

# THE HEIGHTS

ANATOMY OF A SKYSCRAPER

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## A NOTE TO READERS

*The downturn in the global economy that began in 2008 did little to dent the world's appetite for tall buildings. In the two years it took to write this book, hundreds of new skyscrapers opened for business across the globe. And the race for the sky continues, with hundreds more targeted for completion in 2011 and 2012.*

*While many of these new skyscrapers and their older counterparts are remarkable, very few have found their way into the pages that follow. Rather than celebrate individual skyscrapers, the book focuses on the forces that shape the way tall buildings work. Particular skyscrapers are highlighted only to shed light on the concepts that underpin their form and operation.*

*Not surprisingly, a wealth of detail and technical data are required to explain how these remarkable structures work—and each of the ensuing chapters is comprised of both. While every effort has been made to ensure that this information is accurate at the time of publication, neither the publisher nor the author assumes responsibility for errors or for changes that occur after publication.*

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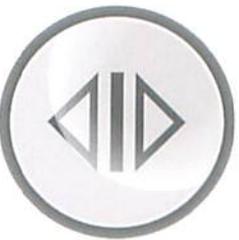
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# INTRODUCTION



**What is the chief characteristic of the tall office building? It is lofty. It must be tall. The force and power of altitude must be in it, the glory and pride of exaltation must be in it. It must be every inch a proud and soaring thing, rising in sheer exaltation that from bottom to top it is a unit without a single dissenting line.**

—Louis Sullivan, "The Tall Office Building Artistically Considered," *Lippincott's* magazine, 1896



hen it comes to buildings, size matters—more so today than ever before. Look up in the heart of any of the world’s major cities and your eyes will likely alight upon a towering, glass-walled structure—if not literally scraping the sky, then certainly pointing in that direction.

The proliferation of skyscrapers is accelerating rapidly. Prior to the year 2000, fewer than 250 buildings around the world reached higher than 600 feet (180 meters); between 2000 and 2009, that number more than doubled. And it continues to grow faster than ever before: at the beginning of 2010, almost 400 new skyscrapers were under construction around the world. Not only are there more tall buildings, but they are in more places. Once a purely American phenomenon, the construction of skyscrapers is now very much a global one. Of the 38 skyscrapers over 600 feet (180 meters) completed in 2009, 22 of them were in Asia and seven were in the Middle East. The “tallest” metropolis in the world is in Asia: the combined height of Hong Kong’s skyscrapers is roughly three times that of New York City’s.

So prolific are these towers today in the world’s metropolises, and so enthusiastic are their planners, that there are now adjectives that differentiate between them: “tall” is often used to describe skyscrapers between 500 and 1,000 feet (150 to 300 meters); anything above that is considered “supertall.” Even measuring the building is now a science: do you measure it from street level or from the basement? To the highest occupied floor or to the top of its crown?

Some readers may wonder why we should care how tall these towers are or how many of them exist. Are they not just the product of speculation and greed on the part of a handful of wealthy developers? Or the modern incarnation of some age-old form of civic pride? The answer is no—they are much more than that. Thanks to a variety of factors causing people to migrate from rural to urban areas, they are increasingly the way the world’s people live today—and almost certainly the way most of them will live in the future.

A United Nations study found that half of all humanity lived in urban areas in 2008—and that percentage is rising. By 2050, the study estimated a full 70 percent of the world’s population will be city residents. Just how our cities will be able to accommodate these people physically is thus an increasingly important question—not just to urban planners but also to architects, transportation engineers, and sociologists.

It is not simply the external configuration of our tall buildings that we should care about. Modern society spends an estimated 90 percent of its time inside, a far

cry from early civilizations whose livelihoods were tied closely to the outdoors. Today we work inside, we sleep inside, and typically we socialize inside as well. Whether we know it or not, the inside workings of our built environment affect our health and well-being—and shape almost every facet of our daily existence.

Modern skyscrapers are effectively small cities, providing infrastructure and services to thousands of inhabitants, often at enormous heights. They may be residents of apartments and hotel rooms, workers in corporate offices, or users of a more transient nature—shoppers, restaurant goers, or observation deck visitors. Regardless of their purpose aloft, these sky dwellers demand the same array of services they would require if they were closer to the ground: shelter, fresh air, clean water, plumbing, electricity, vertical transportation, and communication. Just how these services are provided thousands of feet up in the sky lies at the heart of this book.

The first section focuses on the building of skyscrapers, and on their component parts. Nowhere more than here, in the design and engineering that goes into these extraordinary structures, does a tall building differ in its needs from a smaller one. The interplay between architecture and engineering informs everything—from the building’s foundations to its structure to the skin that encloses it and to the way it is constructed.

The second section of the book looks at the services that must be brought into the skyscraper once its core and shell have been completed. Over the course of history, tall structures—such as pyramids, cathedrals, and bell towers—were generally uninhabited and thus needed little by way of supporting services. In contrast, today’s skyscrapers rely on a vast network of infrastructure to sustain life in the sky—from power, air, and water to telecommunications and elevators.

The third and final section of the book touches on the more mundane concerns needed to keep tall buildings functioning on a day-to-day basis: maintenance and cleaning, safety, and sustainable technologies. Less sexy perhaps than other topics, these functions touch more immediately and more intimately on the daily lives of skyscraper occupants than almost anything else.

