INDUSTRIES OF INDIA

THE SKYSCRAPER

Steel, Glass, Sky



KETINENI RAMARAO

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Reference numbers in square brackets resolve in the companion volume, The Skyscraper: Source Companion.

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PART I - THE TYPE

Chapter 1 - What a skyscraper is

Stand at the corner of Jackson and Dearborn in Chicago and look up at the Monadnock Building, sixteen stories of purple-brown brick finished in 1893, and you are looking at the problem this book begins with. The Monadnock is the tallest commercial building ever raised on load-bearing masonry walls - walls six feet thick at the street, eighteen inches at the top, the masonry doing all the work of holding itself up [SK5]. Two decades before it, nobody in Chicago had built anything like it. Two decades after it, nobody needed to build anything like it again, because a different idea had arrived: the skeleton. The Monadnock's own south half, added in 1893, was framed in steel, and it cost 15 percent less, weighed 15 percent less, and returned 15 percent more rentable space than its masonry twin [SK5]. Between the two halves of one building on one block, the word "skyscraper" changed what it meant.

The word itself came from the sea. Before it meant a building, a skyscraper was the topmost sail on a square-rigged ship, the scrap of canvas set highest above the deck, and Americans of the nineteenth century borrowed it for anything immoderately tall: a horse, a hat, a fly ball. When it attached itself to buildings in the 1880s, it attached to Chicago's, and by one account its first architectural use was for the Home Insurance Building of 1885, the ten-story office at LaSalle and Adams that William Le Baron Jenney framed in iron and steel [SK3]. The name outlasted the building. The Home Insurance Building came down in 1931; the word it fathered now describes some of the largest artifacts human beings have ever made.

Defining the thing the word names turns out to be surprisingly hard, and the difficulty is instructive. There is no absolute definition of a tall building. The Council on Tall Buildings and Urban Habitat - founded in 1969, known everywhere as the CTBUH, and renamed the Council on Vertical Urbanism in October 2025 - is the recognized arbiter of such questions, the body that bestows the designation "World's Tallest Building" [SK1][SK25]. It says so plainly on its criteria page: tall is subjective, judged against context, proportion, and technology [SK1]. A fourteen-story building is unremarkable in Hong Kong and a landmark in a provincial European town. A building can be tall because it is slender, or because it carries the technologies of tallness: structural wind bracing, vertical transport beyond the reach of stairs. As a working threshold the Council suggests fourteen or more stories, or more than 50 meters, roughly 165 feet [SK1]. Above that, the vocabulary hardens into classes. A "supertall" building is one of 300 meters or more; a "megatall," 600 meters or more. As of the Council's 2024 year-in-review, the world had 2,596 completed buildings of 200 meters or more - half of them in China - of which 258 were supertall; and its running list of the hundred tallest completed buildings, as of November 2026, is supertall all the way down:

it opens with Burj Khalifa at 828 meters and passes 390 meters before its fiftieth entry [SK51][SK26]. Four buildings on that list, in Dubai, Kuala Lumpur, Shanghai and Mecca, reach 600 meters or more, the megatall threshold [SK26]. Nearly all of them were built in the last thirty years. The class of building this book follows, in other words, is at once a century and a half old and overwhelmingly a phenomenon of the present.

Even measuring a skyscraper is an argument. The Council recognizes three heights, each with its own defenders and its own distortions [SK1]. Height to architectural top runs from the lowest significant open-air pedestrian entrance to the top of the building's designed form, counting spires - which are part of the architecture - but not antennas, flagpoles, or signage, which are equipment that comes and goes. This is the measure behind the famous rankings. Height to highest occupied floor measures to the highest level a person can actually work or live in, and it is the measure that punishes vanity: by it, towers with ornamental crowns sink below humbler neighbors whose roofs are full of offices. Height to tip measures to the highest point of anything at all, antenna included. The three measures crown different champions, and the differences are not small. When the Petronas Towers in Kuala Lumpur were completed in 1998 with spires counted in their official height, they displaced Chicago's Sears Tower - a building whose highest occupied floor sat well above Petronas's - as the world's tallest, and the decision to rank by architectural top became a genuine controversy, the moment the whole world learned that height is a convention before it is a fact [SK1]. The Council's own example diagram for the rule is still Willis Tower versus Petronas.

Floors, the other everyday unit of tallness, are worse. Floor-to-floor heights vary between offices and apartments; a mechanical level can be double height or hidden entirely; in Hong Kong the numbers 4, 14, and 24 routinely vanish from elevator panels because four sounds like death in Cantonese; and owners number their floors for marketing reasons that have nothing to do with the physical stack. The Council warns that its floor counts may differ from other published accounts for exactly these reasons [SK1]. A "story" is a real estate term before it is a measurement.

There is even a boundary below the boundary: when is a tall structure a building at all? The Council's answer is occupancy. To count as a building, at least half of a structure's height must be occupiable space [SK1]. That single rule is what keeps the Eiffel Tower, at 330 meters taller than any skyscraper of its era and the tallest thing in the world for four decades, off the list of tallest buildings. It is a tower, not a building - a distinction that matters more than it looks, because it draws the line exactly where this book's subject begins. A skyscraper is not a monument to height. It is height that pays: floor upon floor of rentable, occupiable space stacked on expensive land.

And that is the definition this book will use, because it is the one the market has always used. The skyscraper is a speculative or corporate real estate venture in vertical form. It exists because land in certain places became so valuable that the only way to own more of it was to buy the same parcel many times over, one floor at a time, and because a particular stack of technologies - the steel skeleton, the safety elevator, the caisson foundation, the curtain wall, the wind-braced tube - made that multiplication physically possible and financially tolerable. Every chapter that follows is about some piece of that bargain: the geology under the foundations, the finance behind the cranes, the zoning that shaped the silhouette, the tenants whose rent made it all arithmetic instead of sculpture.

Two clarifications before the story starts. First, what this book means by the industry's own bookkeeping. The Council tracks every tall building through a lifecycle of statuses - proposed, under construction (which begins, precisely, when foundation piling starts), topped out, completed, on hold, never completed [SK1]. Those words will appear here with those meanings; a stalled supertall is not a ruin, it is "on hold," and the distinction has cost fortunes. Second, the cast of recurring names. SOM - Skidmore, Owings and Merrill, the Chicago firm that designed more of the buildings in this book than any rival - appears so often it is effectively a main character. So do the two cities that invented the type, Chicago and New York, and the engineer, Fazlur Rahman Khan, whose structural ideas made the modern supertall possible. But the true protagonist is the building type itself: where it came from, how it works, who builds it, who pays, and why the world keeps deciding to reach higher.

A NOTE ON THE NUMBERS

Heights in this book are given in meters and feet as the sources give them, and are to the architectural top unless a chapter says otherwise - the same convention the Council uses for its rankings [SK1]. Where sources disagree, and they disagree often, the text says so rather than silently choosing. Dates of "tallest in the world" follow the Council's convention of counting from completion, not topping out or announcement. The skyscraper industry has always announced towers taller than it eventually built; the New York Times of the 1920s is a graveyard of hundred-story press releases [SK10]. This book counts what stands.

Chapter 2 - Why build tall

Ask why the skyscraper exists and the tempting answers are the wrong ones. Pride, vanity, the urge to touch the sky - these are real, and this book will meet them repeatedly, but no city ever built fifty towers out of pride. The skyscraper exists because of arithmetic: the price of land, divided by the floors you can stack on it.

The logic predates the technology. New York's real estate was broken from its colonial beginnings into many small parcels, and the island's role as American finance's home made those parcels expensive early; between 1860 and 1875, before a single skyscraper existed, New York property values rose by more than 90 percent [SK17]. Chicago grew from a village of perhaps fifty people in 1830 to a city of nearly 300,000 by 1870, became the railroad hub of the West, burned almost to the ground in October 1871, and rebuilt on its grid under ordinances that banned wooden construction [SK17]. In both cities the question a landowner faced was newly sharp: my parcel is fixed and its value is soaring; how many floors of rentable space can I extract from it?

Every skyscraper since has been an answer to that question. The measure the industry uses is the floor area ratio, the FAR: total floor space divided by lot area. Build eight stories covering your whole lot and your FAR is 8. The numbers can be startling at the extreme. Lever House, the elegant glass slab of 1952, sits at a FAR of about 6. Rockefeller Center runs about 12. The Empire State Building, stacking its bulk on a full Midtown block, reaches about 25 [SK13]. A FAR of 25 means the owner of that block multiplied it twenty-five-fold - sold the same land, in effect, twenty-five times, once per floor, without buying another square foot of Manhattan. That multiplication is the whole economic idea of the building type. Everything else - the steel, the elevators, the zoning, the spires - is instrumentation.

The multiplication only works if people will pay for the upper floors, and for most of human history they would not. In the walk-up city, rents fell as you climbed; the top floor of a five-story tenement was the cheapest because the stairs taxed every trip. Two nineteenth-century machines reversed the gradient. The safety elevator - Elisha Otis's brake of 1852, the passenger installation in the Haughwout Building in 1857 - made the climb effortless [SK4]. Steel-frame construction with big windows and, soon, electric light made the upper air pleasant. By the 1880s the gradient had inverted: high floors offered light, quiet, and view, and began to command the highest rents rather than the lowest. Office rents were further shaped by what stood at street level: shops at the base of Chicago's early skyscrapers rented for five or six times the rate of office space

above, which is why the ground floors were marble and the tenth floors were plain [SK17]. The skyscraper is a machine for manufacturing premium floor space out of altitude.

There is a second engine, less tidy than rent: agglomeration. Businesses cluster because proximity is worth money - the banker next to the exchange, the lawyer next to the bank, the stationer next to them both. When a district agglomerates, everyone in it needs to be within a short walk of everyone else, and the walkable circle is fixed by legs, not by land. The only way to fit more business into the circle is up. This is why skyscrapers are not distributed evenly across cities but packed into districts - the Loop, Wall Street, Midtown, Central Hong Kong, Pudong, Dubai's Sheikh Zayed Road - and why their heights spike where agglomeration is most valuable. It also explains the otherwise puzzling fact that land can be worth so much more than the buildings on it. The Equitable Building of 1915, 1.2 million square feet of speculative office space, was by the 1920s the most valuable building in New York City - not because its architecture was loved, it was widely loathed, but because forty floors of offices one block from the heart of American finance were worth a fortune in rent [SK20].

Third, and never absent: the tower as advertisement. Frank Woolworth did not need 792 feet of office space; his five-and-ten-cent chain needed perhaps a quarter of the building that bears his name. What he bought with the rest was the phrase "tallest building in the world," and a Gothic tower lit at night that functioned as the company's trade mark in masonry - the Cathedral of Commerce [SK11]. The Singer Manufacturing Company did the same in 1908, and the Metropolitan Life Insurance Company in 1909, each seizing the title in turn [SK17]. Walter Chrysler, assembling his secret spire inside the fire tower of his building in 1929, was not adding rentable floor area; he was buying the headline [SK10]. This motive is real but must be kept in its place: it operates at the margin of the economics, deciding who builds the very tallest, not whether tall buildings make sense. The skyline of a commercial city is a bar chart of land values, and the spikes at the top are signed by whoever wanted the publicity most.

Against these pressures pushing towers upward runs one pushing back: the rising cost of height itself. Structure is the obvious case. A tall building must resist the wind as well as carry its own weight, and the engineer Fazlur Khan drew the curve that rules the industry: the structural material required per floor grows with height, a penalty he named the "structural height premium" [SK7]. His life's work, which Part IV follows, was flattening that curve - his John Hancock Center of 1969 used about 145 kilograms of steel per square meter of floor where the Empire State Building had used about 206 and One Chase Manhattan Plaza about 275 [SK12] - but no innovation has ever made height free. Elevators consume a growing share of each floor as towers rise, which is why the World Trade Center's sky-lobby system, letting local elevators stack in one shaft like subway lines,

lifted usable space from 62 to 75 percent and made 110 stories rentable [SK14]. Foundations, wind bracing, fire systems, construction logistics: all grow dearer with altitude. Every completed skyscraper stands at the point where, on that site, in that year, the upward pressures and the cost curve crossed - where one more floor of rent stopped paying for the floor beneath it.

This is why the skyscraper, alone among great building types, has always been a speculative instrument first and a monument second. “Current American architecture is not a matter of art, but of business,” the writer Barr Ferree complained in 1893. “A building must pay, or there will be no investor ready with the money to meet its cost. This is at once the curse and the glory of American architecture” [SK17]. The developers who built the type - Boston insurance money like the Brooks brothers behind the Monadnock, sewing-machine fortunes like Singer’s, retail fortunes like Woolworth’s, and the professional speculators who came after - understood themselves to be in the business of manufacturing rent. The towers they left behind are read now as architecture, as symbols, as skyline. They are. But each of them first had to close as a deal.

PART II - BEFORE THE FRAME

Chapter 3 - The old hunger for height

For almost the whole of recorded history, the tallest thing humans built was something nobody could live or work in. That fact is worth sitting with, because it marks exactly where the skyscraper departs from everything before it.

The Great Pyramid of Giza, finished around 2560 BC, rose 146.5 meters - 481 feet - and remained the tallest structure on Earth for more than 3,800 years [SK16]. It is solid stone, a mountain with a burial chamber hidden in it; there is almost no inside. The ages that followed kept to the same rule. The ziggurat of Dur-Kurigalzu in Mesopotamia reached about 70 meters around 1400 BC; Babylon's Etemenanki, the likely original of the Tower of Babel story, about 91 meters in 601 BC; the great stupa at Amaravati, 73 meters around 300 BC [SK16]. All were monuments: masses of masonry whose height existed to be seen, not to be used. The minarets of Islam added a working purpose - a platform for the call to prayer - but no floors of rentable or habitable space. The Koutoubia minaret at Marrakesh, about 77 meters, was completed around 1195 [SK16].

