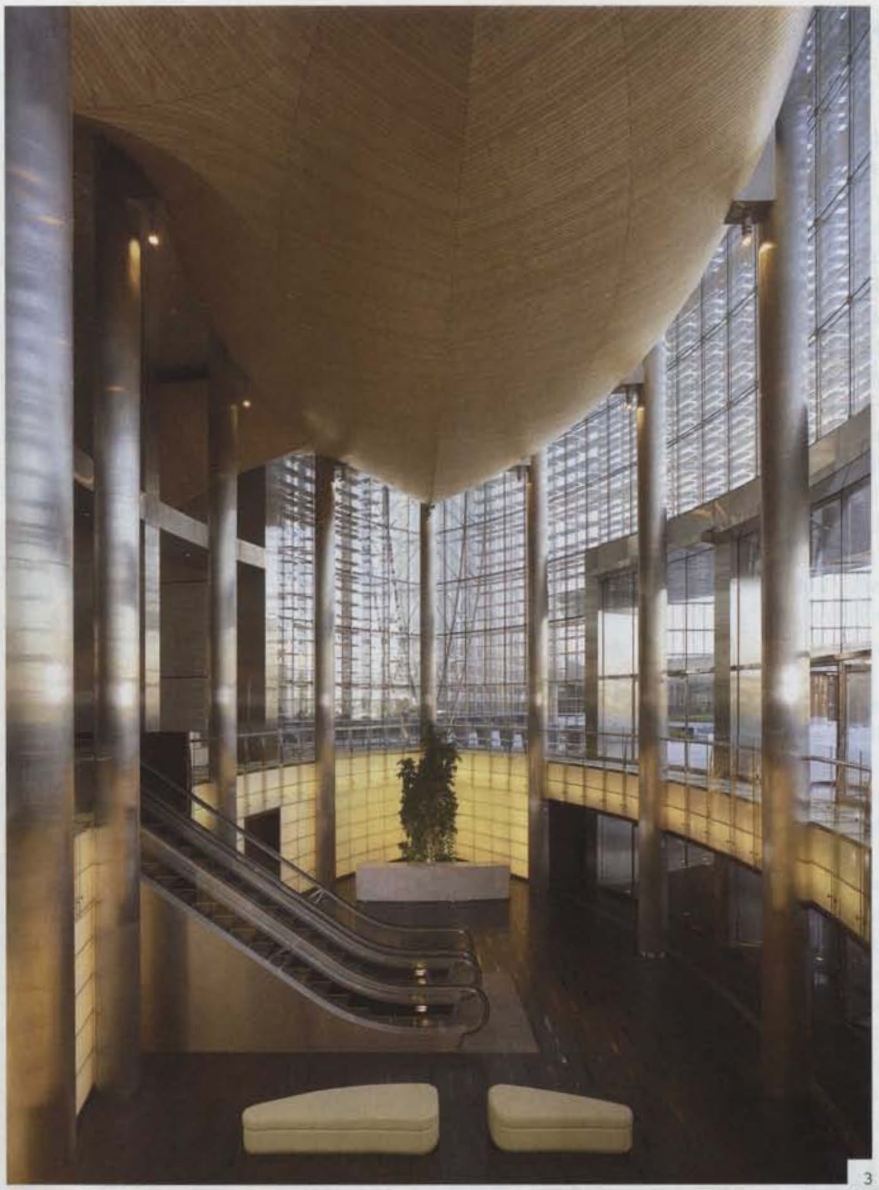
The tower's extraordinary height, Smith insists, was not his – or his client's – aim, but an outgrowth of his desire to prevent the tower from appearing stubby, as it did in earlier, shorter schemes. "I just wanted the proportions to be right," said Smith, who left SOM in 2006 to start his own firm, Adrian Smith + Gordon Gill Architecture. "That was the singular motivation for reaching to that height – not a number."

The tower is equally persuasive at ground level, achieving Smith's aim that it approximate the effect of a vertical stalagmite that grows naturally out of the earth. Footlike extensions of its Y-shaped floors step down nimbly to the surrounding plaza. Lacking an immediate context, Smith built one in the form of wedge-shaped low-rise annexes (an office building and a health club) that belly up to the Burj and shape relatively intimate spaces around it. Pedestrians approaching the tower encounter lozenge-shaped entrance pavilions outfitted with precisely detailed, cable-supported double walls. The pavilions have the added benefit of deflecting downdrafts that could knock visitors off their feet.

Upstairs, the benefits of the tower's structural parti are readily apparent. By dispensing with closely spaced perimeter columns and deep floor plates, the buttressed core opens the interior to million-dollar

PHOTOGRAPHY: © NICK MERRICH/HEDRICH BLESSING (THIS SPREAD)

2



3

views of the Gulf, Dubai's skyline, and the surrounding desert. While the "At the Top" observatory on the 124th floor is not truly at the tower's top, as its name implies, it is still a splendid lookout point. From bottom to top, SOM's interiors team wisely employed soothing, understated finishes, creating oases of calm that sharply contrast with Dubai's visual cacophony.