Across all three of the sections the book draws on examples from around the world to illustrate concepts and ideas. Yet it is in no way an exhaustive study of the world’s tall buildings; indeed, many interesting and architecturally significant towers receive scarcely a mention on the pages that follow. Instead, the book is designed to leave the reader with an understanding of—and hopefully a greater appreciation for—the inner workings of this new and potentially highly sustainable urban form: the vertical city.

# HISTORY

**B**uilding tall, of course, is not unique to the present age. For all of recorded history, mankind's fascination with structures that rise toward the sky has been constant. The Egyptians devised an ingenious system of moving rock to unprecedented heights as they completed the Great Pyramid of Giza. Equally impressive were the great Gothic cathedrals of France and the medieval towers of Italy—symbols of religious or personal power meant to instill awe and respect. The connection between size and power was not lost on the new nation west of the Atlantic, whose

civic buildings were often as grand and as tall as its churches—and whose soaring state capitol buildings remain important symbols today.

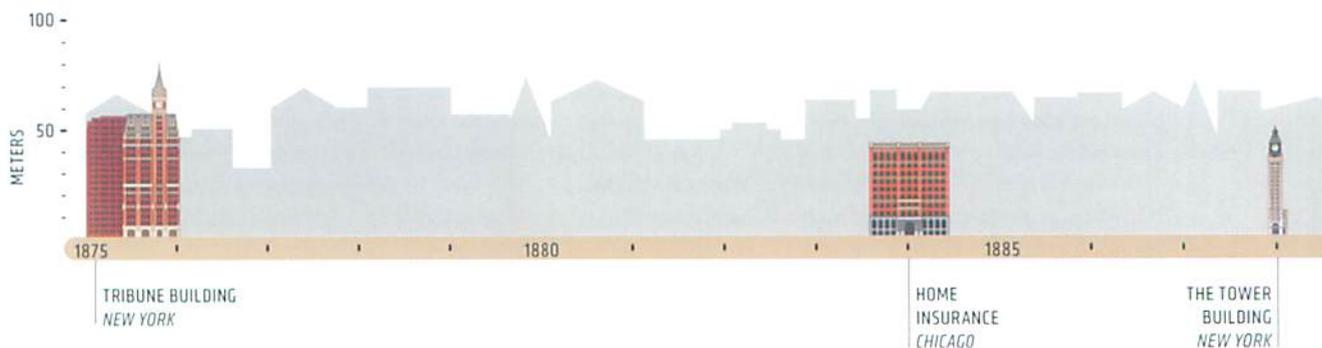
From this lineage, then, comes the skyscraper—a modern-day symbol of commercial power and civic pride. But today's skyscrapers distinguish themselves from everything tall that has come before in two important and related respects: they are built to make money and, to do that, must support people living or working inside of them. For the first time in history, the challenge is not just to construct a monumentally tall structure but also to make every inch of it work for human beings.

The modern skyscraper is very much a global phenomenon, but its origins are

almost entirely American. This is perhaps not surprising, given that its original purpose was to make money out of real estate. Its heritage is also an urban one, as skyscrapers only make sense as a commercial undertaking where the cost of land is high and rents can cover the costs of constructing and maintaining a building hundreds of feet up in the sky.

The history of skyscrapers is thus a story of urban America, and even more so of just two of its cities. Though historians disagree on the details, it is generally accepted that the form was invented in Chicago and New York in the late 1880s—and born not of lofty ambition but of more mundane, commercial necessity. Maturing American businesses

Gray skyline shows the average height of the tallest 10 buildings built each year.



(or at least their executives) wanted to be located downtown—where high land values ensured that new structures would need to reach as high as possible to cover their costs.

In Chicago, space was at a particular premium. Much of the downtown had been gutted by a devastating fire in 1871, leaving office space scarce. Despite the increased demand, buildings could grow no taller than a dozen or so stories: as they reached higher, the load-bearing masonry walls supporting them had to get thicker—rendering the lower floors of the building less and less usable. The structural requirements of supporting the gravity load of a building put a natural cap on its height.

A series of inventions would, of course, allow buildings to rise higher. Following close on the heels of the elevator, which appeared in the 1870s, the development of the internal steel skeleton permitted larger windows and more usable floor area. By running cast-iron columns within the supporting masonry walls, William Le Baron Jenney found that the thickness of the walls of his Home Insurance Building could shrink significantly—opening up more of the building for commercial use and enabling greater light penetration. The new metal frames provided more rentable area at the base of the building, and quickly proved cheaper to construct.

The initial skyscraper skeletons were made of cast iron, but framing technology would develop quickly. As Henry Bessemer perfected his technique for the mass