The Christian cathedral broke the pyramid's record and confirmed the rule. From roughly 1311, when the central spire of Lincoln Cathedral was completed at about 160 meters, the title of tallest building in the world belonged to churches for nearly six centuries [SK16]. The record chain reads like a ledger of faith and structural luck: Lincoln's spire collapsed in a storm in 1549; St. Mary's at Stralsund inherited the title; the crossing tower of Beauvais Cathedral took it in 1569 at 153 meters and lost it in 1573 when the tower collapsed; Stralsund again; then, from 1647, Strasbourg Cathedral at 142 meters, which held the title for over two centuries, until 1874 [SK16]. The cathedrals were occupied, of course - worshippers filled their naves - but their height was almost entirely in towers and spires, empty stone reaching toward heaven. Their builders pushed masonry to its absolute limit, and sometimes past it: Beauvais, the most daring of them all, collapsed twice.

That limit is the point. Stone and brick are strong in compression and useless in tension, and a masonry wall must carry not only its building but itself; the taller the wall, the thicker its base must grow, until the geometry defeats the purpose. The medieval builders reached their ceiling at about 160 meters of mostly hollow spire. When commercial builders later tried the same material for offices, they hit the same wall much lower down - and this is where the prehistory of the skyscraper ends and its history begins. The Monadnock Building in Chicago, finished in 1893, is the terminal case: sixteen stories of load-bearing brick, 215 feet, the tallest commercial masonry building ever constructed. To stand up, its ground-floor walls had to be six feet thick, swallowing the rentable space they were built to create, and even so the building has spent a century sinking -

designed to settle eight inches, it had passed that mark by 1905 and had sunk twenty inches by 1948, so that visitors now step down from the street into its lobby [SK5]. The Monadnock proved two things at once: that an ordinary commercial street could produce a tower as tall as the great cathedrals' naves are long, and that masonry could take the type no further.

Three nineteenth-century novelties broke the impasse, and none of them was architectural. The first was structural iron. As early as 1797, the Ditherington Flax Mill in Shropshire, England - five stories of spinning machinery - had been framed internally in cast iron to resist fire, making it, in the words of later historians, the grandfather if not the father of the skyscraper [SK3][SK17]. Iron columns and beams let a building's skeleton, not its skin, do the carrying; walls could thin into mere weather-screens. But early iron frames were not obviously better: they were not fireproof, they frightened city officials, and for decades they appeared mainly in mills and warehouses, where no one cared what the building looked like. The second novelty was the safety elevator, Elisha Otis's 1852 brake, which made height usable; Chapter 4 follows it. The third was cheap steel. Iron carried the first experiments, but steel - stronger, more consistent, and after the Bessemer and open-hearth processes dramatically cheaper - gave the frame its real strength. The Home Insurance Building of 1885 was among the first to put structural steel into its frame alongside wrought iron [SK17], and within a generation the masonry wall had been demoted to a curtain.

While the materials changed, the old ceremonial hunger for height found two last monumental outlets, and they are the direct ancestors of the skyline. In Washington, the obelisk to George Washington was capped in 1884 at 169 meters - the tallest structure in the world, and deliberately a structure, an uninhabitable stone needle; Otis installed a steam elevator in it in 1888 so visitors could ride twelve minutes to the top [SK4][SK16]. Five years later, in Paris, Gustave Eiffel's iron lattice tower reached 300 meters for the Exposition Universelle of 1889, nearly doubling the record, with Otis elevators curving up its legs [SK4]. The Eiffel Tower held the structural record for over forty years. Yet neither monument was a building by the measure this book uses, because neither was occupiable through its height - the modern rule that at least half a structure's height must be usable space formalizes a distinction the nineteenth century had already made in practice [SK1]. What the monuments proved was that iron, and then steel, could stand at heights masonry never approached. What they could not do was pay rent.

That final step - turning structural height into occupiable, rentable floors - happened in one American decade and two American cities. The preconditions assembled quietly: Philadelphia's City Hall, a masonry colossus topped out in 1894 at 548 feet, briefly the tallest occupied building in the world and, in

hindsight, the last great monument of the old way [SK16][SK17]. In the same years, Chicago’s builders were laying the skeleton of the new one. The next part follows them.

Chapter 4 - The elevator before the tower

Every account of the skyscraper must pause for the machine without which none of the rest matters. Steel could stand twenty stories up by the 1880s; what it could not do was make anyone want to climb there. The limit on the height of buildings, for most of history, was not engineering. It was legs.

Six floors was the practical ceiling of the stair-climbing city - above that, rents collapsed with the altitude. Hoists and lifting platforms are ancient, and powered freight elevators were working in England by the 1830s and in American factories and hotels by the 1840s [SK17]. But a hoist is only as trusted as its rope, and ropes broke. What the age needed was not a way to lift people; everyone had that. It needed a way to make lifting people feel safe.

Elisha Graves Otis supplied it in 1852: a wagon spring and a toothed rack, arranged so that if the hoisting rope parted, the spring snapped the brake into the guide rails and locked the platform in place. He sold his first elevator in 1853, and in 1854, at New York's Crystal Palace Exhibition, he staged one of the great sales demonstrations of the industrial century. Standing on his own hoisted platform high above the crowd, he ordered the rope cut with an axe. The platform dropped a few inches and stopped dead. The immortal cry - "All safe, gentlemen, all safe!" - is the legend's embroidery rather than the record: contemporary accounts describe the demonstrations at the Crystal Palace's 1854 season, but the closest historian of the episode finds no evidence for the words, and none that P.T. Barnum paid for the stunt [SK60]. In 1857 he installed the first passenger elevator in the E.V. Haughwout Building, a five-story china-and-glassware department store on Broadway whose wealthy customers included Mary Todd Lincoln [SK4]. Otis took out his patent in January 1861 and died four months later, aged forty-nine, in a diphtheria epidemic; his sons Charles and Norton built the company [SK4].

The elevator's first effect was not height but luxury and convenience - the Haughwout was only five stories, after all, and the early machines were status as much as transport. The 1870s made them load-bearing. George B. Post's Equitable Life Assurance Building of 1870 in New York is generally credited as the first office building designed around passenger elevators from the start, rising seven floors plus a mansard to about 130 feet - and its upper floors proved that altitude could attract premier office tenants, including Delmonico's, which opened a branch inside [SK17][SK18]. (The 1870 Equitable Life building burned in 1912; its 1915 replacement, the Equitable Building, will detonate the zoning fight in Part V.) Power improved in step: hydraulic elevators arrived in 1870, and after their early design flaws were resolved by 1876 they could serve the first genuinely tall buildings; Otis's roped hydraulic machines of 1878 reached 800

feet per minute [SK4][SK17]. By 1888 Otis was lifting visitors up the Washington Monument and the Hong Kong Hotel; by 1889, up the legs of the Eiffel Tower [SK4].

The last constraint was speed and machinery size, and it fell in 1903 with Otis's gearless traction machine - the electric motor driving the sheave directly, no gears, no hydraulic plunger growing ever longer beneath the shaft. The company's own history states flatly that the gearless machine "allowed previous height limits to be surpassed, enabling construction of true skyscrapers" [SK4]. The claim is a vendor's, but the record supports it: the Singer Building of 1908, the Metropolitan Life Tower of 1909, and the Woolworth Building of 1913 - each in turn the world's tallest - all ran on gearless Otis machines [SK4]. In 1931 the Empire State Building opened with sixty-one passenger elevators and six freight elevators, "robot elevators" with automatic controls handling tens of thousands of trips a day; in 1932 the Cities Service Building introduced the double-deck elevator, two cabs stacked in one hoistway [SK4].

Two deeper points follow, and they structure much of this book. The first is that the elevator is not an accessory to the skyscraper; it is the load-bearing member of its economics. The number of shafts a tower needs grows with its floors, and every shaft is floor space that cannot be rented - the reason the World Trade Center's architects, asked to make 110 stories pay, borrowed the subway's express-and-local trick and stacked local elevators atop one another out of sky lobbies on the 44th and 78th floors, raising usable space from 62 to 75 percent [SK14]. Vertical transport is the physics problem at the heart of the real estate. The second point is quieter: the tall-building industry has always rested on a small, almost invisible layer of specialist firms - the elevator makers above all - whose products every architect depends on and few visitors notice. Otis, consolidated with thirteen rivals into the Otis Elevator Company in 1898, sold its machines into the Singer, the Woolworth, the Empire State, the World Trade Center, and the Burj Khalifa's competitors; by the 1980s the industry's center of gravity had moved with the towers themselves to Asia, and China became, as it remains, the world's largest elevator market [SK4]. The skyline runs on their rails.

PART III - THE INVENTION

Chapter 5 - Chicago: the first generation

The skyscraper was not invented by a genius with a drawing board, whatever later plaques claimed. It was assembled in about fifteen years, mostly in one burnt and rebuilding city, out of available parts: iron frames from English mills, fireproofing from a string of urban fires, caissons from bridge-building, elevators from Otis, cheap land cleared by catastrophe, and clients who wanted floor space, not beauty.

The standard story begins at the northeast corner of LaSalle and Adams Streets. William Le Baron Jenney, a Chicago architect trained as an engineer in Paris, designed a ten-story office building for the Home Insurance Company of New York; construction began May 1, 1884, and finished the next year at 138 feet [SK3]. What made the Home Insurance Building different from every tall building before it was that its weight - floors and eventually walls - traveled down a metal skeleton instead of thickening masonry. The frame mixed wrought iron with a new material, structural steel, in its upper columns. The building weighed about a third of what equivalent masonry would have; city officials, alarmed, stopped construction while they satisfied themselves it would not fall down [SK3]. Two floors were added in 1891 without incident.

Honesty requires saying that the title “first skyscraper” is contested ground, and the contest is part of the story. Iron-framed mills had stood in England since 1797; Philadelphia’s Broad Street Station of 1881 had a structural steel frame with masonry reduced to a curtain; Chicago’s own Montauk Block of 1882-83 preceded Jenney’s building; New York’s Equitable Life Building of 1870 had been the first office building planned around passenger elevators [SK3][SK17]. The Chicago press of 1885 did not hail anything revolutionary on LaSalle Street, and the “first skyscraper” label was retrofitted decades later, in a campaign that began with Jenney’s own circle and was canonized by demolition-era boosters in 1931 - the economist Jason Barr, in the fullest modern account, calls it the Jenney myth, and the structural case notes that the building’s two interior-facing party walls were load-bearing masonry, its iron columns embedded in brick piers - a metal cage inside a masonry building, not yet a self-standing skeleton [SK63]. Carol Willis of the Skyscraper Museum dissolves the question itself: the more specific the claimed first, the less meaningful it becomes - the skyscraper had no birthday [SK64]. What is true, and enough, is this: the Home Insurance Building was the most influential early proof that a tall commercial building could hang its entire weight, walls included, on a metal frame. A 1932 plaque in the lobby of its replacement called it “the true father of the skyscraper,” and on that softer claim the argument has rested ever since [SK3].

The frame improved with startling speed. Jenney's was bolted; the Tacoma Building of 1889 introduced riveted connections; the Rand McNally Building of 1890 became the first skyscraper framed entirely in steel, self-supporting from sidewalk to cornice [SK17]. Each step thinned the walls, quickened the work, and lowered the weight that Chicago's treacherous ground had to carry. That ground was the city's private engineering problem: not Manhattan's convenient bedrock but a deep sandwich of soft clay. The Chicago answer was the floating foundation - a raft of concrete and steel rails spreading the building's load across the clay like a snowshoe, invented by John Wellborn Root for the Montauk and refined under every tower after. The Monadnock rests on one two feet thick, reaching eleven feet out under the surrounding streets [SK5]. Buildings were designed to settle, and settle they did, gracefully when the engineering was honest.

Around the technology grew the first great architectural community of the type, the Chicago school: Jenney; Burnham and Root; William Holabird and Martin Roche, both trained in Jenney's office; Dankmar Adler and Louis Sullivan. And behind them, the clients - above all Peter and Shepherd Brooks, Boston shipping-insurance money, and their Chicago agent Owen F. Aldis, the man Louis Sullivan credited as co-author of the modern office building [SK5]. The Brooks-Aldis partnership built the Montauk in 1883, the Rookery in 1888, and the Monadnock in 1891-93, and by century's end Aldis had created over a million square feet of Loop office space and managed nearly a fifth of it [SK5]. These were speculative ventures run on ruthless arithmetic: Brooks forbade ornament on the Monadnock because "projections mean dirt" and do not "add strength to the building" [SK5]. The beauty that resulted - the Monadnock's sheer, unornamented cliff of brick is now considered one of the great commercial facades ever built - was an accident of accounting, and all the more instructive for it.

By 1893 Chicago had a dozen skyscrapers of sixteen to twenty stories, and the type had become a civic spectacle: tourists hired cabs and lay back across the seats to see the tops [SK17]. The Masonic Temple of 1892, 302 feet of shops beneath Masonic halls, advertised itself as the tallest commercial building in the world; the rival Odd Fellows announced a 556-foot answer that was never built, an early lesson that in this industry the press release is always taller than the building [SK17]. And then Chicago stopped. In 1892, spooked by the towers it had invented, the city capped new construction at 150 feet [SK17]. The cap held for decades. The center of the skyscraper world packed up its drafting tables and moved east, to the one city whose land values, ambitions, and lack of a height limit were all larger than Chicago's.

Chapter 6 - The skeleton matures

A skeleton alone does not make a skyscraper. The young frame of the 1880s had to survive three enemies - wind, fire, and water - and it had to learn to dress itself. The decade after the Home Insurance Building was the skyscraper’s apprenticeship, and its graduation photograph is a white terracotta building on Washington Street in Chicago that looks, startlingly, like 1950.