For all the design skill, the question looms: Is the skyscraper nothing more than beautiful folly? Undeterred by the Burj's empty spaces, Emaar reports that the tower's Armani Hotel is recording "strong occupancy levels," that the observatory is on target to attract 1.2 million visitors in its first 12 months of operation, that owners are starting to occupy the condos, and that the transfer of offices to owners will begin this summer. Nonetheless, due to Dubai's sharp decline in real estate prices, some Burj condo owners are renting out apartments rather than flipping them.

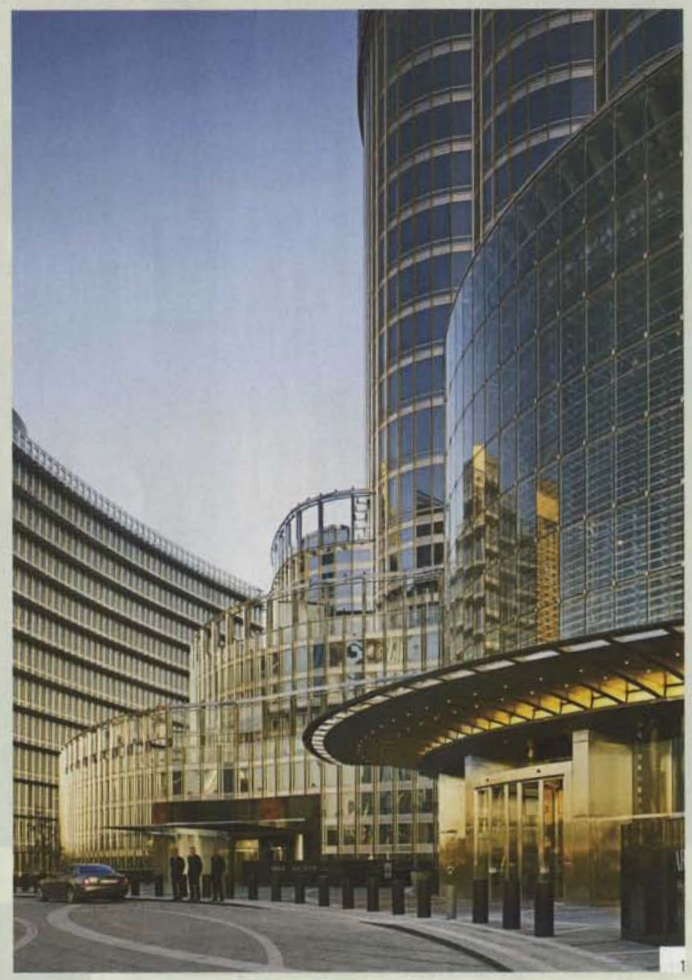
For his part, Smith argues that the Burj is not the last blast of the age of spectacle, but a harbinger of the future, as developing countries follow its prototype of the mega-scale, master-planned community anchored by an iconic tower. With Saudi Arabia contemplating a kilometer-high skyscraper, and other developing countries getting set to join the supertall race, time may well prove him right – just as it did the backers of the Depression-era giant that eventually became synonymous with the exuberance of New York City and the resilience of America. ■

4

Armani Hotel Dubai: A World Within a World

BY SUZANNE STEPHENS

As one more sign of the decline of the West and its dominance in things ultra-chic, Milanese fashion designer Giorgio Armani chose the Burj Khalifa tower in Dubai for the setting of his touted debut in the hotel business. New York and Milan just have to wait—albeit they are on the list for forthcoming Armani hotels. Armani could not have chosen a more dramatic venue than this desert city on the Persian Gulf for displaying his "minimalist opulence," as the Armani literature puts it. For one thing, there is the deep contrast between his and other luxe-level Dubaian caravansaries. These hotels seriously strive for over-the-top-dom marked by panoply and panache. You can get an ocular migraine visiting the self-proclaimed "seven star" Burj Al-Arab Hotel (designed by Tom Wright of WS Atkins in 1999), where 22-karat-gold leaf is the default interior finish.



1

In relation to the gimme-gilt syndrome, the cerebrally elegant Armani Hotel Dubai, a joint project with Emaar Properties, the Burj's developer, appears amazingly discreet.