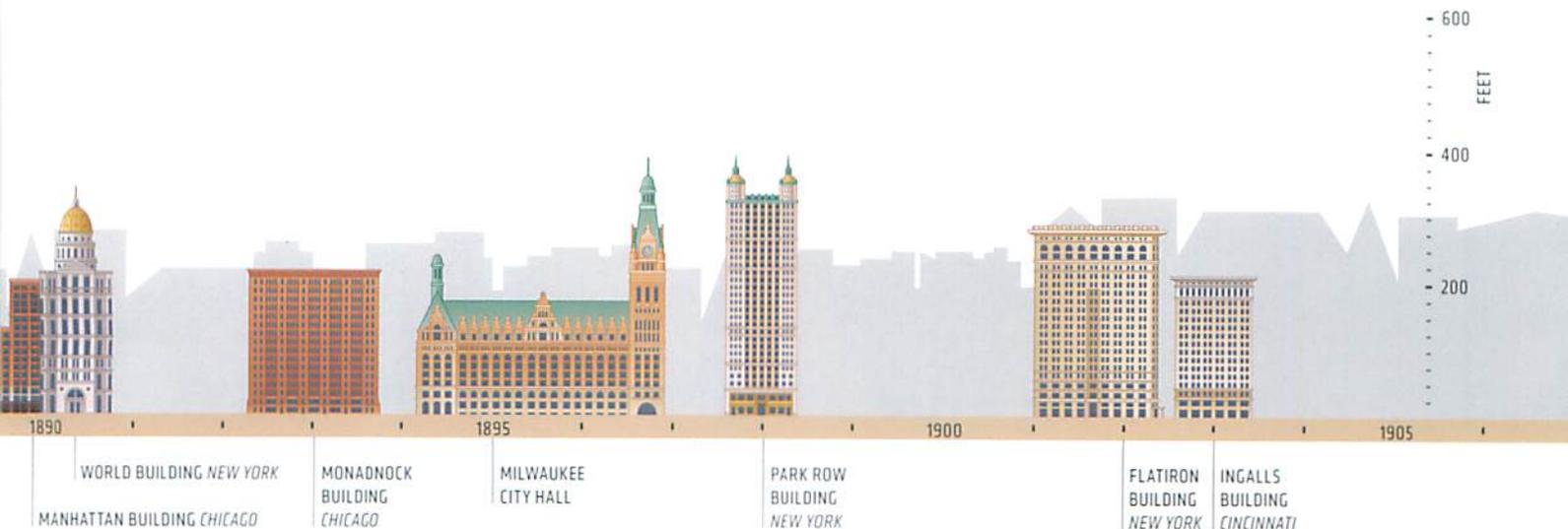
production of steel in the second half of the nineteenth century, the price of steel dropped dramatically—from \$167 per ton in 1867 to \$24 per ton in 1895. By the turn of the century, steel had replaced cast iron as the backbone of choice for new skyscrapers, and buildings of 15 to 20 stories had been completed in both New York and Chicago.

Advances in elevator technology played a large role in making these new skyscrapers habitable, with hydraulic power replacing steam in the 1870s and providing access to greater heights. Heating and cooling technology also advanced by leaps and bounds, thanks to the invention and expansion of steam heating systems, electrical plumbing pumps, and district central heating. Electricity gave skyscrapers a big boost as well; Thomas Edison's invention of the incandescent bulb made it possible for office workers to control light at their own workplace with almost no effort.

The inventions that gave rise to the skyscraper era went beyond just those providing human comfort. Steam power paved the way for the use of new and more powerful tools during the excavation and erection of buildings. Simultaneously, early experiments with telephones were under way—efforts that would ultimately transform communications between office dwellers and the outside world. In sum, the modern skyscraper was very much a product of the Industrial Revolution—and of a myriad of its most transformative inventions.

But while the Industrial Revolution was felt simultaneously across the Atlantic, in both Britain and on the continent, it never translated there into the development of tall buildings. Nothing in Europe would rise as tall as the buildings under construction in Chicago and New York. Nor would any other U.S. city come even close to competing with Chicago and New York in pushing the boundaries of commercial construction. The race for height—over an entire century in time—would be a tale of two cities.

Initially the emphasis was on improving the performance of the metal skeleton supporting the building's weight. The Tower Building in New York—completed four years after Chicago's Home Insurance Building—was the first building to rely exclusively on a steel skeleton for support, albeit one encased in masonry. The first tower to incorporate a wire-braced frame to withstand sway was begun in Chicago in 1888, sporting a rather confusing name: the Manhattan Building. Soon after, the idea of relying on a system of steel beam-based cages to support the building's weight made its debut in New York. Built by the engineer George Fuller, it was originally called the Fuller Building but—due to its irregular shape—quickly became known as the Flatiron Building.



## Cathedrals of Commerce

Developments in Chicago and New York influenced each other tremendously at the outset of the skyscraper era, particularly with respect to engineering and structure. But the engineering advances did not always translate into pioneering heights, particularly in Chicago, where municipal laws passed in 1893 limited the height of downtown buildings to 130 feet (40 meters), or roughly 10 stories. Chicago's height regulations resulted in the development of boxy towers with relatively large footprints, penetrated at their center by courtyards to provide light.

New York, with no height cap, would very quickly produce a different skyline. To maximize value on the smaller lots that had been defined in the Commissioners' Plan of 1811, developers built taller, more slender towers. By 1913, New York had roughly 1,000 buildings over the height limit in effect in Chicago; 50 of them were more than 20 stories. New York was competing against only itself in the race for height.

But, importantly, this race for height was geared to more than just maximizing real estate profits. The egos and pride of New York's business world drove the competition for height in the early years of the twentieth century. Big corporations banked heavily on the promotional value of signature real estate. The 612-foot (187 meters) Singer Building opened in 1908 on lower Broadway; one year later, the 700-foot (213 meters) Met Life Building, located on Madison Square Park, was completed. Each of these briefly held the title of world's tallest building.

Perhaps the most famous of these corporate undertakings was F. W. Woolworth's Woolworth Building, a towering 57-story affair that opened in 1913 on Broadway in lower Manhattan. Cass Gilbert's ornate design relied heavily on the Gothic cathedrals of Europe for inspiration; indeed, one onlooker referred to it as "the cathedral of commerce." Yet its ornate exterior belied perhaps the most advanced systems of any skyscraper to date, incorporating many of the technologies associated with more modern skyscrapers: a concrete caisson foundation, a braced frame to resist wind, and high-speed (local and express) elevators.