Wind first. A masonry wall resists lateral force by sheer mass; a light steel cage does not have that option. The early frames swayed, creaked, and frightened their tenants, and engineers responded by turning the frame itself into a bracing system. The Monadnock, though masonry outside, carried inside it an iron frame with what Root devised as America’s first portal system of wind bracing - rigid frames of columns and deep beams, struts riveted between columns, stiffening the whole against the lake wind [SK5]. Later Chicago designers hid knee braces and portal frames within partition walls; still later ones, as Part IV describes, would move the bracing to the perimeter and finally make the entire exterior wall the structure. The physics was understood early thanks to Augustin-Jean Fresnel’s equations for wind loads on large structures; the problem was never knowledge but economy, bracing enough without paying for steel that earned no rent [SK17].

The iron frame itself was older than Chicago, and its motive was fire before it was ever height: the five-storey spinning mill of the Ditherington Flax Mill at Shrewsbury, built in 1796-7 to Charles Bage’s design, is recognized as the first building to replace timber beams and joists with incombustible cast and wrought iron - a fireproofing invention, a full ninety years before the Home Insurance Building [SK65].

Fire was the worse terror, because the cities themselves kept burning. The iron frame’s dirty secret was that unprotected iron fails faster in fire than the timber it replaced - it conducts heat, expands, and lets go of its rivets. Chicago burned in 1871, Boston in 1872, and the insurance industry demanded answers. The answers came from the work of Peter Wight in the 1860s, translated in the 1870s into a generation of patented fireproofing systems: hollow terracotta tiles wrapped around columns and beams, porous plaster, concrete encasement [SK17]. The Monadnock was among the first buildings lined with hollow fire-clay tile so that its metal frame would survive even if the facing brick were destroyed [SK5]. Fireproofing added cost and weight, but it made the steel frame insurable, and what is insurable is financeable. The chain from fire insurance to skyline is direct, and it runs through terracotta.

The third apprenticeship was the wall itself. Once the skeleton carried the building, the exterior wall had nothing left to do but keep out weather - a “curtain wall,” carrying only its own weight, hung from the frame floor by floor and

transferring wind back into it [SK27]. The idea had surprising ancestors: Peter Ellis's Oriel Chambers in Liverpool, in 1864, had fronted a courtyard with a metal-framed glass curtain wall, and the Statue of Liberty's thin copper skin of 1886 is a non-load-bearing envelope in the same sense [SK27]. But the skyscraper's version arrived in Chicago, and its landmark is the Reliance Building. The Reliance's story is pure Chicago improvisation: an elevator manufacturer, William Ellery Hale, wanted a tower on a lot whose existing tenants refused to leave, so he had their upper floors jacked up on screws, demolished the ground floor beneath them, and built a new base by John Root in 1890; Root died of pneumonia in January 1891, and Charles B. Atwood, recruited by Daniel Burnham, completed the tower in 1895 with engineer E.C. Shankland [SK22]. Atwood wrapped the steel frame in white glazed terracotta - marketed, wrongly, as self-washing - and filled the bays with plate glass. The Reliance was the first skyscraper whose surface was mostly glass, one-third the weight of an equivalent stone building, its top ten floors of steel erected in fifteen days [SK22]. Critics called it proto-modern; historians trace a straight line from Washington Street in 1895 to Mies van der Rohe's all-glass Friedrichstrasse proposal of 1921, and from there to every glass tower in this book [SK22].

The curtain wall also quietly changed what a building cost to build and to run. Hung from the frame rather than stacked from the ground, it went up with the frame instead of after it; unit by unit it could be fabricated in a shop and bolted on at height. Its thinness returned rentable inches to every floor. And its materials - terracotta first, then steel mullions and plate glass, later the aluminum extrusions that took over in the 1970s - could be repeated identically for a hundred floors [SK27]. The modern systems that resulted divide into families: stick systems assembled piece by piece on site; ladder systems with split mullions fabricated in sections; unitized systems arriving as complete factory-glazed panels, trading factory cost for field speed [SK27]. All of them solve the same quartet of problems the 1890s discovered: carrying their own weight back to the frame, passing wind load through anchors into the structure, moving with a swaying building without cracking their glass, and keeping water out - the rainscreen principle, which equalizes air pressure across the outer seal so that water is never drawn through the joints [SK27]. The glass wall that defines the modern skyline is not a style choice; it is the mature form of the load-bearing wall's abolition.

By the century's end the kit was complete: riveted all-steel skeleton, floating or caisson foundations, portal wind bracing, fireproofed members, curtain walls of terracotta and glass, electric light from 1878, steam heat, forced ventilation, iron-pipe plumbing, and the passenger elevator [SK17]. The skyscraper was now a manufacturable product. What it lacked in Chicago was permission - the 150-foot cap - and what it found in New York was the opposite: no cap, deeper bedrock, pricier land, and clients with national names to advertise.

Chapter 7 - New York takes the lead

New York came late to the skeleton. The city's building officials distrusted metal framing - New York did not permit an iron-framed skyscraper until 1889, when Bradford Gilbert's eleven-story Tower Building went up on lower Broadway - and the city had only four buildings over sixteen stories by 1893, when Chicago had a dozen [SK17]. What New York had instead was everything else: the nation's finance, its deepest bedrock, its most expensive land, and no height limit at all. When the American Surety Building of 1895 rose to twenty stories and 303 feet and broke Chicago's height record, the transfer of leadership was complete, and the city never gave it back [SK17].

The New York tower developed its own grammar, different from Chicago's broad palazzo blocks. Manhattan's small, dear parcels bred narrow, speculative towers climbing straight from the lot line, and its architects, trained in the Beaux-Arts rather than in engineering offices, dressed them as campaniles, columns, and chateaux - eclectic, flamboyant, and often derided as ungainly [SK17]. Daniel Burnham's Flatiron Building of 1902 showed what the type could be: a steel-framed Renaissance palazzo squeezed onto the triangular block where Broadway crosses Fifth Avenue, twenty-two stories and 307 feet, built by George A. Fuller's company - the same Fuller, trained in Chicago on the Monadnock, who carried the Chicago method east and became the skyscraper era's great contractor [SK19] [SK5]. The Flatiron was never close to tallest, but it proved the frame could take any shape the street grid demanded, and it remains, per square foot of floor, probably the most beloved speculative office building ever built.

Then came the corporate towers, and with them the first sustained contest for the sky itself. The Singer Manufacturing Company, the sewing-machine giant, commissioned Ernest Flagg's Beaux-Arts tower at 149 Broadway: completed in 1908, 612 feet to the roof, the tallest building in the world [SK23]. Singer's tower was, in hindsight, a warning about the type as well as a triumph: when the company later wanted modern floor space, the slender shaft that made it beautiful made it obsolete, and the Singer Building was demolished in 1967-68 - to this day one of the tallest buildings ever deliberately destroyed, a reminder that a skyscraper is an asset with a balance sheet, not a monument with a guarantee [SK23].

Singer held the title barely a year. In 1909 the Metropolitan Life Insurance Company completed its tower on Madison Square - 700 feet, a marble-and-white-brick homage to the campanile of St. Mark's in Venice, the medieval tower form reissued by an insurance conglomerate [SK24]. Both were what the Equitable

Building was not: slender, romantic, and signed - corporate symbols built by famous architects for famous companies [SK20]. And both were surpassed in 1913 by the building that defined the whole first era of the skyscraper.

Frank W. Woolworth, whose five-and-ten-cent stores had spread across America, wanted a headquarters that would advertise the chain in every newspaper in the country, and he paid for it - $13.5 million, in cash as he liked to boast - out of nickels and dimes [SK11]. Cass Gilbert gave him a neo-Gothic tower at 233 Broadway: a thirty-story base carrying a thirty-story tower, terracotta cladding over a steel frame by engineers Gunvald Aus and Kort Berle, built by Thompson-Starrett, topped out July 1, 1912, and opened April 24, 1913, when President Woodrow Wilson pressed a button in Washington to light it [SK11]. At 792 feet the Woolworth was the tallest building in the world, and it kept the title for sixteen years. A clergyman’s 1916 booklet gave it the name that stuck: the Cathedral of Commerce [SK11]. Gilbert reportedly disliked the religious comparison, but the building’s meaning was exactly that fusion - a counting house built like a church, medieval Gothic engineering reborn as corporate real estate. It was also, not incidentally, a working building filled with working systems: twenty-six high-speed Otis elevators, its own power plant, a basement swimming pool, an observatory on the 57th floor [SK11]. Its afterlife illustrates the asset logic better than any eulogy. Woolworth’s company kept it for most of the twentieth century; the Witkoff Group bought it in 1998; in 2012 the top thirty floors were sold and converted to luxury apartments - the office cathedral turned residential, because that is what the market would pay most for a Gothic tower over City Hall Park [SK11]. Designated a National Historic Landmark in 1966, it has outlasted the five-and-dime business that built it; the chain is gone, the address remains prime, and the building’s third career is residential [SK11].

Beneath the famous towers, the real transformation was statistical. Between roughly 1900 and 1916, lower and midtown Manhattan filled with speculative steel frames built by the hundred, and the white-collar workforce to fill them - the typists, clerks, accountants, and telephone operators of the new corporate economy - grew with them [SK17]. The skyscraper had ceased to be an experiment and become the standard form of American business real estate. It had also begun to create the problem that would define its next era: shadows. A city of lot-line towers was a city of darkening streets, and the bulkiest offender of all was rising at 120 Broadway.

Chapter 8 - The office becomes a machine

The skyscraper’s exterior gets the photographs; its economics paid the bills. Barr Ferree, one of the few architectural writers of the 1890s willing to say the quiet part aloud, put it in one sentence in 1893: “Current American architecture is not a matter of art, but of business. A building must pay, or there will be no investor ready with the money to meet its cost. This is at once the curse and the glory of American architecture.” [SK17] Cass Gilbert, architect of the Woolworth Building, compressed the same truth to seven words: the skyscraper is “a machine that makes the land pay” [SK64]. Every chapter of this book runs on that sentence. The skyscraper is the most expensive way humanity has ever found to sell floor space, and everything about it - the skeleton, the elevators, the curtain wall, the zoning envelope, the observation deck - exists because someone calculated that a vertical acre could be worth more than a horizontal one.

The machine had a floor plan. The typical early skyscraper office was a cubicle about twelve feet wide strung along a long corridor, a layout first used at Peter Ellis’s Oriel Chambers in Liverpool in 1864 and imported wholesale into Chicago and New York [SK17]. Small firms rented one or two cubicles and expanded by renting the next one over; the building was, in effect, a stack of identical, infinitely subdivisible rental units. Light determined geometry. Before air conditioning and dependable electric light, no desk could sit far from a window, which is why the era’s plans are full of light courts, atria roofed in glass, and narrow wings - the Woolworth Building’s architects bragged that every office stood within ten feet of a window [SK11]. Ground floors paid for the rest: shops and restaurants at street level rented for five or six times the office rate, and lobbies were fitted out in Numidian marble and bronze not from vanity but as advertising, to signal solvency to tenants and their clients [SK17]. The tripartite Chicago facade - ornate base, plain shaft, clear crown - was the same logic in elevation: spend where the passerby and the tenant’s visitor can see it, save everywhere else [SK17].

Inside, the building employed a workforce of its own. The Chicago Board of Trade, one of the best-documented of the early towers, spent a fifth of its rental income on forty-one service employees - janitors, elevator operators, engineers, an electrician - and the big towers added shops, barbers, tailors, newsagents, restaurants, and libraries until contemporaries described them, accurately, as small cities [SK17]. The building manager emerged as a new profession. Chicago’s Owen Aldis, whom Louis Sullivan credited as one of the two men responsible for the modern office building, put the management of towers on a systematic footing: by the end of the century he had created over a million square feet of Loop office space and was managing nearly a fifth of it, treating a skyscraper as a portfolio of leases to be actively traded, modernized, and remarketed [SK5].

Aldis’s maxim - that no well-designed office building should ever need to be demolished for obsolescence - guided the Monadnock’s repeated modernizations across the twentieth century and remains the industry’s founding defense of the type [SK5].

The machine also changed who worked in it. The first towers were male spaces, full of tobacco smoke and profanity, as alarmed contemporaries put it; then the typewriter arrived - from 146 machines in American offices in 1879 to 65,000 by 1890 - and with it the typist and the stenographer [SK17]. In Chicago the share of clerical workers who were women rose from 11 percent in 1880 to 30 percent by 1900, a shift in the composition of the white-collar workforce that the office tower both housed and accelerated [SK17]. The expanding corporations of the era - insurance, railroads, manufacturing trusts, mail-order houses - needed clerks by the thousand, and the clerks needed desks near light, near transport, and near one another. The skyscraper was the machine that stacked them.

By 1913 the pattern was set that still governs the industry: a speculative or corporate owner assembles a parcel, borrows against projected rents, builds to the envelope the law and the market allow, and fills the stack with tenants whose combined rent must service the debt, pay the forty-one service staff, and return a profit on the land [SK17]. When the calculation works, the building is a Cathedral of Commerce. When it does not - when the office market softens, the technology dates, or the neighborhood moves - the same machine produces the Singer Building’s fate: the world’s tallest tower, razed at sixty years old, because its narrow floors no longer earned their ground rent [SK23]. Understanding the skyscraper means holding both outcomes in view at once.

PART IV - THE TECHNOLOGY STACK

Chapter 9 - From cage to tube: the structure learns to think

For eighty years the skyscraper got taller by making the same bargain: a dense grid of steel columns, braced against the wind, paying what engineers call the premium for height - every additional floor demands more material to hold up the floors above and to resist a wind that grows with the square of the building's size. The Empire State Building, supreme product of the cage era, consumed about 42 pounds of steel per square foot of floor. By the 1960s the bargain was strangling the type: beyond roughly sixty or seventy stories, a conventional frame spends so much on stiffness that the tower stops making money. The man who broke the ceiling was not an architect but a structural engineer, and his idea came from bamboo.