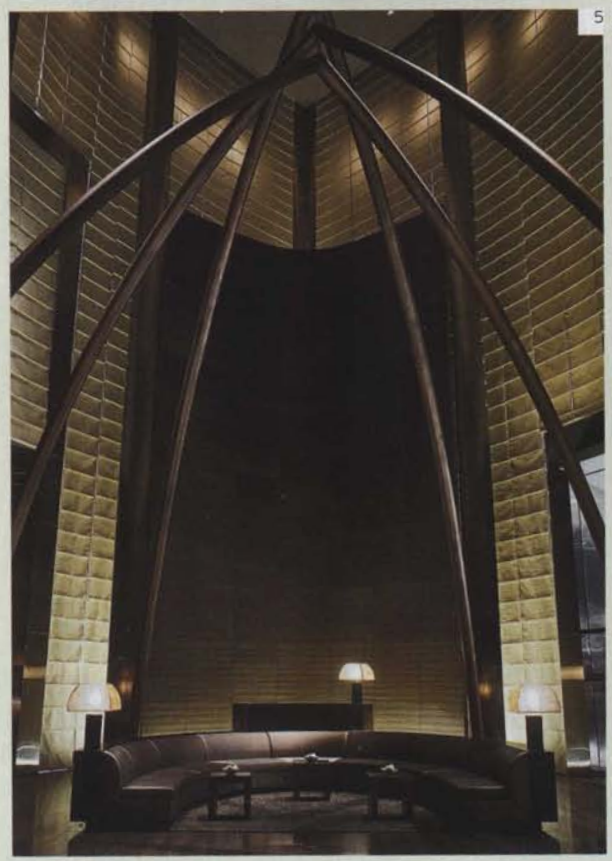
Stepping into the hotel through one of the three glass pavilions nestled between the lobes of the tower, the visitor enters a cool, shadowy lobby dominated by a tubular arch construction, rather like an abstracted version of a spider sculpture by Louise Bourgeois. The hotel's materials contrast textures—such as Eramosa limestone floors with the sheen of fabric wall coverings. Its color scheme is Full Armani Jacket, veering confidently from beige to tan to gray to charcoal. The public spaces and 160 guest rooms and suites are located mostly on the first eight floors of the tower, plus floors 38 and 39, with 144 Armani-designed short-stay apartments on floors 9 through 16. Elsewhere in the Burj, residences designed by Skidmore, Owings & Merrill (SOM)—for Armani—fill out floors 19 to 39, with more SOM-designed condos on 43 to 72, and luxury ones on floors 76 to 108— not to mention the offices on floors 112 to 154. In addition, Adam Tihany is designing a restaurant appropriately named Atmosphere on the 122nd floor, slated to open at the end of the year.

The halls of the Armani Hotel's guest-room floors, paneled in zebrawood and trimmed with LED cove lighting at the base and fluorescent lighting at the ceiling, impart the sleek look of a sci-fi catwalk to a calmer world. They lead to somnolently lush guest rooms where Armani partitioned spaces with serpentine walls to echo the curves of the tower's exterior. Since most of the furnishings and fabrics belong to the designer's home furnishings line, Armani Casa, the *gesamtkunstwerk* idea never stops. The rooms' plush look is calming and soothing. For a bit of oomph, many rooms overlook the Dubai Fountain's Busby-Berkeley-goes-to-Arabia floor show designed by WET in the lake next to the Dubai Mall.

Restaurants, cafés, and lounges in the hotel religiously adhere to the Armani aesthetic, along with boutiques, a nightclub, and a spa. The Italian-oriented Ristorante most serenely imparts the soigné Armani imprimatur, where tan, curvilinear banquettes and floor lamps arcing over circular tables echo the tower's formal thematic. The Japanese restaurant, Hashi, presents a coolly casual look (with disco music thumping in the background), but Peck, a gourmet deli with Milanese-Viennese early Modern overtones, might appeal more to architects: It looks as if Adolf Loos were hovering over the hand of the designer. An Indian restaurant, Amal, on the other hand, comes out looking anorexic, owing to the bleak lighting and attenuated scale of the fittings (more arches!). Oddly, this seems to be the only place where touches of color made it through the door, but that alone simply doesn't provide the heat. Fortunately, these drawbacks can be fixed.

Although Giorgio Armani meticulously supervised the entire design of the hotel, down to the room controls and the soap, he was backed up by Wilson Associates, the interior design firm headquartered in Dallas. Because of its past experience in designing hotels and resorts, including the Ritz-Carlton, Four Seasons, Kempinksi, Disney, and Emaar Properties, it stands to reason that Wilson's advice would be useful. But make no mistake about the person at the controls: as Bernard Himel, managing director of Wilson Associates says, "Giorgio Armani had the vision and intense attention to detail—he was personally involved in almost every decision." Not surprisingly, you sense that when you go there. It will be interesting to watch how the company, Armani Hotels & Resorts, formed in 2005 with Emaar Properties, retains this aesthetic for the series of hotels it is planning in the years to come. ■

FOR CREDIT AND SOURCE INFORMATION, PLEASE SEE PAGE 124.



1. The entrance to the Armani Hotel Dubai is located between two lobe-like wings of the Burj Khalifa.

2. A Milanese ambience overlaid with Viennese overtones characterizes Peck, a gourmet deli in the Armani Hotel.

3. The hotel's Ristorante, offering Italian cuisine, effectively employs soft lighting, monochromatic colors, and circular forms that echo the formal motifs of the Burj Khalifa itself.

4. The lobby's height is dramatized by a tubular arch construction that echoes in elevation the sinuous lines of the Burj's three-lobed plan.

5. In the hotel's hallways, lighting strips (LED at the base, fluorescent at the top) and zebrawood paneling provide an eerily svelte path to the guest rooms.