Two years later, in 1915, the Equitable Building—another downtown colossus—was completed on lower Broadway in New York. In contrast to the corporate headquarters

that had preceded it, the Equitable was a developer's building: it was designed to make money. It did that by maximizing the amount of office space, while keeping construction costs (and hence architectural details) to a minimum. The building rose 38 stories straight up from the street, in almost clifflike fashion, with little external adornment. A massive 1.2 million square feet (111,000 square meters) of office space lay within it in the form of an H, to allow light to penetrate beyond its soaring street walls.

The great mass of the Equitable Building, and the extent to which its towering walls blocked light and air, was not lost on the citizens or planners of New York City. It became the poster child for a burgeoning movement to adopt regulations governing the mass and height of the city's skyscrapers. One year after the Equitable opened, in 1916, the Building Zone Resolution—the first comprehensive zoning law in the country—was adopted in New York City.

The 1916 Zoning Resolution, as it is often called, did more than simply place limits on the design and height of tall buildings. To minimize the historic conflicts between residential, commercial, and industrial uses in various parts of the city, it assigned these uses to specific districts in each of the city's five boroughs. With respect to tall building construction, it stopped short of placing an overall cap on height (as Chicago continued to do) but instead permitted height to remain unrestricted over one quarter of the lot. It also established setback rules for specific tower heights, thereby ensuring that light and air would continue to reach the street and that towering street walls like the Equitable's could never be built again.

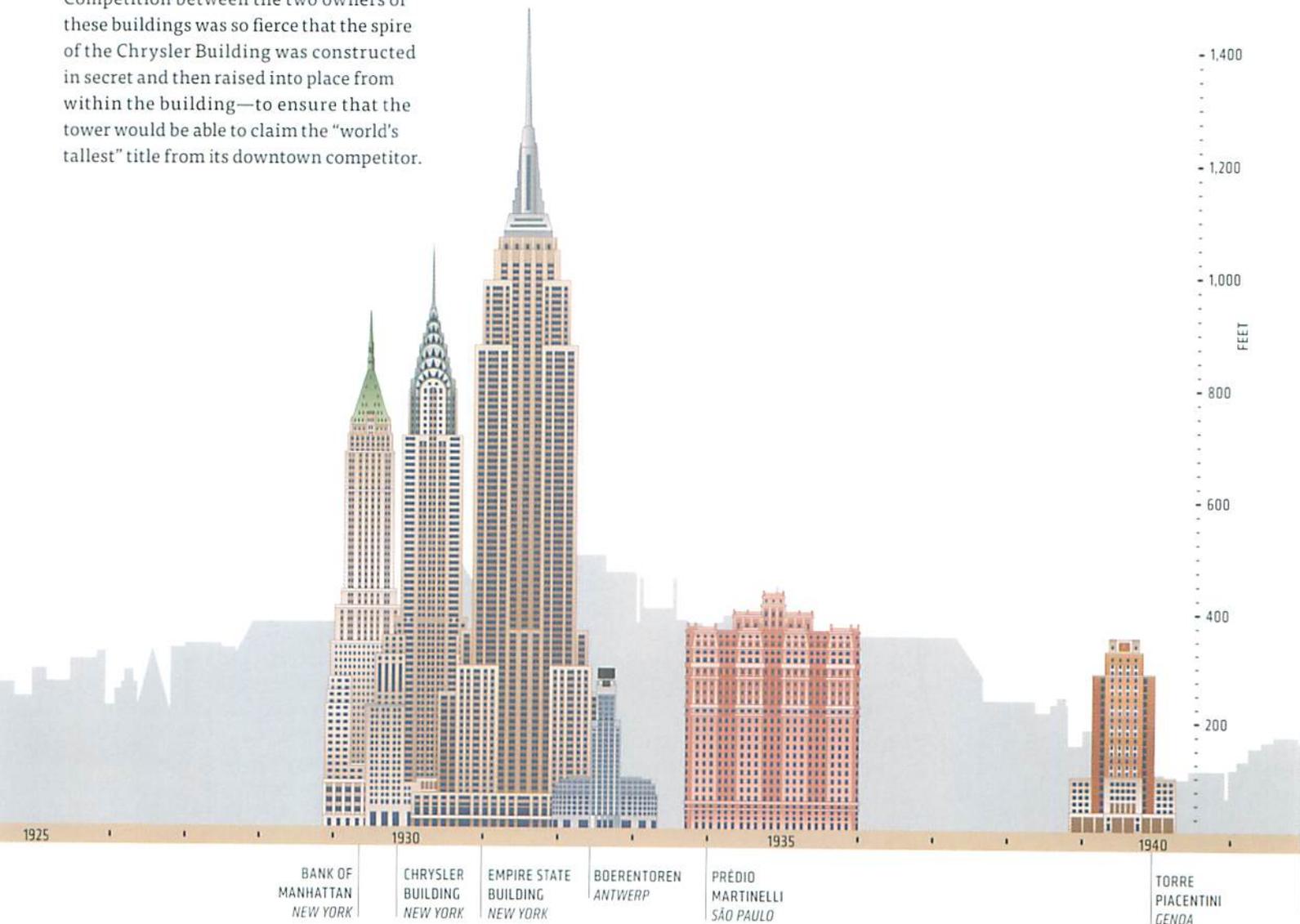


New York's new zoning laws, and particularly its regulations governing setbacks, would have a major impact on the shape of buildings designed in the city from that point forward. Yet such was the demand for space that they did little to curb the growing number of tall buildings being constructed in the city. Throughout the 1920s commercial office towers reached record-setting heights—growing to 40 or 50 stories, albeit with slimmer, tapered towers and wedding cake-like, tiered façades.