Fazlur Rahman Khan was born in Dhaka in 1929, in a city with no building taller than three stories, and trained as a civil engineer before taking his doctorate at the University of Illinois and joining the Chicago office of Skidmore, Owings and Merrill [SK12]. The bamboo that sprouted around Dhaka lodged in his mind: a hollow tube, thin-walled and jointed, that stands many feet tall against the monsoon wind [SK12]. Khan's insight was that a tall building is a vertical cantilever sticking out of the ground, and the efficient shape for a cantilever is not a forest of sticks but a tube - all the structural material pushed to the perimeter, where its leverage against overturning is greatest [SK7]. The framed tube, first realized in the 42-story DeWitt-Chestnut Apartments in Chicago in 1963, turned the exterior wall into the structure: closely spaced perimeter columns tied by deep spandrel beams, a perforated hollow box that resists wind the way the bamboo does [SK12][SK59].

Then Khan iterated, fast. For the 100-story John Hancock Center in Chicago, completed in 1969, he added giant diagonal braces across the perimeter - the trussed tube. The X-bracing does more than stiffen: it redistributes gravity loads across the frame, letting the tube behave as a stiffened box and making the structure itself the facade, the giant silver Xs that are still the building's entire visual identity [SK7]. The Hancock used about 30 pounds of steel per square foot - the 145 kilograms per square meter of Chapter 2 - less than many forty-story cages [SK7][SK12]. For Sears, Roebuck in 1970 he bundled nine square tubes into a single 225-foot-square plan, the tubes rising to different heights and terminating in steps at the 50th, 66th, and 90th floors; the Willis Tower reached 1,450 feet and 110 stories at roughly 33 pounds of steel per square foot - less than the Empire State used to reach a height it exceeded by 200 feet - and the bundled tube saved Sears an estimated $10 million against conventional framing [SK6] [SK28]. Khan then translated the trussed tube into concrete, replacing diagonal

steel members with filled-in window panels on buildings like 780 Third Avenue in New York, proving the concept worked in the cheaper material that would dominate residential towers [SK7]. The trussed tube's descendants include the Onterie Center, the Citigroup Center, and I.M. Pei's Bank of China Tower in Hong Kong [SK12].

The system's final mutation is the tallest building on Earth. For the Burj Khalifa, SOM - where Khan had worked until his death from a heart attack in Jeddah in March 1982, aged 52, still a general partner - developed what his successors called the buttressed core: a hexagonal central concrete hub with three wings, each wing buttressing the other two, stepping back in a spiral of setbacks as it rises [SK8][SK9]. The Burj is a tube turned inside out: the stiffness lives in the core and the buttressing wings rather than the perimeter, an arrangement suited to reinforced concrete and to a tower that is mostly hotel and residence rather than office [SK8]. It reached 828 meters in 2010. The lineage from Dhaka bamboo to Dubai is direct and documented - Khan's tube concept, extended by the firm he built, is the structural reason the supertall era exists at all [SK12].

The tube revolution changed the economics as much as the engineering. By cutting the premium for height, it reopened the race that the Depression and the war had closed: almost every building in the top hundred today stands on some descendant of the framed tube, the trussed tube, the bundled tube, or the buttressed core. The skyscraper's second century belongs to Khan the way its first belonged to Jenney.

Chapter 10 - The wind

Gravity is honest: it pulls straight down, it never changes its mind, and a structure that survives its first day will usually survive gravity forever. Wind is dishonest. It pushes, gusting and eddying; it sucks, creating leeward suction that can exceed the pressure on the windward face; and around a tall, regular object it sheds vortices in an alternating rhythm - vortex shedding - that can lock onto the building's own natural frequency and set the whole tower swinging like a tuning fork. Occupants get seasick. Facade seals fail. Elevator cables slap their shafts. By the 1960s, as Khan's tubes made ever taller and lighter towers possible, wind replaced gravity as the load that designs the skyscraper, and it has never handed the job back.

The engineers' first answer was stiffness, and the measure of the era's progress is the steel bought for each square foot of floor: the Empire State's 42 pounds, the Willis Tower's 33, the Hancock's 30 [SK12][SK6]. One widely read reference renders the same trio as 42, 33, and 26 pounds per square foot, but it is measuring structural stiffness - a related accounting, not the same one [SK28]. But stiffness alone scales badly - a mile-high tower built stiff would be solid metal at the base. The second answer was to confuse the wind itself. A prismatic tower presents the same face to the air at every height, so vortices shed coherently up the whole height and reinforce one another. Break up the shape and you break up the rhythm. The Burj Khalifa's spiral of setbacks was tuned in the wind tunnel exactly so that the vortices shed at different frequencies on different parts of the tower, never organizing into a single coherent push; SOM's engineers describe the building's sculpted, stepping form as an aerodynamic device as much as an aesthetic one [SK9][SK8]. The Shanghai Tower takes the strategy furthest. Its outer glass skin - one of two layers, the tower is a stack of nine cylindrical zones wrapped in a twisting outer sheath - completes a full 120-degree rotation from base to crown, a form refined in wind tunnels that cuts wind loads on the building by 24 percent against a comparable rectangular tower. That single design decision saved roughly 25 percent of the structural steel a conventional 632-meter design would have needed: shape is a budget line [SK33]. Even so, the tower carries its own tuned mass damper: a 1,000-tonne mass spanning five floors at the crown, known as the Shanghai Eye - the largest in the world when commissioned in 2016, and the first in a high-rise to dissipate motion as eddy currents in a copper plate rather than heat in oil, raising the tower's damping from 1 to 3 percent of critical and cutting the acceleration occupants feel by nearly half [SK33][SK62]. At 632 meters there is no such thing as too much insurance against resonance.

The third answer is to let the building move and pay a counterweight to move against it. A tuned mass damper is a pendulum or sliding mass, tuned to the tower's natural frequency, that sways out of phase with the building and bleeds

the motion away as heat. The type's famous exemplar hangs in Taipei 101, slung between the 87th and 92nd floors on eight 42-meter cables, and on public view: a 660-tonne sphere of 41 stacked steel plates, five and a half meters across, designed and built by the firm Motioneering [SK35][SK61][SK74]. Taipei 101 sits in one of the world's most punishing environments: typhoon winds every autumn, and a major fault line just 200 meters away. Outrigger trusses at eight-floor intervals lash the central core to the perimeter megacolumns; the great pendulum absorbs the wind; two further six-ton dampers at the tip of the spire keep the antenna itself from fatiguing; and the curtain wall is detailed to ride through 95 millimeters of seismic displacement without damage [SK35]. Together they let a 508-meter tower stand where the first generation of engineers would have called the site unbuildable [SK35].

Seismic design is wind design's mirror: the earthquake shakes the base instead of pushing the top, but the tower answers with the same vocabulary of stiffness, mass, damping, and ductility - the ability of steel and properly reinforced concrete to bend without breaking, dissipating the quake's energy through controlled deformation rather than sudden failure. The modern supertall tower is in this sense a musical instrument that must never be allowed to resonate: its shape detunes the wind, its mass dampers absorb the resonance that remains, and its structure is detailed to flex rather than snap. Every gleaming needle in this book's later parts is, underneath the glass, a machine for disagreeing with the weather.

Chapter 11 - The machine in the shaft

Every skyscraper is built around a hole. The elevator core - shafts, lobbies, machine rooms - is the one part of the floor plate that earns no rent, and the entire history of vertical transportation is an effort to move more people through less hole. The arithmetic is brutal: a 100-story office tower that ran a single bank of elevators from the lobby to every floor would be mostly shaft. The technologies that made towers past fifty stories viable are, at bottom, strategies for shrinking the core, and they deserve their own chapter, because without them Khan’s tubes would be sculptures full of stairs.

The first problem was speed. Elisha Otis’s safety brake made the elevator trustworthy in 1852, but the early machines were slow; Otis’s roped hydraulic elevator of 1878 reached 800 feet per minute, and the electric gearless-traction machines that followed made express service practical - the Woolworth Building’s twenty-six Otis cars ran at up to 700 feet per minute, astonishing for 1913 [SK4] [SK11]. The second problem was automation. The Empire State Building opened in 1931 with sixty-one Otis passenger elevators and six freight cars, marketed as “robot elevators” for their automatic controls, handling tens of thousands of trips a day [SK4]. The third problem was the one that mattered most: geometry. Otis’s double-deck elevator, introduced in the Cities Service Building in 1932, stacked two cabs in one hoistway so eight shafts did the work of sixteen [SK4].

Then came the idea that defines the modern supertall: the sky lobby. If you cannot run every car from the ground, treat the building like a metro system - express cars to interchange stations partway up, local cars from there. The World Trade Center’s twin towers, for which Otis won the contract in 1967, organized their 110 floors around sky lobbies, with express and local systems that shrank the structural core and freed enormous areas of rentable floor; Otis called it arguably the largest vertical-transportation system in history to that date [SK4][SK14]. The Willis Tower planned 103 elevators, fourteen of them double-deckers, with sky lobbies at the 33rd/34th and 66th/67th floors, from which local banks fanned out to the office stories above; as of 2018 the system carried millions of trips a year, and one freight car ran the full 1,440 feet from basement to roof, reserved for the fire department in an emergency [SK32]. The Burj Khalifa’s sixty-five Otis elevators include the world’s fastest double-deck machines at ten meters per second [SK4][SK8].

Speed itself became a record category: the Shanghai Tower’s express elevators hit 20.5 meters per second, the world’s fastest at the building’s 2015 opening, before Guangzhou’s CTF Finance Centre edged past at 21 meters per second in 2017

[SK33]. At those speeds the physics shifts from hoisting to aviation - pressure management so passengers' ears survive the descent, aerodynamic cab shrouds, active roller guides to suppress vibration.

The final transformation is intelligence. Otis's Elevonic 101 of 1979 put microprocessors in charge of dispatching, coordinating speed, position, and direction against the building's traffic flow [SK4]. Modern destination-control systems ask passengers where they are going before they board and group them by destination, cutting both waiting time and the number of shafts a given population needs. Remote monitoring followed - OTISLINE in 1983, and today's IoT platforms that watch every car in real time and predict failures before they strand anyone [SK4]. And a quiet revolution in the machine room - its abolition, with compact gearless machines inside the hoistway - returned still more space to rent. The elevator began as a safety demonstration at the Crystal Palace; it is now the dispatching brain of the vertical city, and the constraint that decides, more often than steel does, how tall a tower can usefully be.

Chapter 12 - What the ground will bear

Every skyscraper begins as a hole and a wager. The wager is that the ground - invisible, heterogeneous, saturated, and unforgiving - will carry the load without moving. All the glamour of the skyline rests on the least photogenic part of the building, and the history of foundations is a history of cities learning what their own soil would tolerate.

Chicago’s soil was the first great teacher. Beneath the Loop lies spongy clay, dozens of feet of it, too soft to carry concentrated loads and too deep to dig through. John Root’s answer, devised for the Montauk Building in 1882 and perfected on the Monadnock, was the floating foundation: a broad raft of steel rails and concrete that spread the building’s weight across the clay like a snowshoe, accepting that the building would settle and designing it to settle evenly [SK5]. The Monadnock was designed to settle eight inches; by 1905 it had passed that, and by 1948 it had sunk twenty inches - so much that visitors step down from the sidewalk to enter [SK5]. The settlement was a success, not a failure: the walls never cracked, because they sank as one. But the lesson stood: Chicago clay had a ceiling, and heavier towers would have to go through the clay to something harder.

That meant caissons - watertight chambers, invented in England in 1830, in which men could excavate below the water table and pour concrete piers down to bearing strata [SK17]. The Reliance Building’s frame stands on caissons sunk as much as 125 feet [SK22]. New York’s pneumatic caissons, sunk under air pressure that kept the water out while sandhogs dug the muck by hand, carried the Manhattan towers to their bedrock; the work was dangerous, the bends a routine occupational hazard, and it remained the standard method for half a century [SK17].

The tube era deepened the game. The John Hancock Center’s engineers, expecting Chicago’s usual strata, found bedrock far deeper than anticipated; the building needed fifty-seven concrete caissons reaching down as much as 197 feet - the deepest foundation yet attempted - bored by a massive auger, sheathed in steel, and poured in segments [SK7]. When one six-foot caisson abruptly shifted an inch in a single day in the summer of 1966, under the weight of a lone steel column, the engineers drilled three holes the full length of the shaft and mapped its interior by lowering sensors and reading the returning pulse wavelengths - an early, improvised use of sonic integrity testing that has since become standard practice [SK7]. The Willis Tower followed with 201 caissons, 114 of them socketed into the underlying limestone [SK32].

Asia turned foundation engineering into a heavyweight contest of its own. The Petronas Towers sit on what were, at construction, the deepest building foundations in the world: 104 concrete piles per tower, bored between 60 and 114 meters down, capped by a raft of 13,200 cubic meters of concrete poured continuously over 54 hours for each tower [SK34]. The choice of high-strength concrete for the towers' structure, familiar to Asian contractors and twice as effective as steel at damping sway, doubled the weight the foundations had to carry [SK34]. Taipei 101's 380 piles reach 80 meters into the ground, extending 30 meters into bedrock, anchoring the tower against the fault line 200 meters away [SK35]. The Burj Khalifa's foundation is comparatively modest - a mat 3.7 meters thick, poured in four lifts totaling 12,500 cubic meters, on bored piles 1.5 meters in diameter and 43 meters long - because Dubai's geology, for all its faults, is kinder than Taipei's [SK8]. The pattern generalizes: the taller the tower and the worse the ground, the more of the building's real engineering budget is spent below the sidewalk, in concrete no one will ever see.