PHOTOGRAPHY: © ANDREA FERRARI (THIS PAGE)

Beyond Limits

The Burj Khalifa's designers tackle extreme height and extreme climate to create a landmark for the 21st century.

By Josephine Minutillo

SKEPTICS QUESTION THE LOGIC behind building a supertall skyscraper in the middle of the desert. Others are less interested in why the Burj Khalifa exists than how it was built. The secrets to its construction might surprise you. While the Dubai landmark dwarfs its closest rival in the competition for world's tallest building by more than 1,000 feet, it doesn't flaunt its architectural muscle. Rather, its design is as straightforward and logical as it gets.

At the heart of that logic is the building's triaxial geometry. "The Y-shaped plan is ideal for a residential building because it gives plenty of surface area per unit, and structurally, it is much better than a cruciform or linear tower," explains Adrian Smith, FAIA, former design partner at Skidmore, Owings & Merrill (SOM) in charge of the project through the completion of construction documents. And though SOM's competition-winning design for the Burj far exceeded the approximately 550-meter (1,800 foot) height called for in the brief to make it the world's tallest, the scheme – originally at about 700 meters, or 2,300 feet – was selected based on its appearance and construction feasibility, according to Smith.

The center of the structural-concrete tower features a hexagonal core that surrounds the elevators. Since the core is not big enough to rise to such extreme heights on its own, it is buttressed by the three wings. While the core functions as an axle to keep the building from twisting, 2-foot-thick corridor walls on either side of each wing act like the web of an I-beam; cross walls like the flanges. Round columns are located at the pointed end of each wing between ordinary flat plate slabs. The result is a tower that is extremely stiff laterally and torsionally.

"These are very conventional systems, just arranged in a unique manner," says William Baker, structural engineer partner at SOM. The driving force behind the structural design was wind. "Tall building design is dominated by wind forces, even in most seismic areas where earthquakes are a major concern," Baker says. Since wind velocities increase with height, it was an even greater concern here. Consulting engineers Rowan Williams Davies and Irwin (RWDI) carried out extensive wind-tunnel testing over the course of two years in its renowned facilities in Ontario, Canada. First, balsa wood models of the slender tower were subjected to force balance tests. Later, more sophisticated aeroelastic tests were conducted. RWDI studied the building's six important wind directions – the pointed end, or nose, of each of the three wings, and the areas between two wings, called tails.

The Burj Khalifa's organic form has a triaxial geometry. The Y-shaped building's three wings are connected to a central core. As the tower rises, one wing at each tier sets back in a spiraling pattern.

Continuing Education

Use the following learning objectives to focus your study while reading "Burj Khalifa, Dubai" (page 78) and this month's ARCHITECTURAL RECORD/AIA Continuing Education article "Beyond Limits." To earn one AIA learning unit, including one hour of health, safety, and welfare (HSW) credit, turn to page 94 and follow the instructions.

Learning Objectives

1. Identify the various challenges involved in designing a supertall structure.
2. Describe the structural system utilized in the design of the Burj Khalifa.
3. Discuss the various m/e/p and life-safety systems used in the Burj Khalifa.
4. Discuss how the Burj Khalifa differs from other supertall structures.

The most significant change to come from RWDI's analysis did not significantly affect the building's design but rather its orientation. Since analysis indicated less excitation in wind patterns blowing at the nose, the tower was rotated 120 degrees from its original position so that the noses faced into the wind. RWDI also suggested that the Burj's different tiers be made more regular. "Initially, the building spiraled much more dramatically," says Smith. "But each time it steps back, it changes how the wind reacts. To keep the wind from organizing into vortices, we evened out the setbacks."

While changes to the design were being made, so too were changes to the building's use. Originally meant to be all residential, the client, Dubai-based Emaar Properties, added offices to the program. Corporate suites were located at the top of the tower, which, with floor areas as low as 5,000 square feet, is more ideally suited for apartments, the original intent for those floors.

But the program was not the only element to be in flux. The tower's final height remained a question mark until rather late in the game. It wasn't until after the foundation was in place and construction of the superstructure began that the magic number – 828 meters, or 2,717 feet – was finally determined. "I hated the proportions of the shorter tower and kept pushing for it to be taller," recalls Smith. The economy was on Smith's side at that point, and the client agreed it looked better taller.

The tower's strategic design allowed flexibility in terms of changes in program and height. The addition of offices required an extra set of elevators, which were accommodated in one of the wings. The other two wings would then house elevators for the apartments and hotel, respectively. Issues of proportion and scale were paramount in the Burj Khalifa's design. Unlike the Willis (formerly Sears) Tower, which scales by the cube, the Burj scales by the square. So whereas doubling the height of the Willis Tower would increase its area eightfold, doubling the height of the Burj only increases its area fourfold; its wings would get longer but not wider.