Some rose much taller. The 71-story Bank of Manhattan Building opened on Wall Street at 927 feet (283 meters) in April of 1930, garnering the title of the world's tallest building. But it would hold that honor ever so briefly: one month later the 77-story Chrysler Building opened in Midtown. Competition between the two owners of these buildings was so fierce that the spire of the Chrysler Building was constructed in secret and then raised into place from within the building—to ensure that the tower would be able to claim the “world's tallest” title from its downtown competitor.

The extravagance of the commercial towers built in New York in the twenties as monuments to commerce was staggering. Some, like the American Radiator Building, contained dramatic display halls for corporate products—in this case heaters (when the building was sold to the American Standard Company, plumbing appliances replaced the heaters). Others commissioned promotional artwork that became an integral part of the building; the New York Telephone Company's building, completed in lower Manhattan in 1927, featured a lobby floor with bronze plates depicting the construction of the city's telephone network, as well as ceiling frescoes commemorating the history of communication.

Not all the towers that arose in New York and Chicago in the early part of the twentieth century were corporate trophies. Most were wholly speculative, and even the corporate towers contained sizable amounts of space that were rented out to others. Indeed, the tallest building constructed in New York during this period did not even carry a corporate name. The Empire State Building, constructed by a developer in just over a year, eclipsed both the Bank of Manhattan and Chrysler buildings in height when it opened in 1931. Its 102 stories rose 1,250 feet (380 meters) into the sky and contained over two million square feet (186,000 square meters) of office space—a vast amount even by today's standards. It would remain the tallest, and the largest, building in the world for almost four decades.



## The International Style

Throughout the first half of the twentieth century, skyscrapers remained almost exclusively an American affair. In 1930, 99 percent of the tallest 100 buildings in the world were in North America; the exception was the 28-story Prédio Martinelli, which opened in São Paulo, Brazil, in 1929. Europe remained generally resistant to the idea of constructing tall towers—in part for aesthetic reasons and in part due to concerns about safety. The earliest skyscrapers to appear on the continent were relatively modest affairs, such as the 26-story Boerentoren in Antwerp (1932) or the 31-story Torre Piacentini in Genoa (1940).

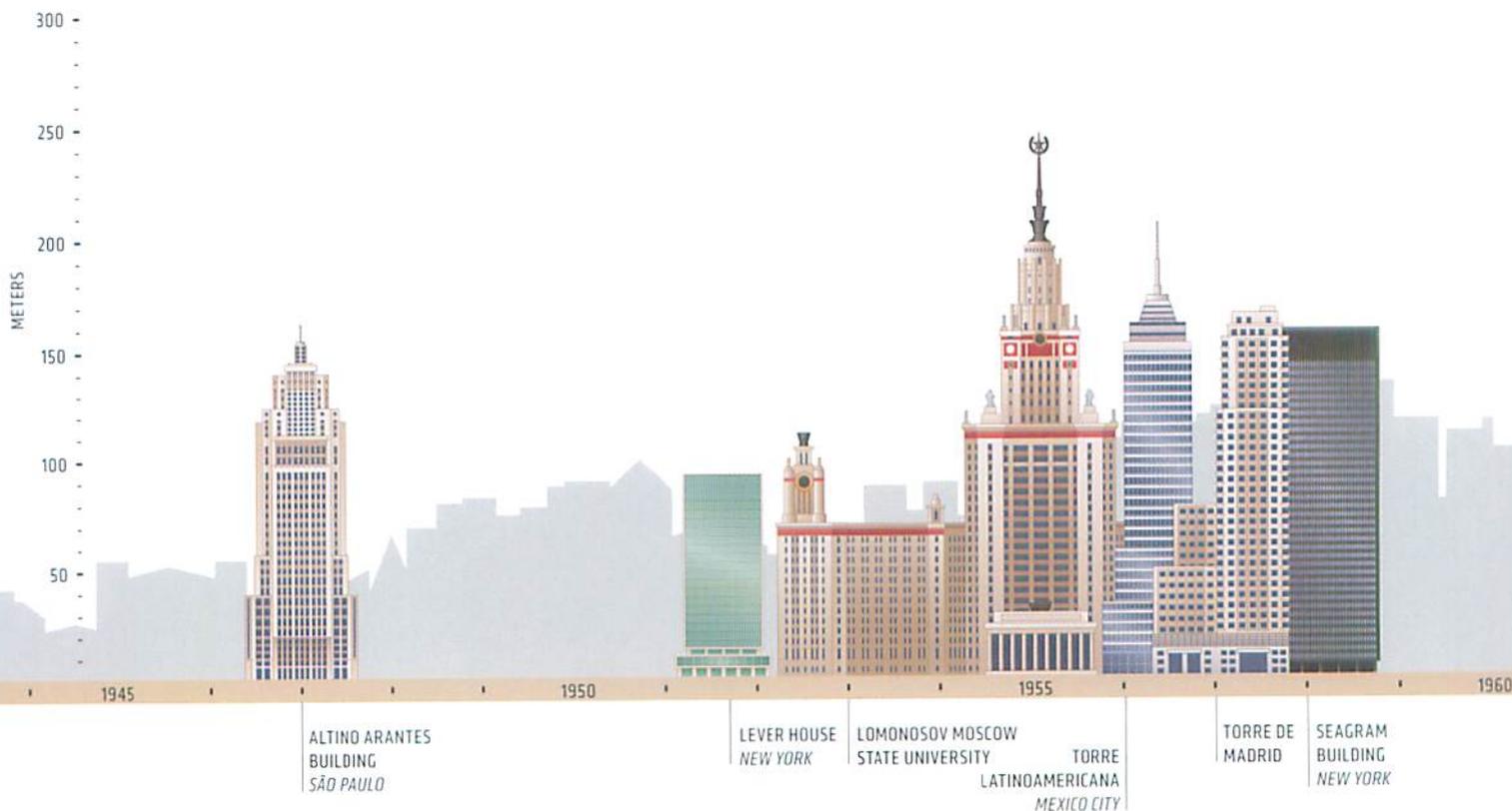
The Depression and Second World War put a halt to private-sector development around the world, and the race for height would not resume for decades. But the modern skyscraper did not stand still in the period following the war. In many ways, it changed more dramatically after the war than it had before it and in a primarily aesthetic sense—with a move away from the elaborate detailing of the early decades of the century to a much simpler, geometric form.