Chapter 13 - The skin

The curtain wall that Atwood hung on the Reliance Building in 1895 spent its first half-century as a promising minority taste. Terracotta and plate glass were still assembled piece by piece on site, behind masonry conventions; the wall was non-structural but not yet a product. What turned it into the defining surface of the twentieth-century city was a trio of buildings in five years: Mies van der Rohe’s apartment towers at 860-880 Lake Shore Drive in Chicago in 1951, the United Nations Secretariat, and SOM’s Lever House on Park Avenue in 1952 [SK27] [SK13]. With them the glass box arrived, and Part VI tells its story as architecture; this chapter is about the wall as a machine.

The machine’s first marriage was with air conditioning. A sealed glass skin is only habitable if the building can cool itself, and a fully air-conditioned building no longer needs windows that open. Lever House made the bargain explicit and, unusually, published its arithmetic. Gordon Bunshaft and Natalie de Blois of SOM wrapped the 21-story slab in fixed heat-absorbing glass and stainless steel: the curtain wall cost $28,000 more than ordinary sash windows, the double glazing $135,000, and a custom window-washing gondola $50,000. In return the sealed envelope cut $90,000 from the air-conditioning system’s upfront cost, $3,600 a year from its energy bills, and $2,000 a year from window washing - each of the 1,404 fixed panes could be cleaned in ninety seconds, a third of the time a sash window took, by two men riding the gondola on a six-day cycle [SK13]. The numbers are the whole story of the modern facade in miniature: spend on the skin, save on the services, and count the savings forever. Lever Brothers’ staff, most of them women in 1952, worked in offices all within 25 feet of glass, in a tower whose slab was deliberately kept 53 feet deep so that no desk would sit in darkness [SK13].

The wall industrialized. Aluminum extrusions took over from steel and bronze in the 1970s, and fabrication split into two philosophies: stick systems, assembled mullion by mullion on the building; and unitized systems, factory-glazed panels a full story high, trucked to the site and craned into place, trading factory cost for field speed and quality control [SK27]. At the luxury end, Mies’s Seagram Building of 1958 - chosen by Phyllis Lambert, the Seagram heir who had vetoed the company’s original pedestrian design and persuaded her father to hire Mies - proved the wall could be a bespoke product: vertical mullions of architectural bronze, spandrels of Muntz metal, and amber-gray glass, aging in public like a violin [SK30]. At the volume end, the unitized panel made the identical glass wrap available to every developer on earth. The tension between those two ends - Seagram’s hand-finished bronze and the anonymous extruded grid - runs through every skyline photograph of the last seventy years.

The physics kept tightening the screws. Glass had to admit light and view while excluding heat, glare, ultraviolet, noise, water, and wind pressure; it had to tolerate the building's sway and, after the attacks and accidents of later decades, resist blast [SK27]. Each demand layered on technology: tinted and heat-absorbing glass, then reflective coatings, then insulated double glazing, then low-emissivity coatings that pass visible light while reflecting infrared. The furthest development returns, full circle, to the idea of the wall as a climate device in its own right: the Shanghai Tower's outer skin is a second facade wrapped around nine stacked interior zones, the cavity between them acting as a thermal buffer - the building wears a glass overcoat - while the twist of that overcoat works on the wind, as Chapter 10 described [SK33]. A wall that was invented to carry nothing now manages light, heat, air, water, wind, and blast, and its engineering budget rivals the frame's. The skeleton made the skyscraper possible; the skin decides whether anyone can afford to work in it.

PART V - THE CLASSIC AGE, 1916-1940

Chapter 14 - The law draws the skyline

In 1915, on the full block of Broadway between Pine and Cedar Streets, the Equitable Life Assurance Society replaced its burned-out headquarters with the bulkiest object American capitalism had yet produced. Ernest Graham's Equitable Building rose 40 stories and 555 feet straight up from the sidewalk, with not one inch of setback, and packed 1.2 million square feet of offices onto the lot - each upper floor 30,000 square feet, an H-plan squeezed to the legal maximum [SK20]. The building was, by the standards of its day, a magnificent piece of engineering and an act of urban violence. One journal calculated that it cast a seven-acre shadow; the Singer Building, briefly the world's tallest, stood in permanent shade to its 27th floor, the City Investing Building to its 24th, and at least three smaller neighbors never saw direct sun again [SK20]. Nearby owners did what New Yorkers do: they filed for reduced property assessments, arguing in effect that the Equitable had stolen their sky [SK20].

The political response had been brewing since 1913, when the city's Building Commission published its first zoning studies, but the real estate industry had resisted every restraint on what an owner could do with a lot. The Equitable Building ended that argument - after it, the industry itself withdrew its objections - and on July 25, 1916, New York adopted the country's first citywide Zoning Resolution [SK20]. Its height rule was elegant geometry rather than a cap: a building could rise only so far at the street line - a multiple of street width - and then had to step back; but on one quarter of the lot, a tower could rise without limit [SK20]. The law's authors could not have designed what followed, because the law itself became the designer. Architects massed their towers as a series of mandated setbacks up to the 25-percent tower, and the silhouette the equation produced - the stepped, tapering wedding cake - became the signature of the American skyline between the wars and the official face of Art Deco [SK17]. The style the world calls Manhattanism is, at bottom, a zoning diagram rendered in limestone and brick.

The resolution's genius was that it regulated shape rather than ambition. An owner could still build as much total floor space as the market wanted - but had to stack it differently: bulk low, where the street could absorb it, and slenderness high, where the sun could get past. The 25-percent tower clause became the escape hatch through which the next generation of masterpieces climbed: the Chrysler Building's shaft and the Empire State's upper tower both occupy roughly a quarter of their lots, legally unlimited in height [SK20][SK17]. Thirty-five years later, Lever House would invert the same arithmetic - a thin slab covering well under a quarter of its plot, no setbacks required, floating over a public courtyard - proving the old law could produce the glass box as readily as the wedding cake [SK13]. Regulation, in other words, did not flatten the skyline; it composed it.

New York’s resolution became a national template through the federal Standard State Zoning Enabling Act, which spread the model across the country in the 1920s [SK20]. The deeper significance was a transfer of authorship. Before 1916, the skyline was the sum of private decisions; after it, every tower in New York - and soon everywhere - was a negotiation between the developer’s rent roll and the public’s claim to light and air. The Chrysler Building’s crown, the Empire State’s massing, Rockefeller Center’s plazas, Lever House’s open ground floor, and today’s billion-dollar trade in air rights all live inside the legal universe created in reaction to one oversized block on Broadway. The Equitable Building still stands, still sheer, still shadow-casting: the exception that wrote the rule.

Chapter 15 - The race

In the autumn of 1929, while the stock market collapsed, three Manhattan developers ran the most famous footrace in architectural history - upward. The prize was the title of tallest building in the world, held since 1913 by the Woolworth Building at 792 feet, and the contestants were the Bank of Manhattan Company's tower at 40 Wall Street, Walter Chrysler's monument to himself at 42nd and Lexington, and, arriving late, the Empire State project on the site of the old Waldorf-Astoria at Fifth Avenue and 34th Street [SK11][SK10].

H. Craig Severance's Bank of Manhattan building opened the bidding. When the designers learned that Chrysler's tower was planned at 925 feet, they added a "sun parlor," observation rooms, and a lantern capped with a flagpole to reach 927 feet themselves, and when 40 Wall Street was completed in the spring of 1930 it claimed the title - for about a month, until the Chrysler Building was completed on May 27, 1930 [SK10][SK21]. What Severance could not know was that William Van Alen and Walter Chrysler had secretly fabricated a 125-foot steel "vertex" inside the Chrysler Building's fire tower, where the rivals' surveyors could not see it. On October 23, 1929 - days before the crash - workmen raised the vertex through the crown in ninety minutes and riveted it into place: 1,046 feet, the first structure on Earth taller than the Eiffel Tower [SK10][SK29]. The sources quarrel over the exact dates and the order in which the title changed hands - 40 Wall's claim to a brief reign depends on which measurement and which month one credits - but the outline is undisputed: a hidden spire, a public ambush, and a title decided by theatrical engineering rather than by floors anyone could rent [SK21].

The Empire State group answered like men who had been watching. John J. Raskob, the General Motors financier, and Al Smith, the former governor and presidential candidate who fronted the corporation, had announced their tower in August 1929 with Smith insisting the plans had not been altered to chase the height record - a denial the municipal archivists, working from the project's 1929 blueprints, politely note "seems unpersuasive" [SK10]. When the Chrysler vertex made the tower suddenly second-best on paper, the Empire State's designers added a 200-foot dirigible mooring mast above the 102nd floor, taking the building to 1,250 feet at the observatory roof and 1,454 feet at the tip [SK10][SK28]. The mast was fantasy dressed as infrastructure: dirigibles could not safely dock at a thousand feet in Manhattan's updrafts, two attempts after opening failed, and the mast's lasting function was the one nobody admitted to - winning the race [SK10]. Meanwhile the developer Abraham Lefcourt announced a 1,050-foot tower for Times Square, fifty feet taller than the Empire State as first designed; the crash killed it and a dozen rivals [SK10].

Construction of the winner remains the benchmark against which all fast building is measured. Work began on March 17, 1930, and the building opened on May 1, 1931 - thirteen and a half months later, 102 floors, for $40,948,900 [SK28]. Starrett Brothers and Eken, the general contractors, ran the most disciplined site of the age, and the images of its riveting gangs on the open beams became the era's enduring portrait of work at height [SK28]. The Empire State Building held the world's-tallest title for nearly forty years. It also spent its first two decades nearly empty - the "Empty State Building," not fully rented until after the Second World War [SK10]. The race had been run in the teeth of the Depression, and the prize was a magnificent tower that the office market could not yet fill: proof, carved in Indiana limestone, that the skyscraper answers to two masters, and one of them was on strike.

Chapter 16 - Rockefeller Center: the classic age builds its capital

The classic era’s last word was not a tower but a city. Rockefeller Center occupies 22 acres of midtown Manhattan on land that Columbia University leased to John D. Rockefeller Jr. in 1928 - a parcel originally earmarked for a new Metropolitan Opera House, until the Met discovered it could not afford the move and the project collapsed into something far larger: a private business city, planned as a single composition, in the depth of the Depression [SK31]. Construction began in 1931 and the first buildings opened in 1933, the worst year of the crash, when no sane balance sheet argued for building anything at all. Rockefeller built anyway, and the payroll became one of the largest private relief programs in the country.

The design was deliberately anonymous and deliberately collective. The architects worked under the umbrella of “Associated Architects” so that no building could be credited to a single firm, with Raymond Hood - the era’s most gifted skyscraper stylist - as principal designer [SK31]. Their invention was to take the 1916 zoning envelope and compose with it: instead of one wedding-cake tower, a family of limestone slabs arranged around gardens, a sunken plaza, and a private street, each slab thin enough to put every desk near a window and tall enough to hold the skyline. The centerpiece, the RCA Building at 30 Rockefeller Plaza, rose 70 stories as a slab rather than a spire - a shape the zoning law had been making possible for sixteen years, here finally treated as an aesthetic in its own right rather than a compromise with it [SK31][SK20]. Radio City Music Hall and the RCA/NBC broadcasting enterprise anchored the complex in the newest mass medium; the Center was, from the start, a media company rendered in real estate [SK31].

The Empire State Building, ten blocks south, was meanwhile becoming a broadcasting mast in earnest: NBC and RCA began experimental television transmissions from its antenna in December 1931, and Edwin Armstrong tested FM radio from it in 1934 [SK28]. The two complexes settled into a division of labor that has lasted a century - one the city’s official emblem (King Kong climbed it in 1933, and more than 250 films and television series have used it since), the other its working capital of modernity [SK28]. Together they closed the era. By 1940 the classic age’s conditions - cheap money chasing scarce midtown land, an exploding clerical workforce, ornament still cheaper than abstraction - were gone, and the war froze construction outright. When American building resumed in the late 1940s, the skyscraper would return speaking a different language: no setbacks, no crowns, no limestone, and no apologies. The wedding cake was over. The glass box was next.

PART VI - THE GLASS BOX, 1945-1975

Chapter 17 - The glass box takes Manhattan

When American construction resumed after the war, the skyscraper shed its skin and its syntax at once. The setback silhouette, the limestone, the crowns and gargoyles - the whole vocabulary of the classic age - was replaced within a decade by the International Style: the flat-roofed glass prism, raised on columns, wrapped in a factory-made curtain wall. The transformation had intellectual roots in prewar Europe, but its conquest of the American downtown was a business story, and its two founding documents stand half a mile apart on the east side of Manhattan.

The first was a soap company’s headquarters. Lever House, completed in 1952 for Lever Brothers at 390 Park Avenue, was designed by Gordon Bunshaft and Natalie de Blois of SOM: a 21-story glass slab, only 53 feet deep so that no desk would be far from daylight, floated over an open public courtyard on stainless-steel columns [SK13]. Chapter 13 told the building as engineering; here it matters as a detonation. Park Avenue above Grand Central was an avenue of masonry apartment houses; within fifteen years of Lever House it was a canyon of glass office towers, the corporate heart of the country [SK13]. The building also proved the postwar corporate logic of architecture: a soap company bought itself a century of advertising out of 260,000 square feet of rentable space, because the building’s image - clean, rational, modern - was the brand [SK13].

The second document was liquor’s answer, and the era’s masterpiece. The Seagram Building of 1958 exists because Phyllis Lambert, the 27-year-old daughter of Seagram’s chief Samuel Bronfman, read the design her father’s executives had commissioned - a conventional speculative slab by Pereira & Luckman - and wrote home in horror, then led the search that hired Ludwig Mies van der Rohe, with Philip Johnson assisting [SK30]. Mies delivered the most disciplined tower ever built: 38 stories and 515 feet of bronze and amber-gray glass, set back ninety feet from Park Avenue behind a pink-granite plaza with two fountains [SK30]. Every visible decision was controlled to the inch, from the bronze I-beam mullions - structural in appearance, not in fact - to the uniform blinds that could be set in only three positions so the facade would never look ragged. The New York Times called it one of New York’s most copied buildings, and the copying was the problem: Seagram’s plaza proved so potent, and its generosity so photogenic, that the city’s 1961 Zoning Resolution wrote it into law, trading bonus floor area for privately owned public plazas - a bargain that filled midtown with pale imitations, towers behind windswept slabs of paving that had all of Seagram’s geometry and none of its grace [SK30].