Nevertheless, most of the extra height was in the spire, which Baker calls "a nest of steel triangles that sits on the hexagonal walls." At the opposite end, at the very bottom of the building, a 12-foot-thick concrete mat, or raft, foundation rests on the surface of a calcisiltite rock mass. It was constructed in four separate pours – one for each of the three wings and the center core. Then, 194 5-foot-diameter piles were driven 140 feet below the mat. Most of the piles are located toward the edge of the mat, with very few at the center. "It's all about decreasing wind forces and managing gravity," says Baker. "By the time you get to the bottom, everything is in compression, so you don't need much reinforcing. The reinforcing there is similar to what you'd see in an average 20-story building. We're very proud of that."

None of this would have been possible without recent material advancements. "We discovered this new material called concrete," Baker jokes. "It is so different from the stuff we used to call concrete." While in the past, slump tests were used to measure how hard and consistent a sample of concrete was, the chemicals in the ultra-high-performance concrete used for the Burj make it so flowable that it forms a puddle. (Silica fume and fly ash are its main ingredients.) The quality control comes in measuring the diameter of the puddle.

Regardless of the concrete's 100 MPa (14,500 psi) strength, all concrete changes dimension over time. Fifteen separate three-dimensional finite-element analysis models predicted the effects of creep, shrinkage, and foundation settlement. "We made precise calculations with data that is very rough," says Baker. "It's all going to shrink. The problem comes when one part moves differently from another."

The key to minimizing that kind of differential movement was to use the same concrete in every vertical element, and to ensure that columns and walls had similar volume-to-surface ratios so that they dried at the same rate. There are virtually no transfers within the concrete structure. Designers adhered to a strict 9-meter (29.5 foot) module. Where a wing sets back and the columns at its nose drop off, the next set of columns appears directly over the walls beneath it.

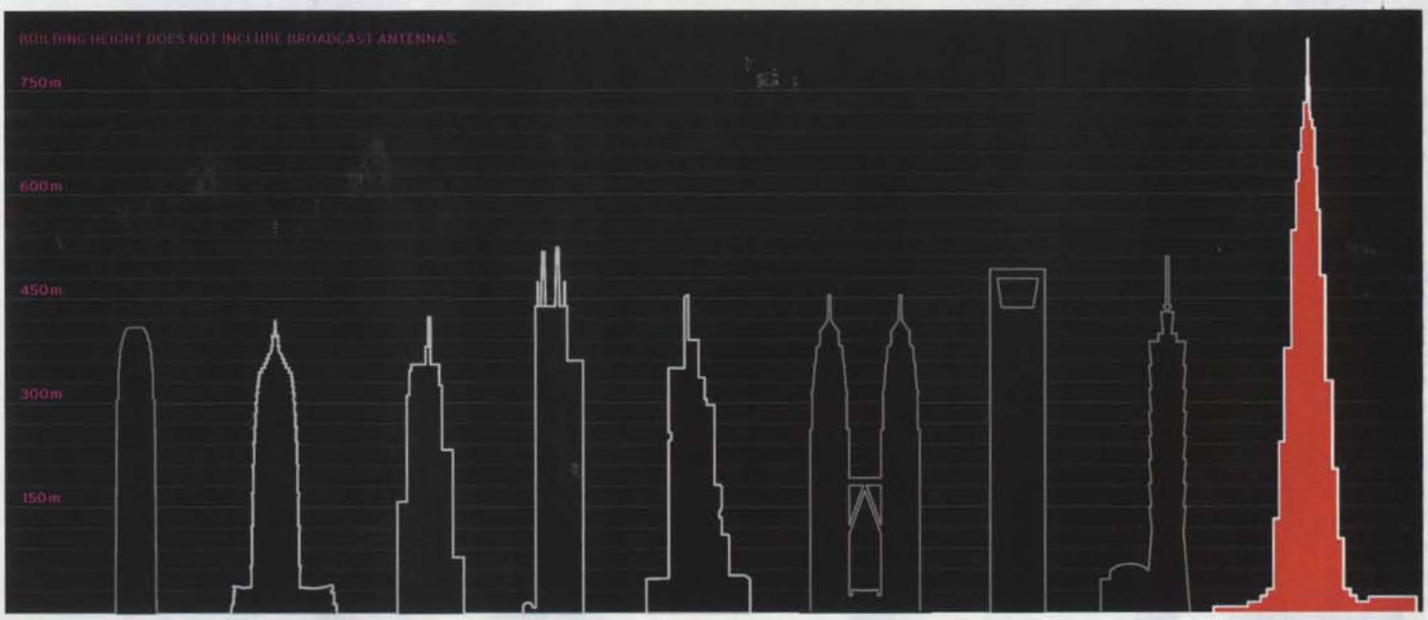
"You verify as much as possible through computer programs and calculations, but it's not an easy thing," Baker admits. "In the end, you walk the building and look for cracks." So far, the building has settled about 2 inches.

Samsung Corporation was responsible for making the design a reality. The Seoul-based contractor used an automated self-climbing formwork system to build the concrete structure. Specially developed pumps brought the concrete to heights of 600 meters (1,970 feet). The structural steel spire was constructed from inside the building and jacked to its full height of over 200 meters, or approximately 700 feet, using a hydraulic pump.