This modernist or international style approach to skyscraper design is generally attributed to Mies van der Rohe, a German architect who had proposed free-form towers encased only in glass panels as early as 1920. Mies's move to Chicago just before World War II set in motion a wave of European modernism perhaps best represented by his Seagram Building and by Skidmore, Owings & Merrill's Lever House, both completed along Park Avenue in Manhattan in the 1950s. These rather minimalist boxes, characterized by glass-sheathed steel and flat roofs, represented a dramatic break with the fussy art deco and gothic styles that had to that point characterized skyscraper design.

The advent of the glass “curtain wall,” as the external skin of a building is defined, offered significant benefits to developers. Glass was less expensive than stone and allowed greater light penetration to the interior. Along with the development of fluorescent lighting and air-conditioning, the penetration of light permitted the design of larger blocks of contiguous, open space within commercial towers—which meant greater flexibility for users and more rentable area for developers.

While New York and Chicago were refining the aesthetics of the commercial tower, other parts of the world were just beginning to embrace the idea of height. The 37-story Torre de Madrid was completed in Spain in 1957, marking the earliest real skyscraper on the continent. By the mid-1960s, skyscrapers in the range of 30 to 40 stories were either being built or had been completed in other places as well—including Africa, the Middle East, and Australia.

If skyscraper aesthetics were changing, so too was the technology that underpinned their structure. In the late 1960s, a structural engineer named Fazlur Khan at Skidmore, Owings & Merrill in Chicago developed the idea of a “tubed” support structure—a building whose external perimeter walls would consist of a series of load-bearing tubes, instead of simple steel columns. These tubes could not only take greater weight, allowing buildings to reach higher, but because they could be arranged in a variety of shapes they also freed towers from the boxy, rectangular, or square shapes that had more or less defined the international style for two decades.