The glass box won because every interest aligned. Developers loved the curtain wall’s speed and the deep, column-free floors; corporations loved the image; tenants loved the light; architects loved the discipline; cities loved the tax base. What the era lost - the street wall, ornament, the distinction between one city’s tower and another’s - was already visible to its critics. Lewis Mumford looked at the new slabs and saw “glass-and-metal filing cabinets” [SK13]. He was wrong about the best of them and right about most of them, and the argument he started has never really ended.

Chapter 18 - The state builds the tallest: the World Trade Center

The biggest skyscraper project of the century was not a private speculation but a government program. The Port Authority of New York and New Jersey, a bistate public agency rich on bridge and tunnel tolls, took over a modest trade-center idea in the early 1960s and scaled it into something the private market would never have attempted: two 110-story towers holding ten million square feet of offices - a directive from the Port Authority's own planners, who inspected the site and decided to increase the floor space until the complex rivaled the Pentagon, then the largest office building on Earth [SK14]. The justification was promotion of world trade; the instrument was eminent domain over Radio Row, a lived-in commercial district of some 323 small businesses, most of them electronics dealers, whose expropriation the project's opponents fought to the courts and lost [SK14].

The architect was an improbable choice. Minoru Yamasaki had built exactly one high-rise, a 30-story tower in Detroit, and when the Port Authority's letter arrived offering him a $280 million commission he assumed the number was a typo [SK14]. His design answer to the vast program was twin square prisms, and his structural answer came straight from Fazlur Khan's new playbook: the framed tube. Each tower's perimeter wall was a dense lattice of steel columns - the windows between them only 18 inches wide, a dimension Yamasaki chose partly to soothe his own fear of heights - carrying the wind loads at the edge so that the office floors inside could be vast, column-free lofts [SK14][SK7]. Below, engineers dug the six-story basement inside a slurry wall, a trench kept open by dense fluid and then filled with concrete - the "bathtub" that held back the Hudson - while above, wind-tunnel tests on models subjected a skyscraper to systematic aerodynamic study as few before it [SK14]. The sky-lobby elevator system of Chapter 11 made the floor plates economical.

Construction ran from 1966 to 1975; the North Tower took its first tenants in December 1970, the South Tower in January 1972, and the complex was dedicated on April 4, 1973 [SK14]. The towers took the world's-tallest title from the Empire State Building in 1970, ending a forty-year reign [SK4]. They were also, from the first day, a real-estate problem: ten million square feet of new space dumped on a softening market by an agency that answered to governors, not shareholders. The private developers who had fought the project said exactly that, and for years the state had to move its own agencies into the towers to fill them [SK14]. The lesson is structural to this book: at the top of the market, the difference between a landmark and a white elephant is not engineering but absorption - the economy's willingness to fill what was built. The towers

eventually filled, and became the city’s binary signature; their destruction on September 11, 2001, belongs to a later chapter, but no honest account of the type can pass over what the framed tube’s most famous children came to mean [SK14].

Chapter 19 - Chicago answers: Hancock and Willis

New York owned the glass-box era’s headlines, but its engineering capital remained Chicago, and in the space of five years SOM - the same firm, now with Bruce Graham designing and Fazlur Khan engineering - produced the two towers that closed the era and previewed everything after.

The John Hancock Center, topped out in 1968 and completed in 1969, was the trussed tube’s debut: 100 stories and 1,127 feet on Michigan Avenue, its giant exterior X-braces making the structure the entire facade [SK7]. Chapter 9 covered the system; the building’s further significance was programmatic. It was a true mixed-use tower - shops, offices, apartments, an observatory stacked in one shaft - and its taper made that mixture structural sense: big floor plates low, where retail and offices want them, small plates high, where apartments want windows on all sides [SK7]. Its foundation crisis - the fifty-seven caissons bored to a bedrock that lay as much as 197 feet down, and the inch that one caisson dropped in a day in the summer of 1966, caught by sensors lowered down holes drilled through the shaft itself - was the era’s most dramatic demonstration that the ground still voted [SK7]. Khan and Graham’s collaboration on it became the model of the architect-engineer partnership: Khan called himself the structural artist, and the Hancock is his signature [SK7].

The Willis Tower - born the Sears Tower - followed in 1973: nine bundled tubes, 110 stories, 1,450 feet, the tallest building in the world, a title it held for a quarter century [SK6][SK32]. Sears, then the largest retailer on Earth, needed millions of square feet and wanted them efficient; Khan’s bundled tube delivered both the record and the rent roll at less steel per square foot than the Empire State had needed to rise 200 feet less [SK6][SK28]. The building was planned with 103 elevators, fourteen of them double-deckers, organized around sky lobbies, and 201 caissons, 114 socketed into limestone [SK32]. It was also the purest statement yet of the skyscraper as corporate logistics: a company so large it stacked its own headquarters like inventory, then discovered within two decades that it preferred the suburbs and sold the tower, which has been renamed, refinanced, and renovated ever since while the skyline keeps its silhouette [SK32].

Together the two towers mark the high-water line of the first American century of the skyscraper. In 1973 the three tallest buildings on Earth were all American - two in Chicago, one pair in New York - and all built to house the American corporation at its most confident. The oil shock of that same year, the fiscal crises of the mid-1970s, and the deindustrialization of the downtowns ended the boom; for nearly two decades after the Willis Tower, almost nothing taller rose anywhere. When the race resumed, it would not resume in America.

PART VII - THE ASIAN CENTURY

Chapter 20 - Hong Kong: the laboratory of density

If New York invented the skyscraper and Chicago perfected its structure, Hong Kong was where the type became a way of urban life. The city's constraint was absolute: a small buildable area squeezed between Victoria Harbour and the Peak, an economy exploding with trade and manufacturing money, and, after 1949, wave upon wave of arrivals from the mainland. Hong Kong answered with density no Western city had attempted - the Mid-levels district above Central became perhaps the most densely developed square kilometer on Earth, its slender apartment towers rising on tiny lots at up to eighteen times the lot area under liberal zoning [SK38]. By the time America had stopped building tall altogether, Hong Kong was building tall as a matter of course.

Two headquarters announced the city's arrival as the skyscraper's new frontier. The Hongkong and Shanghai Banking Corporation - in effect the territory's central bank, issuing its currency - decided in the late 1970s that with the 1997 handover to China looming, it needed "the best bank building in the world," a conspicuous bet on the territory's capitalist future [SK36]. Norman Foster delivered it in 1985-86 at a cost that made it briefly the most expensive building on Earth, and he did it by reinventing the office tower from first principles: no conventional frame, but five groups of floors hung from giant "coat-hanger" trusses slung between steel masts at the building's ends, the structure exiled to the edges so the banking floors could be column-free; the whole 47-story machine prefabricated as a global kit - 30,000 tonnes of steel modules from Glasgow shipbuilders, service pods from Japan, floor panels from America - and assembled on site like, in the phrase of the time, a vertical jumbo jet [SK36][SK38]. The building gave its ground floor back to the city as a shaded public plaza, and organized its workforce into five "social villages" stacked between the trusses [SK36]. Not every gadget aged well - the celebrated computer-guided "sunscoop" mirrors meant to light the ten-story atrium mostly lost to the fluorescent tube - but the tower proved that the skyscraper type could still be rethought wholesale [SK36].

Five years later, I.M. Pei's Bank of China Tower rose next door, and it was a political statement in structural steel. Completed in 1990 - the first building outside the United States to exceed 1,000 feet - its seventy-two stories of triangular shafts, shedding mass as they climbed until a single prism remained, were designed with Fazlur Khan's trussed-tube lineage and meant to read as a bamboo shoot: growth, section by section [SK37][SK38]. Where Foster had designed for a colonial bank anxious about China, Pei designed for China itself, and everyone in Hong Kong read the message [SK37]. Everyone also read the feng shui. Pei's original X-bracing was redrawn as diamonds after local geomancers objected; HSBC's masters judged the new tower's sharp corners as

knife edges slashing at their fortune and answered by mounting two cannon-shaped maintenance gantries on their own roof, aimed back at the Bank of China [SK36][SK37]. The story is charming, and it is also a serious fact about the Asian century of the skyscraper: in Hong Kong, and soon across the region, a nine-figure tower’s design genuinely had to satisfy two clients - the board and the dragon.

Chapter 21 - The pencil towers: height as a financial instrument

The strangest skyscrapers of the twenty-first century are not offices, not landmarks in any civic sense, and mostly not full. They are extremely slender residential needles - 432 Park Avenue in New York runs fifteen times taller than it is wide - and they exist because of a collision between three facts: land in a handful of global districts is worth more than almost anything else; zoning lets that value be stacked if the floors stay small; and the world's wealthy will pay extraordinary prices for views they may visit twice a year [SK39]. The pencil tower is the skyscraper as a financial instrument, and its engineering is dictated by that logic as surely as the Equitable Building's bulk was dictated by the absence of zoning.

432 Park Avenue is the type specimen. Rafael Viñoly designed it for developer Harry Macklowe as a regular grid of poured white concrete - Viñoly cited a 1905 Josef Hoffmann trash can as the lattice's inspiration - precisely because he believed a concrete frame would reassure residents that a tower this thin was stout [SK39]. It topped out at 1,396 feet in 2014-15, briefly the tallest roof in New York - tall enough to need Federal Aviation Administration approval - with just 84 numbered stories, because in a residential needle the floors are few, the ceilings high, and the buyers pay by the view [SK39]. The building's thinness was legal as well as physical: nearly a quarter of its floor area is structural and mechanical space, exempt from the zoning's floor-area limits, a loophole the design leans on hard [SK39]. And its thinness was a physics problem. The tower's engineers punched five double-height open windbreak floors through the shaft, one every twelve stories, to let the wind bleed through rather than push against a solid sail; the mechanical equipment lives in those gaps [SK39]. Even so, the completed facade developed cracks under wind forces it had not fully shrugged off - a reminder that at a 15:1 slenderness, the wind is not a load case but a landlord [SK39].

The pencil towers close a loop this book opened with. The first skyscrapers stacked offices because firms would pay rent for proximity; the corporate towers stacked prestige because companies would pay for image; the needles stack views because the global rich will pay for altitude itself. Each era's tallest buildings are an X-ray of its economy, and the X-ray of the 2010s shows capital, not labor, filling the tower. It is worth sitting with what changed: the Empire State Building was built to house ten thousand workers and went half-empty for two decades; the needles were built to house a few hundred fortunes and filled immediately - on paper, at least, whatever their dark windows suggest at night.

Chapter 22 - Kuala Lumpur: the title moves east

For a quarter century after the Willis Tower, the world's-tallest title slept in Chicago. It woke up in 1998 in Kuala Lumpur, and the manner of its waking told everyone that the skyscraper's center of gravity had crossed the Pacific - and that the title itself had become ambiguous enough to fight over.

The Petronas Towers were a nation-building commission in the most literal sense: the headquarters of Petronas, Malaysia's state oil company, ordered up as the centerpiece of the Kuala Lumpur City Centre development and as Prime Minister Mahathir Mohamad's declaration that Malaysia had arrived. Cesar Pelli designed a pair of 88-story towers, 451.9 meters to the tops of their spires, joined by a skybridge at the 41st and 42nd floors; their plans and facades weave Islamic geometric motifs into a thoroughly Khan-derived tube-in-tube structure, built in high-strength concrete rather than steel - a material Asian contractors knew intimately, which stiffened the towers against sway at the price of doubling the weight pressing down on what were then the deepest foundations in the world [SK34]. Two consortia raced the two towers upward side by side, Japan's Hazama building one and Korea's Samsung C&T the other [SK34].

Then came the argument. Petronas claimed the world title at 1,483 feet - but the Willis Tower's roof was higher, its highest occupied floor was higher, and its broadcast antennas reached 527 meters, far above the Malaysian spires. The difference was definitional: Petronas's spires counted as architecture, Willis's antennas as equipment [SK32]. The dispute forced the Council on Tall Buildings and Urban Habitat to formalize four separate categories of "tallest" - to architectural top, to highest occupied floor, to roof, and to tip - a taxonomy that still governs every record claim in this book [SK32][SK1]. Petronas took the headline category; Chicago grumbled, accurately, that nobody lived or worked above the 88th floor. Both sides were right, which is precisely why the rules had to be written down. The episode established the pattern of the Asian century: the records would move east, the measurements would be engineered as carefully as the towers, and the height of a building would be, at the margins, a negotiation between physics and publicity.

Chapter 23 - Taipei 101: engineering against the elements

Taipei’s bid for the title answered the measurement wars with a sweep. Taipei 101, designed by C.Y. Lee and C.P. Wang and completed in 2004, took three of the CTBUH’s four categories at once - architectural top, roof, and highest occupied floor - and held the world title until the Burj Khalifa buried every previous benchmark in 2010 [SK32][SK26]. At 508 meters it was the first building past the half-kilometer mark, and it was built in about the least forgiving location a half-kilometer tower has ever occupied: in the Taipei basin’s soft ground, in the path of Pacific typhoons, two hundred meters from a fault line [SK35].

The engineering response was total, and Chapters 10 and 12 have already described its organs - the outrigger trusses lashing core to megacolumns at eight-floor intervals, the 380 piles reaching eighty meters down, the great 660-tonne pendulum swaying in public view between the 87th and 92nd floors [SK35] [SK61]. What deserves this chapter’s attention is the building’s double legibility. To an engineer, Taipei 101 is a survival machine whose every major system answers a documented local violence. To everyone else, it is a stack of eight upward-flaring segments - eight, the lucky number, a pagoda reimagined at supertall scale, crowned by a spire and, later, dressed in signage for the national celebrations it anchors [SK35]. The Asian century’s signature towers all perform this doubling: Petronas carries Islamic geometry, the Bank of China a bamboo shoot, the Shanghai Tower a spiral of jade. The International Style’s claim that the tall building had one universal language, learned in New York and Chicago, was quietly retired by the buildings that took the records away.