Seven two- to three-story-high mechanical floors are distributed throughout the building, about every 30 floors or so. "It's really a series of 30-story buildings stacked on top of one another," Baker says. "There would be too much pressure in the pipes, and ducts would get too big, if you try to move things too far."

The mechanical floors house various equipment, including water tanks and pumps, air-handling units, and electrical substations. Track-mounted building-maintenance units, used for window washing, are stored in garages within the structure. "We were very aware of the sand

Structural concrete gives way to steel at the tower's top section, where a structural-steel spire utilizes a diagonally braced lateral system.



TWO INTERNATIONAL FINANCE CENTER	JIN MAO BUILDING	TRUMP INTERNATIONAL HOTEL AND TOWER	WILLIS TOWER (FORMERLY SEARS TOWER)	NANJING GREENLAND FINANCIAL CENTER	PETRONAS TOWER 1 & 2	SHANGHAI WORLD FINANCIAL CENTER	TAIPEI 101	BURJ KHALIFA
HONG KONG	SHANGHAI	CHICAGO	CHICAGO	NANJING	KUALA LUMPUR	SHANGHAI	TAIPEI	DUBAI
2003	1999	2009	1974	2010	1998	2008	2004	2010
412 m	421 m	423 m	442 m	450 m	452 m	492 m	508 m	828 m
1,352 ft	1,381 ft	1,387 ft	1,450 ft	1,476 ft	1,483 ft	1,614 ft	1,667 ft	2,717 ft

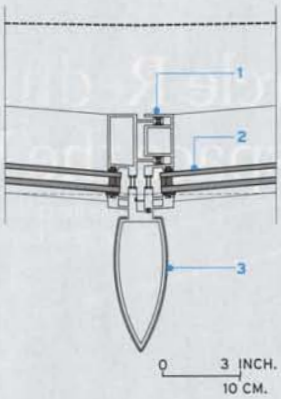
problem," Smith says. "The consistency of the sand in Dubai is more like talcum powder. It sticks to everything." The building was kept as flush as possible, and ledges were kept to a minimum to reduce the number of areas where sand could settle. Window washing is expected to take place every few months.

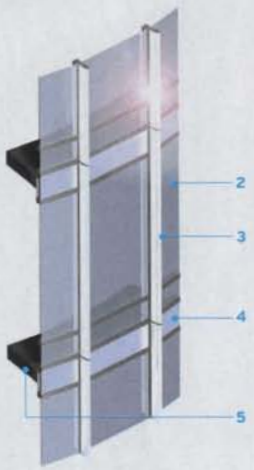
Over 26,000 low-E, antiglare glass panels were used in the exterior cladding of Burj Khalifa, which features more than 1.8 million square feet of glass. Eight-inch-long wing-shaped, stainless-steel mullions occur at every glass joint. "We originally designed the exterior wall with steel tubes, but it looked too industrial," recalls Smith. "The sheen of the vertical stainless steel, especially in the horizontal sun of morning and evening, makes the building sing."

While the building's structure and its exterior, including the cladding, were designed to resist a variety of forces, forces of a different kind needed to be addressed inside the tower. According to SOM's Luke Leung, "There is a tremendous amount of pressure in a building of this height, both on the water side and on the air side."

The typical system pressure for water is 300 psi. The Burj has one of the highest water pressures in the world at up to 460 psi. "Imagine a water pipe that is 800 meters tall," says Leung. "You don't want to be standing under that."

Pressure breaks are typically added in high-rise





CURTAIN-WALL DETAIL

CURTAIN-WALL DETAIL

1 ALUMINUM VERTICAL MULLION
2 CLEAR REFLECTIVE INSULATING VISION GLASS
3 STAINLESS-STEEL VERTICAL FIN
4 HORIZONTAL SPANDREL PANEL
5 CONCRETE SLAB

The tower used over 430,000 cubic yards of concrete and 43,000 tons of steel rebar. To help determine the concrete-to-rebar ratio, three-dimensional finite-element analysis models were used to predict the effects of creep and shrinkage.

buildings to alleviate the forces. In the Burj, SOM created some of the highest pressure breaks ever in a building, consisting mainly of heat exchangers to isolate one riser from another. The tower's water system supplies an average of 250,000 gallons of water daily.

Cooling the water presented another challenge for SOM's engineers. "When we first started coming to Dubai, we noticed that the hot water in our hotels was very hot, and that the cold water was also very hot," says Leung. "Imagine getting hot water out of the cold faucet at the Armani Hotel!"

Since Dubai has limited fresh water and relies on the sea, the water had to travel through the very hot ground during the salt evaporation process. Instead of following that scenario, SOM took advantage of the area's high humidity and the large amount of condensation that results. "The moisture is so high that if you collect condensate in the air during a cooling period, you get a significant amount of water in the 55–65 degree Fahrenheit range," explains Leung. This water is collected and drained in a separate piping system to a holding tank. The system provides about 15 million gallons of supplemental water per year. A sitewide graywater collection system collects water for use in landscape irrigation.