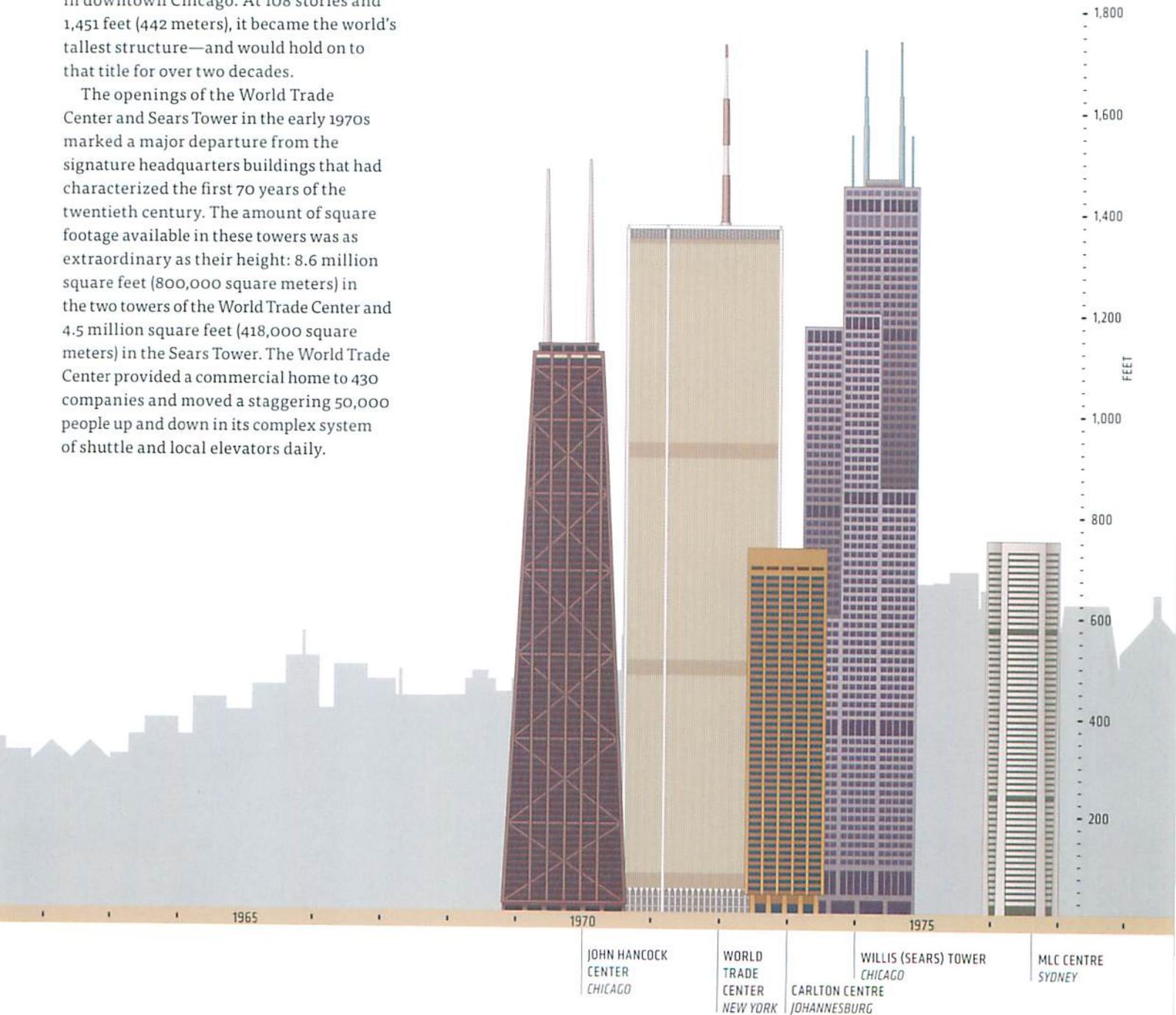


The first tube-based skyscraper to open was, ironically, not one designed by Khan or his firm—it was the two towers of the World Trade Center in New York, which opened in lower Manhattan in 1972. At 110 stories and 1,365 feet (416 meters) in height, the buildings well exceeded the height of the Empire State Building and claimed the title of world's tallest buildings. But the Trade Center's claim would be short-lived. Two years later, in 1974, the Skidmore-designed Sears Tower opened in downtown Chicago. At 108 stories and 1,451 feet (442 meters), it became the world's tallest structure—and would hold on to that title for over two decades.

The openings of the World Trade Center and Sears Tower in the early 1970s marked a major departure from the signature headquarters buildings that had characterized the first 70 years of the twentieth century. The amount of square footage available in these towers was as extraordinary as their height: 8.6 million square feet (800,000 square meters) in the two towers of the World Trade Center and 4.5 million square feet (418,000 square meters) in the Sears Tower. The World Trade Center provided a commercial home to 430 companies and moved a staggering 50,000 people up and down in its complex system of shuttle and local elevators daily.

Supertall buildings (a phrase generally used to describe buildings over 1,000 feet or 300 meters in height) like the Trade Center and Sears Tower could be financed and filled only in a healthy real estate market. The oil crisis and ensuing recession of the mid-1970s halted the race for height, just as the Depression had in the 1930s. For roughly 20 years, no supertall skyscrapers

were planned anywhere in the world. When the market did begin to revive, in the 1990s, the United States was no longer the epicenter of activity. The new supertall towers were located in Asia and the Middle East, and they were no longer exclusively office buildings; most would be mixed-use ones, incorporating residential, retail, and commercial uses under one roof.



## From Tall to Supertall

The geographic shift in skyscraper construction was dramatic and swift. In 1980, roughly 85 percent of the world's buildings over 500 feet (150 meters) were in North America; by 2008 that percentage had dropped to 28 percent.

The shift away from pure office buildings was equally marked. Whereas 85 percent of all skyscrapers in 1985 were used only as offices, by 2008 more than half of the world's skyscrapers incorporated residential and other mixed uses. These new towers were designed to function as veritable cities in the sky, hosting permanent residents as well as a host of retail features like health clubs, movie theaters, restaurants, and supermarkets. Multiple entrances to the buildings served to segregate users from one another.

The new skyscrapers were supertall, often rising over 1,000 feet (305 meters). New technologies, such as outriggers, brought added benefits: concrete cores attached to supercolumns on the perimeter, they allowed the new supertall buildings to be more open than tubed buildings,