Taipei 101 also marked the moment the title stopped being the point. It cost NT$58 billion, anchored a new business district, and made its observatory and its New Year’s fireworks into the city’s identity - revenue and symbolism that justify a tower even when the office arithmetic is thin [SK35]. The next half-dozen record-holders would all be built on some version of that logic: the tower as national or civic announcement, with the rent roll as one argument among several. The skyscraper had begun as the most ruthlessly commercial building type ever devised; by 2004, the very tallest examples were the least commercial things built at scale - closer to cathedrals, finally, than the Woolworth Building ever was.

Chapter 24 - China builds the vertical century

No country has ever built tall the way China has built tall since 1990. The numbers, even in the dated list this book uses for anchors, are lopsided: of the hundred tallest completed buildings in the world as of this writing, about half stand in China, and of the four that exceed 600 meters, only one - the Shanghai Tower - is Chinese; Shenzhen's Ping An Finance Centre falls a single meter short, at 599 [SK26][SK40]. The dated numbers keep the scale honest: in 2024 alone, 138 buildings of 200 meters or more were completed worldwide, 97 of them in China, bringing the cumulative count to 2,596 - half of them Chinese - spread across 210 cities in 41 countries [SK51]. The boom's causes run through every chapter so far: urbanization on a scale without precedent, municipal governments that monetized land, state banks willing to finance monuments, and a construction industry that industrialized the supertall tower the way Chicago once industrialized the ten-story frame.

The Shanghai Tower is the boom's thesis statement, and the place to read it is Lujiazui, the Pudong finance district raised from farmland across the river from the Bund in a single generation. The tower, designed by Gensler's Marshall Strabala and Jun Xia for a company owned by the Shanghai municipal government, was planned from the start as the third and tallest member of the world's first trio of adjacent supertalls - beside the Jin Mao Tower and the Shanghai World Financial Center, a skyline assembled as deliberately as a World's Fair [SK33]. It broke ground in November 2008, topped out in August 2013, and opened in February 2015: 632 meters, 128 stories, CN¥15.9 billion [SK33]. Its engineering weaves together nearly every thread of this book. The double skin creates nine stacked vertical zones with atria between them; the 120-degree twist of the outer wall cuts wind loads by a quarter; the structure carries the largest tuned mass damper installed to that date; the elevators were the world's fastest at opening [SK33]. And its stack of uses - offices, a hotel on the 120th floor that became the world's highest, an observatory on the 121st that did the same - is the mixed-use logic of the John Hancock Center taken to megatall scale [SK33].

The honest account of China's boom must hold two truths at once. The towers are real, the engineering is world-leading, and the urban transformation behind them - hundreds of millions of people moving into cities - is the largest migration in human history. But the boom was also a fiscal machine, in which local governments sold land and celebrated height, developers built ahead of demand, and provincial skylines filled with towers whose economics were never the point. China's regulators eventually reached the same conclusion the market had whispered - and, tellingly, acted after the 72-story SEG Plaza in Shenzhen visibly wobbled in May 2021 without earthquake or storm. In July 2021 the National

Development and Reform Commission banned new buildings over 500 meters outright, strictly restricted anything over 250 meters, and required seismic review for anything over 100; that October the housing ministry went further, capping new towers in cities under three million people at 150 meters and larger cities at 250, with officials who bend the rules ‘accountable for life’ [SK40]. The era of the trophy megatall, outside a handful of global cities, is over. The vertical century China built is permanent; the era that built it is not.

PART VIII - THE SUPERTALL PRESENT

Chapter 25 - The Burj and the new geography of height

On January 4, 2010, Dubai opened the Burj Khalifa and rendered every previous argument about height obsolete in a single evening. At 828 meters it did not edge past Taipei 101; it exceeded it by more than sixty percent, the largest single leap the record has ever taken [SK26][SK8]. The tower is the fullest expression of Fazlur Khan’s legacy: SOM’s buttressed-core system, a hexagonal hub with three wings bracing each other, climbing in a spiral of setbacks that confuse the wind; a structure of high-performance concrete rather than steel; a program - Armani hotel, residences, corporate suites, observatories - mixed at a scale no office tower could support [SK9][SK8]. Its inspiration, SOM says, lies in the geometries of a desert flower; its engineering, in the bamboo of Dhaka by way of Chicago [SK9][SK7]. Fifty-seven thousand people can live and work in it; sixty-five Otis elevators, including the world’s fastest double-deck machines, keep it moving [SK8][SK4].

The Burj’s deeper meaning is geographic. When it opened, the tallest building in the world stood, for the first time since the pyramids, outside the West - in a city that had been a modest trading port within living memory, built by a developer, Emaar, as the anchor of an instant downtown, and renamed at the last minute for the ruler of Abu Dhabi, whose money had rescued Dubai’s debts [SK8][SK26]. The skyscraper had completed a journey: invented in Chicago to house insurance clerks, perfected in New York as corporate theater, industrialized across Asia as nation-building, and finally erected in the Gulf as pure spectacle - an 828-meter advertisement that the desert could host the future.

The spectacle’s economics remain genuinely contested. The Burj itself anchors a district that sells at a premium; the observation decks are reliably among the most profitable floors on Earth; and the tower’s image value to Dubai is incalculable in the literal sense. What is clear is that the megatall threshold - 600 meters, the Council on Tall Buildings’ top class - has been crossed by only four completed buildings anywhere as of this writing: the Burj Khalifa, the 678.9-meter (2,227-foot) Merdeka 118 in Kuala Lumpur - its offices about 70 percent leased by August 2025, its developer says [SK52] - the Shanghai Tower, and Mecca’s Makkah Clock Tower [SK26][SK1]. And the next leap is under construction: in January 2025, Kingdom Holding announced the restart of the Jeddah Tower, designed to exceed 1,000 meters - a full kilometer - with Adrian Smith + Gordon Gill - Smith had designed the Burj itself while at Skidmore, Owings and Merrill - and a 42-month construction contract worth SAR 7.2 billion awarded to the Saudi Binladin Group [SK15]. As of this writing the climb is real and visible: construction had stopped in early 2018 with 63 floors done, restarted in January

2025, and by September 2026 the tower stood at about 116 floors and roughly 466 meters, with 41 of its planned 157 floors to go; the developer's chief executive, Fabian Toscano, now projects completion in late 2028 - a projection, not a commitment, and the final height remains officially undisclosed beyond "a kilometre plus" [SK46][SK15]. (The CTBUH's own 2024 year-in-review dates the restart to late 2024 and lists the tower at a flat 1,000 meters - the two accounts disagree on dates and final height, and both stand here as their authors gave them [SK51].) If it finishes anywhere near that date, the kilometer tower arrives within this decade; if it stalls again, it will merely confirm the oldest rule of the type: the constraint on height was never physics. It is always money, politics, and nerve.

PART IX - THE DEVELOPMENT MACHINE

Chapter 26 - The economics of height

Every skyscraper is an argument about money that happens to be made of steel. The argument has a formal structure, worked out by the economists who study the type: a tower’s rent income rises with height, but at a declining rate - the best views are banked early - while construction cost per floor rises at an increasing rate, because every additional floor must be carried by everything below it and served by more of the building’s unrentable core. Somewhere the two curves cross, and the crossing point is the building’s “economic height” - the tower that maximizes the return on the site [SK42]. The actual skyline is a scatter of bets around that point, some rational, some vanity, all wagers on the future of a city. Measured across 140 years of Chicago data, the per-floor construction cost of a 50-story building runs about three times that of a 10-story building, the penalty rising exponentially with height; what has shifted over the century is the land side - the premium that height-primed land commands has roughly doubled, which is the economics of the skyline’s upward creep in one number [SK55].

The wagers have a discernible rhythm. Measured over more than a century, the height of the world’s tallest completed building each year has grown at a remarkably steady trend of about 1.3 percent a year - less than half the trend growth of the world economy, which is itself evidence against the popular claim that record towers are pure ego: the long run of height tracks fundamentals, not just hubris [SK43]. The average of the hundred tallest completed buildings rose from about 285 meters in 2000 to about 385 meters in 2018, roughly 1.8 percent a year [SK42]. And yet the cycle is real too. Andrew Lawrence’s 1999 “Skyscraper Index” - half joke, half diagnosis - observed that record-breaking towers tend to open on the eve of downturns: the Empire State into the Depression, the World Trade Center and Willis Tower into the 1970s stagflation, Petronas into the Asian financial crisis [SK44]. Later statistical work supplied the cleaner verdict. In the fullest peer-reviewed test, Barr, Mizrach and Mundra found virtually no relationship between record-building timing and the business cycle; instead, height and GDP per capita move together over the long run - booms predict height, because towers are conceived at the peak of optimism and completed years later, whatever the weather - but height cannot predict recessions [SK56]. The cycle story is not nothing: cheap money does inflate land, ambition, and leverage together, as the Index’s defenders formalize [SK57]. But with at least twenty-eight panics and crises against about thirteen record buildings in 125 years, the Index’s most quotable critic - Barr again - notes that even a broken clock is right twice a day [SK58].

The machine has one more gear, invisible from the street: air rights. American property doctrine begins with the medieval maxim that whoever owns the soil owns up to heaven and down to hell; modern zoning caps how much of heaven a

lot may actually use, and modern law lets the unused portion be sold [SK41]. New York turned this into a market. When Grand Central Terminal was proposed for demolition in 1954, the plan was to replace it with a 50-story tower; public protest saved the station, and the eventual MetLife Building rose beside it instead, but the logic survived - a landmark's unused development rights became a salable asset, and today's towers around Grand Central, like the 62-story One Vanderbilt - more than doubled past its site's as-of-right size by air rights transferred from the landmarked Bowery Savings Bank and by bonuses earned for transit and public-space improvements, its top floors advertised in 2021 at up to $322 a square foot - are built from bought air [SK41][SK75][SK76]. The pencil towers of Chapter 21 are the same mechanism at luxury scale: assemble enough neighbors' air, and a small lot can legally hold a very tall, very thin building.

As of this writing the machine is running its strangest cycle since the Depression. Manhattan office availability has fallen to 14.7 percent, the lowest since 2021, but the average conceals a split market: trophy towers lease fast - 21.1 million square feet changed hands in the first half of 2025 - while older Class B buildings sit stranded, and more than 15 million square feet of obsolete office space has been removed from the market by conversion to housing [SK45]. Across the country's largest markets, 2025 was the first year in at least a quarter century when office removals - demolition plus conversion, 23.3 million square feet - exceeded new completions, at 12.7 million [SK47]. The vertical city is not dying; it is sorting. Vacancy itself depends on who counts: CBRE put the national rate at a record 19 percent in mid-2025, while Cushman & Wakefield measured Manhattan's at 22.3 percent in August 2025 - the definitions differ, and so do the numbers [SK47] [SK53]. The conversions are real but slow: New York's conversion starts climbed from 1.6 million square feet in 2023 to 4.1 million through August 2025, and the national pipeline reached a record 70,700 apartments in 2025, yet of the units in development at the start of 2024, only 3,709 were actually finished by its end [SK53][SK54]. The towers that match what tenants now want are fuller than ever, and the ones that do not are becoming apartment buildings - the Woolworth Building's third career, repeated at industrial scale.

Chapter 27 - The tower and time: preservation

The skyscraper was born disposable. The Home Insurance Building stood for 46 years; the Singer Building, once the tallest on Earth, was pulled down at sixty; Chicago and New York tore through their first-generation towers so casually that by the 1960s almost nothing of the type's youth survived intact [SK3][SK23]. A building that cannot pay its ground rent has no constituency, and for the skyscraper's first eighty years, age was simply a form of financial distress.

The turning point, in the United States, was the destruction of Pennsylvania Station - the great Roman vault of the railroad age, razed from 1963 for an arena and an office slab, in the face of protests that arrived too late. New York's answer was the Landmarks Law of April 1965, which gave the young Landmarks Preservation Commission - formed in 1962 - real power to designate and protect buildings [SK48]. It is now the largest municipal preservation agency in the United States, with more than 37,800 designated properties as of 2020 [SK48]. The law's central tension has never gone away: a landmark freezes a building in a market that prices land by what can be built on it. The compromise, as Chapter 26 described, was to let the landmark sell its unused sky - and so preservation law and development law grew up together, each funding the other [SK41].

The skyscraper's own landmarks tell the story in miniature. The Woolworth Building became a National Historic Landmark in 1966, outlived the retail chain that built it, and turned residential when the market priced Gothic office floors below Gothic views [SK11]. The Monadnock survived by successive modernizations - its owners' maxim that a well-designed office building should never die of obsolescence - and by a painstaking piecemeal restoration to its 1891 condition as offices emptied [SK5]. The Reliance Building, the proto-glass tower of 1895, was restored to gleaming life between 1994 and 1999 at a cost of $27.5 million, after decades in which Chicago's own architectural heritage had been allowed to rot [SK22]. The Seagram Building's exterior, lobby, and Four Seasons Restaurant were all designated New York City landmarks in 1989 - a glass box barely thirty years old, preserved as a masterpiece of its kind [SK30]. Even the curtain wall acquired defenders: until the 1980s, almost nobody thought the glass skins of the 1950s and 1960s were worth saving [SK13]. Each generation decides which towers are assets and which are ancestors. The trend of a century runs steadily toward ancestors - which is another way of saying that the skyscraper, the most ruthlessly commercial artifact ever built, has finally been around long enough to become heritage.