The effects of air pressure are more noticeable to the average visitor to the Burj. There is an enormous amount of air movement going through the building. Due to Dubai's high temperatures, reaching 115 degrees Fahrenheit and higher in the summers, the stack effect is reversed. Instead of hot air rising, it is sucked in from the top of the building and directed downward because the inside of the building is cooler than the outside.

Stack effect is a function of both the building's height and the temperature difference between the inside and the outside. Both are extreme in this case. When you enter the building in the heat of summer, the air will feel like it is trying to push you out. "In Chicago, for instance, it is 75 degrees inside and as high as 95 degrees outside on a summer day," Leung explains. "In Dubai, the temperature difference in summer can be more than 40 degrees Fahrenheit."

What is not so apparent from the building's height is the amount of power it consumes. As electricity travels through the building, which in essence is a stack of five 30-story buildings, it loses voltage similar to the way water loses pressure flowing through a small pipe. To supply these massive loads efficiently, the Burj's electrical mains are supplied with 11 kV, 23 times higher than the 480V typically used in the U.S. Transformers located at each of the mechanical levels reduce the voltage to intermediate levels for heavy equipment and to 220V, the normal voltage used in the U.A.E., for office equipment and appliances.

Fire- and life-safety issues are a vital concern in high-rise buildings, particularly one of unprecedented height such as this. The Burj contains 57 elevators, some of the fastest in the world, serving different building zones, though no one elevator travels more than 500 meters (1,640 feet). According to Baker, the longest elevator ride takes under two minutes – with the express elevator to the observation deck on level 124 taking much less time. Baker also admits to walking down the full height of the building (at a leisurely pace) in about 45 minutes. A typical floor contains three sets of concrete-encased fire stairs, one in each wing.

In case of fire emergency, the building deploys a "defend in place" strategy. Fire-rated, air-conditioned refuge areas accommodate building occupants until further instruction. Some elevators are equipped with cameras so that elevator shafts can be inspected remotely.

Despite the challenges involved in designing the Burj Khalifa, and the criticisms leveled against it in the wake of Dubai's subsequent financial meltdown, Adrian Smith staunchly defends it. "The Burj was an important piece for Dubai at the time it was built," says Smith. "Dubai wanted to be recognized as an international player on par with other major world cities, and it needed an international landmark to do that." ■

Shedding Light on the World's Tallest Building

Three firms illuminate the Burj Khalifa with alternating restraint and spectacle.

By Linda C. Lentz

FROM A DISTANCE, the half-mile-high Burj Khalifa in Dubai tapers to a near imperceptible spire like a mirage along the windswept desert coast of the Persian Gulf. Up close, within its urban context, visitors and residents are treated to a densely landscaped setting of terraced drives, esplanades, restaurants, retail outlets, pools, and fountains.

In terms of illumination, it was an interesting challenge, says Paul Marantz, design principal at Fisher Marantz Stone (FMS), the firm responsible for lighting the bulk of the tower, as well as the circular Tower Park around it. "You're either looking up or straight ahead," he says. "So the question we had was, What do you do with a building that is so tall it dwarfs everything else?"

At first Marantz and his associates considered floodlighting the facade. They soon realized that if they did, the tall, lithe skyscraper would almost always be shrouded in a light-polluting nimbus. Unlike the typically crystal clear atmosphere that imparts definition to the cityscape of Las Vegas, the humid air of Dubai is often filtered with blowing sand – a condition that continually alters the building's appearance. So the lighting designers reverted to a "close-in" scheme similar to that of the Jin Mao Tower in Shanghai, an earlier FMS collaboration with Adrian Smith and SOM.

Here they took advantage of the Burj's spiraling lobes to layer the structure with a series of small fixtures that wash its surface in a soft, luminous glow.

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2

1. Fisher Marantz Stone transformed each lozenge-shaped entrance pavilion into a super-size luminaire, illuminating the lobby and adjacent outdoor area with a row of uplights installed in the base of the double-glazed walls and a canopy fitted with metal-halide MR16 downlights and a horizontal, louvered fluorescent light box at the back.

2. The water-feature specialists at WET eclipsed their famed Fountains of the Bellagio in Las Vegas with the even larger Dubai Fountain, which is lit by several thousand 3100K incandescent lamps enhanced by 25 video projectors set to stream color or abstract painterly effects into the water jetting from this giant feature's five rings.