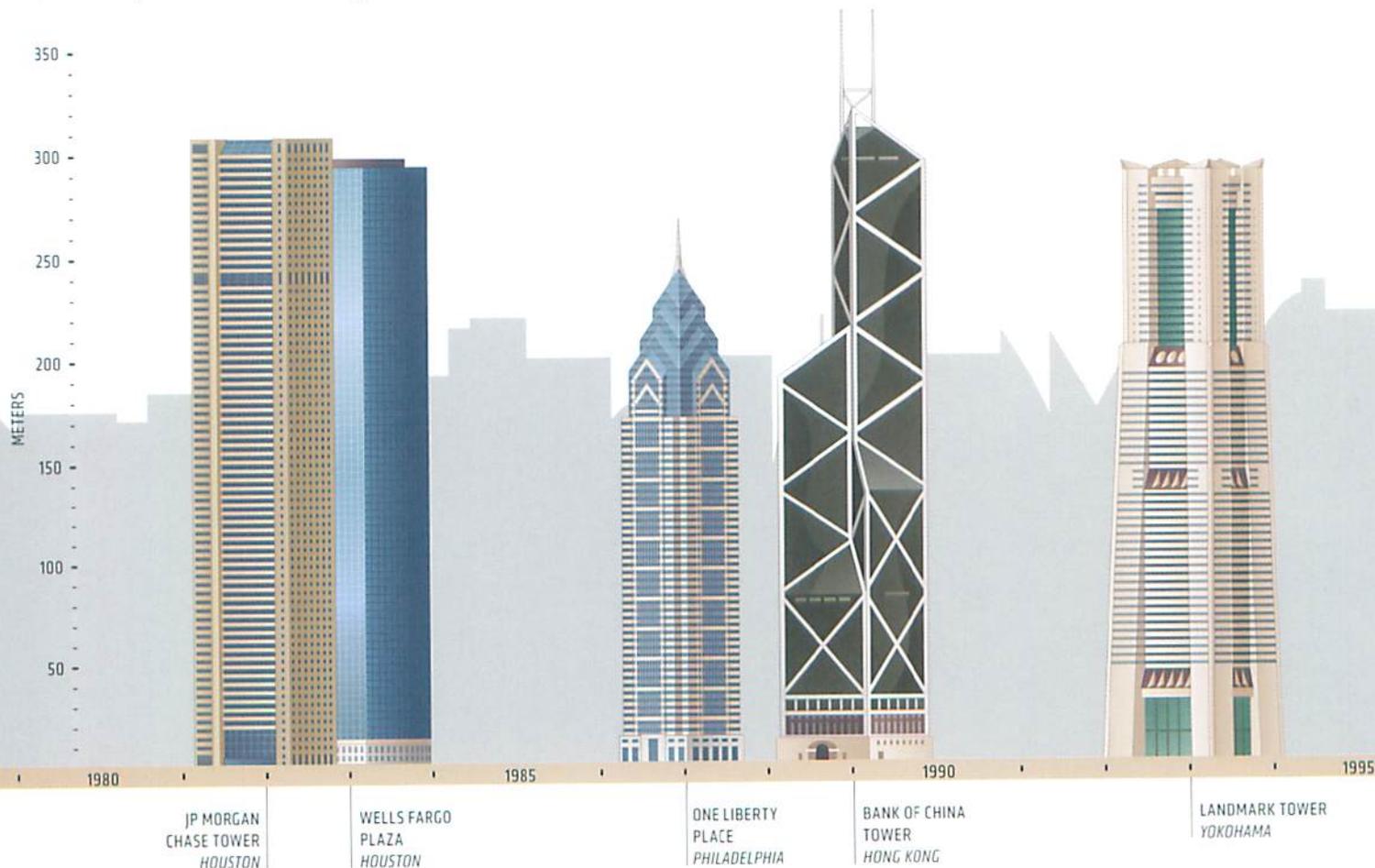
typically characterized by a proliferation of smaller columns on the perimeter.

The leap in heights that the new technology permitted was significant. The Petronas Twin Towers, opened in Kuala Lumpur, Malaysia, in 1998, reached 1,483 feet (452 meters) in height to claim the title of world's tallest inhabited structure from the Sears Tower—though only 88 floors were occupied. Six years later, Taipei 101 opened in Taiwan at 101 stories and 1,670 feet (509 meters). It would hold the title of world's tallest for only five years. In early 2010, the 160-story Burj Khalifa opened in Dubai. A novel buttressed-core system allowed it to reach to 2,684 feet (818 meters), a leap of a full 1,000 feet (305 meters) over Taipei 101.

Many of the supertall towers built in Asia during the first decade of the twenty-first century could not claim the title of world's tallest, but they were enormous nevertheless. The Jin Mao Tower opened in Shanghai's Pudong district in 1988, at

88 stories. In 2008, the 101-story Shanghai World Financial Center opened across the street from Jin Mao. (A third tower, the 128-story Shanghai Tower, is under construction nearby.) And in Hong Kong, the 118-floor International Commerce Center opened in 2010—its height limited by law to that of the surrounding mountains.

These new towers, both in Asia and the Middle East, were remarkable for more than their height. In their architecture, many moved away from the simple geometric shape that characterized midcentury skyscraper architecture. Cultural references were deliberately incorporated into several of the new towers' designs. In Asia, these cultural references took the form of anything from pagodas (Jin Mao) to ancient Chinese symbols (Shanghai World Financial Center). In the Middle East, these cultural references often related to the geometric patterns typical of Islamic architecture.



But notwithstanding their great heights and unusual shapes, today's skyscrapers are perhaps most remarkable for their complexity in operating around-the-clock as mixed-use destinations for thousands of people. The Burj Khalifa in Dubai, for example, contains 1,000 residences, 175 hotel rooms, and 37 floors of office space. As the centerpiece of the massive development known as Downtown Dubai, the complex at its base contains over 12 million square feet (1.1 million square meters) of stores, 22 movie theaters, a four-story fitness/recreation annex, and 3,000 underground parking spaces. To serve visitors and residents alike, the Burj offers over 27 acres

(10.9 hectares) of park and the world's tallest observation deck.

Buildings like the Burj represent a new extension of the skyscraper as an urban form. Today's skyscrapers are not necessarily at the epicenter of a dense city, nor are they wholly devoted to office life—as they once were. Instead, mixed-use buildings like the Burj are increasingly embracing the residential aspects of urban life, as well as the commercial, recreational, and retail ones—becoming, in many ways, their very own “vertical cities.”