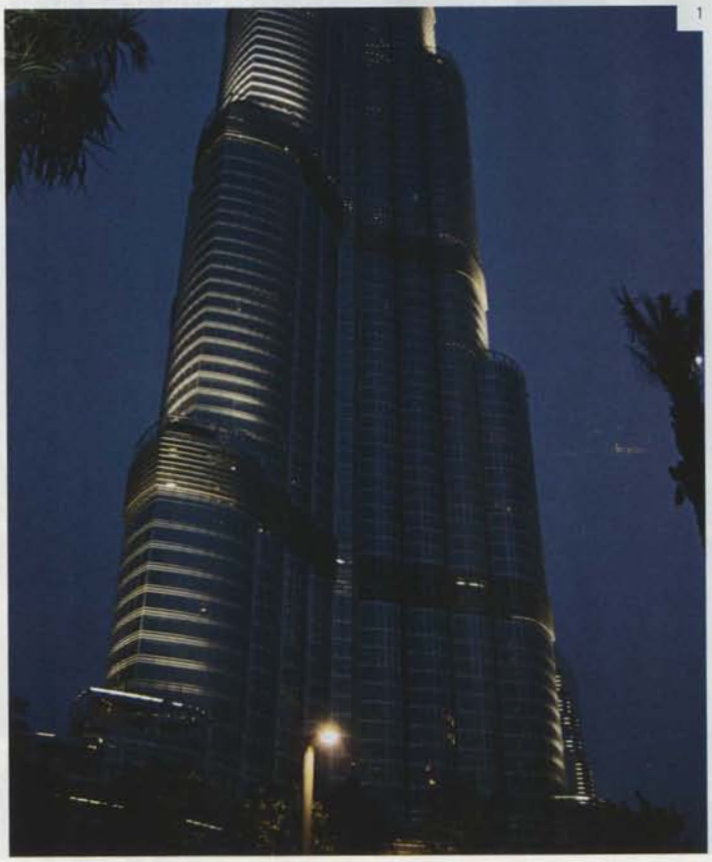
3. Washed by the glow of metal-halide uplights installed on the building's curtain wall and setback terraces, the Burj Khalifa soars above the gently lit paths and landscape of Tower Park and the festive Dubai Fountain set within the man-made lake of the 30-acre Burj Park.

PHOTOGRAPHY: © HEDRICH BLESSING/NICK MERRICK (1,3); COURTESY WET (2)

The custom fixtures include tightly sealed metal-halide uplights bracketed to the curtain wall at the ceiling line of the first two levels and installed around the top of the 10-foot-high glass windscreens at the edge of the setback terraces above; halogen downlights affixed to residential balcony sunscreens; and 400-watt metal-halide floodlights on the parapets beneath the needlelike pinnacle. All fixtures are carefully angled and shielded to enhance the building's texture and form without imposing on the occupants or impeding their views.

Carrying this illuminating parti to terra firma, the FMS design team installed evenly spaced arrays of uplights along the floors between the double glazing of the three entrance pavilions, filling the interiors of the jewel-like lobbies with a bright ambient light that filters through to the outer drop-off areas. A fluorescent glass light box extends this light-wall effect around the lower parking level of the office atrium (where most occupants enter), doubling as a radiant path to and from the plaza. To avoid interfering with the view of the Burj outside, Marantz kept everything in the landscape as close to the ground as possible, using low-level bollards, circular necklaces of in-ground lamps along the roundabouts, and unobtrusive streetlights. Low light levels and warm color temperatures are never harsh or overwhelming.

Of course, festivals and the need to entertain tourists warrant sensation. For this, Emaar Properties tapped two special-effects icons. California-based WET illuminated its dazzling Dubai Fountain with a system that follows the movement of the aquatic displays, while 25 video projectors (in rooms beneath five rings of water jets) are programmed to stream color or painterly abstractions into the bursts. For the Celebration Lighting system, U.K.-based lighting designers Speirs and Major Associates (SaMA) devised a show that morphs the tower into a flashing beacon, with 868 high-power stroboscopes and six searchlights integrated into the facade and palms. A radical juxtaposition to the understated FMS plan, the flamboyant SaMA spectacle, which debuted opening day, is perhaps a fitting tribute to a building and city that demand our attention, yet want to be taken seriously. ■



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1. **The Burj Khalifa is a largely residential building with hotel suites and several offices, so Fisher Marantz Stone devised a solution that avoids light intrusion into the interior and preserves night views for its occupants.**

2. **An easy-to-service, walk-in fluorescent light box greets visitors as they enter and exit the office-tower pavilion from the lower-level parking garage. The light box doubles as an underlit walkway at the main doorway out to Tower Park.**

CREDITS

PROJECT: Burj Khalifa, Dubai
ARCHITECT: Skidmore, Owings & Merrill – Adrian Smith, former design principal.
LIGHTING DESIGN: Fisher Marantz Stone (facade, interior, landscape) – Paul Marantz, design principal; Hank Forrest, Marcel Dion, Rob Schoenbohm, design team; Speirs and Major Associates (Celebration Lighting) – Jonathan Speirs, Keith Bradshaw, Gill Pyatt, Iain Ruxton, Sarah Wisher, design team; WET (The Dubai Fountain) – Jim Doyle, director of technology

SOURCES

EXTERIOR FIXTURES: B-K Lighting; ERCO, Cooper Lighting; Simes; WE-EF Lighting
LAMPS: Philips; Osram; GE LED
CONTROLS: Philips
CELEBRATION LIGHTING: High End (strobes); Fineline (searchlights); ETC, Oasis (control system)