PART X - THE PEOPLE OF THE TOWER

Chapter 28 - Fire in the shaft

The skyscraper’s oldest fear is fire, and its fire history is a ratchet: each disaster tightens the code, and each tightening makes the next tower safer than the last. The first teeth were the terracotta fireproofing of the 1870s and 1880s, demanded by insurers after Chicago and Boston burned, that wrapped the iron skeleton so it would not soften and let go in the heat [SK17]. The ratchet turned again through the twentieth century’s office-tower fires, and its mechanism was usually the same: a technology that existed but was not required.

The defining modern case is One Meridian Plaza in Philadelphia. On the night of February 23, 1991, a fire started on the 22nd floor of the 38-story tower and burned for nineteen hours, spreading upward floor by floor [SK49]. The building’s standpipes delivered too little pressure for the hoses; a sprinkler technician, arriving mid-fire, fixed the water pressure, but by then several floors were fully involved and hoses alone could not stop it [SK49]. Three firefighters - a captain and two men of Engine 11 - went up to ventilate the stairwells, became disoriented in the smoke, and died on the 28th floor, out of air [SK49]. The fire was finally brought under control only when it reached the 30th floor - one of the few floors in the building with automatic sprinklers installed [SK49]. That sentence is the entire argument of modern high-rise fire regulation in one line: where the sprinklers were, the fire stopped. The tower was declared a total loss and demolished in 1999 [SK49]. The codes that followed across the United States - sprinklers retrofitted or required in existing high-rises, pressurized stairs, smoke compartments, voice evacuation - are One Meridian Plaza’s legacy, written in the passive voice of building ordinances.

Fire also exposed the skyscraper’s structural secret: unprotected steel does not burn, but it weakens, and a tall building that loses its frame’s strength locally must redistribute loads instantly or fail progressively. The fires of the twentieth century proved that fireproofed steel, compartmentation, and sprinklers could keep even a nineteen-hour blaze from bringing a tower down - One Meridian Plaza never collapsed [SK49]. That record, and the confidence it built, is the backdrop against which the morning of September 11, 2001, must be understood: the one time the ratchet’s logic - fireproof the steel, compartment the floors, control the fuel - was defeated by a fuel load and an impact energy no designer had been asked to imagine, and the framed-tube towers of Chapter 18 fell [SK14]. The next chapter is theirs.

Chapter 29 - September 11

Every account of the skyscraper must stop, sooner or later, at the morning the type's assumptions were murdered. At 8:46 a.m. on September 11, 2001, a hijacked Boeing 767 struck the North Tower of the World Trade Center between the 93rd and 99th floors; at 9:02 a second struck the South Tower between the 77th and 85th [SK66]. The towers' designers had, in fact, thought about airplanes: a Port Authority document from the design years shows that an impact by a Boeing 707 - lost in fog, low on fuel, seeking an airport - was analyzed, and the structure was judged able to take it [SK14][SK66]. The buildings took the impacts. What they could not take was everything after.

The federal investigation, run by the National Institute of Standards and Technology over three years, reconstructed the mechanism with a coroner's patience [SK66]. Each aircraft, debris and atomized fuel moving at over 500 miles per hour, cut through the perimeter tube, destroyed core columns, and - decisively - stripped the sprayed fireproofing from the steel of whole floor systems. The jet fuel itself burned off in minutes; what it ignited was the ordinary, enormous fuel load of furnished office floors, burning across multiple floors at once at up to 1,000 degrees Celsius. Unprotected steel does not need to melt to fail; at those temperatures it loses most of its strength. The long-span floor trusses softened, sagged, and pulled the perimeter columns inward - the photographs of the towers' walls bowing in, minutes before the end, are the sagging floors' signature. When the south face of the North Tower and the east face of the South Tower could no longer carry their share, the sections above the impact zones came down, and the intact structure below had no conceivable way to absorb the falling mass. The South Tower fell at 9:58 a.m., 56 minutes after impact; the North Tower at 10:28, after 102 minutes [SK66]. NIST is explicit about two things the decade's folklore got wrong: the collapses were not a floor-by-floor "pancake" failure, and the fires did not melt the steel [SK66]. And the sprinklers, the hero of Chapter 28, never had a chance - the impacts severed their risers, and even intact systems, sized for a 1,500-square-foot fire, would have been irrelevant against multi-floor infernos [SK66].

The number that matters most is 2,735 - the people who died in the attacks on the two towers [SK66]. The number that matters second is the one nobody can state exactly: the many thousands who got out, down the stairs, in the 56 and 102 minutes the damaged structures stood. Those minutes were not luck. The perimeter tube's redundant load paths - the system of Chapter 9, in which the loss of columns can be worked around - held up a grievously wounded building long enough for the largest evacuation of a burning high-rise ever accomplished. The towers that fell were, in their last hour, also the towers that saved most of the people in them. Both facts are part of the type's history now.

The aftermath rebuilt the code book as surely as One Meridian Plaza had: NIST’s recommendations drove changes in fireproofing inspection, stairwell capacity and hardening, emergency lighting and communications, and occupant-evacuation elevators, and no supertall designed since has been free of that morning’s lessons [SK66]. The World Trade Center site holds, today, the memorial, the museum, the transit hub, and One World Trade Center, whose steel parapet tops out at exactly 1,368 feet - the height of the original Tower 1 - and whose spire reaches 1,776, a year and a vow in feet, ruled the official architectural top by the Council’s Height Committee after the old spire-versus-antenna argument one last time [SK67]. It is the city’s answer, in the type’s own language, to the question of whether New York would build tall again.

Chapter 30 - The people who walk the iron

The skyscraper’s most famous workforce never appears in its brochures: the ironworkers who connected the frame, hundreds of feet above the street, before there was anything to stand on but the frame itself. Riveting gangs worked in fours - a heater at the forge, a sticker-in, a bucker-up, a gun man driving the white-hot rivet home - and their rhythm set the pace of every tower from the Home Insurance Building to the Burj Khalifa’s steel crown. The Empire State’s photographs made them icons; the images of men eating lunch on a suspended beam became the era’s self-portrait. The photographs romanticized; the ledger corrects them. The official toll of the Empire State job was five dead - one demolishing the old Waldorf-Astoria, one in the excavations, three raising the new frame - the figure the contractors announced in October 1930 - the frame just topped out, months of fitting-out still ahead - to deny press reports of fourteen and a radical magazine’s forty-two, and the figure official accounts still give for the job [SK28]. The work drew the men who could do it from particular places.

No community is more bound up with high steel than the Mohawks of Kahnawake, near Montreal. The tradition began in the mid-1880s, when Mohawk men were hired as unskilled labor on a railway bridge being built across the St. Lawrence onto their land; they took to the high iron, earned a reputation as the best connectors in the trade, and turned “booming out” - traveling from the reservation to wherever the next big frame was rising - into a way of life [SK68]. Mohawk crews worked New York from the 1920s onward: the Empire State Building, the Chrysler, the George Washington Bridge, and the World Trade Center; in the 1940s and 1950s as many as 700 ironworking families lived in Brooklyn [SK68]. The Smithsonian’s exhibition on the tradition records the answer one of them gives to the question everyone asks: “A lot of people think Mohawks aren’t afraid of heights; that’s not true. We have as much fear as the next guy. The difference is that we deal with it better” [SK68]. In September 2001, Mohawk ironworkers returned to Ground Zero to cut apart the fallen towers their elders had raised - and then to build the new one [SK68].

The tower’s permanent inhabitants form their own professions. Elevator operators once ran the cars by hand - the Empire State’s “robot elevators” of 1931 were marketed precisely because they did not need them [SK4]; building engineers run the boilers, chillers, and pumps; window washers ride the descent rigs that every glass facade since Lever House has had to design for, ninety seconds a pane, on a building where wind can pin a platform against the glass [SK12]. And around all of them, the white-collar millions for whom the whole apparatus exists: the clerks of Chapter 8, the traders and lawyers and typists-turned-analysts whose willingness to crowd together at altitude is the skyscraper’s only true foundation. The tower is usually photographed from outside. It is lived from within.

PART XI - THE LIMITS

Chapter 31 - The carbon reckoning

The skyscraper is a concentration of everything the carbon age must now answer for: cement, whose production alone accounts for a large slice of industrial emissions; steel, made in blast furnaces; aluminum, made with rivers of electricity; and then fifty to a hundred years of heating, cooling, lighting, and elevating a small city. The supertall era raised the stakes geometrically - the height premium of Chapter 9 is paid partly in emissions - and the industry has begun, unevenly, to reckon with the bill.

The bill is not only in the materials. In the fullest metered study of the question, University College London's Energy Institute compared actual electricity and gas records from some six hundred ordinary British offices - a stock of two-to-thirty-story buildings, not supertalls - and found energy intensity rising with height: buildings of twenty stories or more used nearly two and a half times the electricity per square meter of buildings of six or fewer, and more than doubled their carbon emissions. The association held after accounting for age, prestige, and air conditioning; on the cause, the researchers themselves are careful - likely the harsher exposure of taller buildings to cold, wind, and sun, but not proven [SK77]. The same project undercut a supporting assumption of this whole book: that expensive land leaves no choice but the tower. On the same site, it showed, a court form can achieve higher density than a slab, and a slab higher than a tower - a theoretical result of the 1970s since confirmed on Dutch housing estates, with the achievable-density ratio running as high as three to two to one [SK77]. The skyscraper's first justification, in other words, is locally true and generally false: on a given parcel the tower does multiply the land, but a district that wanted the same floor space could house it lower, and spend less energy doing it. The type survives that finding the way it has survived everything else - because land is not sold by the district, and cities are made parcel by parcel. But the carbon reckoning begins with the knowledge that the tower is a choice, and an expensive one.

The reckoning has two fronts. The first is operational: existing towers must use less energy, and the showcase proof is the Empire State Building. In 2009 its owner, with the Clinton Climate Initiative, the Rocky Mountain Institute and its building-services contractors, announced a deep retrofit designed from a twelve-month study of the actual building: rather than settling for the ten-to-fifteen percent savings of a lighting-and-controls job, the team attacked the loads themselves - remanufacturing the existing windows into insulated units rather than merely resealing them, upgrading chillers, tightening controls - with a target of cutting the tower's energy use 38 percent and saving $4.4 million a year [SK69]. The project was watched precisely because it showed that even an icon from 1931 could be dragged into the efficiency era, and that the binding constraints on greening old towers were not physics but split incentives,

information, and capital [SK69]. The lesson generalizes: the greenest skyscraper is usually the one already built, because its structural carbon was spent decades ago. The conversion wave of Chapter 26 is, in this light, also a carbon strategy.

The second front is material. Mass timber - engineered wood products like cross-laminated timber, in which boards are glued into structural panels - turns the column-and-slab question upside down: the structure becomes a carbon store rather than a carbon cost. In July 2022, Milwaukee's Ascent MKE opened at 25 stories and 284 feet, certified the world's tallest mass timber building, a hybrid of timber slabs and columns over a concrete core and base, passing the same fire tests the Forest Service's laboratory had spent years developing [SK70][SK71]. Twenty-five stories is not a skyscraper by this book's definitions - but the trajectory matters: a century after steel killed the load-bearing wooden city, engineered wood is climbing back up the height chart, and building codes in a growing number of jurisdictions now permit timber towers the 1885 Chicago Fire generation would have found unthinkable - and uninsurable. Nobody serious predicts a mass-timber supertall. Nobody in 1885 predicted the Woolworth Building either.

PART XII - THE FUTURE OF HEIGHT

Chapter 32 - What comes next

The skyscraper’s future will be written by the same four forces that wrote its past: structure, vertical transport, money, and the city. Of these, the one with the most room left to move is the elevator. The rope has been the technology’s bottleneck since 1852: one cabin per shaft, the shaft’s length limited by the rope’s own weight, and the core eating the floor plate as towers rise - the reason very tall buildings became transfer systems with sky lobbies. Thyssenkrupp’s MULTI, unveiled as a working system at its Rottweil test tower in June 2017, cuts the rope: cabins driven like maglev trains, several per shaft, running in loops and moving sideways as readily as up - “a metro system inside a building,” as its makers put it. Its first commercial installation was announced in 2017 for Berlin’s East Side Tower, but the tower was completed in 2023 with conventional double-deck elevators instead [SK72][SK78]. If looped, rope-less vertical transport matures, the geometry of the very tall building is up for renegotiation: the core shrinks, transfers vanish, and the sky-lobby era reads, in retrospect, like the age of changing trains.

The dream at the end of every such extrapolation is Frank Lloyd Wright’s. In 1957, in his book A Testament, Wright published The Illinois: a mile-high tower for Chicago, 528 stories - later revised to 365 - with parking for 15,000 cars and 100 helicopters [SK73]. It was never buildable and never meant politely; but it was not a joke either, and its descendants are telling: Adrian Smith, the architect of both the Burj Khalifa and the Jeddah Tower, has acknowledged the Illinois in his own work’s lineage [SK73]. The kilometer tower under construction in Jeddah is, in a straight line, Wright’s mile at sixty-two percent scale.

What would actually stop a mile-high building is not any single barrier but the compound interest of all of them. The wind premium compounds; the core fraction compounds; the cost elasticity - past supertall, roughly one-for-one and rising, each extra floor costing more than the floor before - compounds; the water must be pumped, the waste pumped, the elevators multiplied, the fire brigade answered [SK55]. Jeddah’s engineers answer one item at a time - “today, you can pump concrete all the way to one kilometre” - and they are right, item by item [SK46]. The question the next century asks is not whether we can build a mile high. It is what a city would have to be, and want, for the answer to be yes.

The first skyscraper was ten stories of iron and brick over an insurance office on LaSalle Street, built because land cost too much to spread out. Everything since - the frame, the tube, the buttressed core, the curtain wall, the sky lobby, the damper, the damper’s eddy currents - has been elaboration of that one economic sentence, in dialects of steel, glass, concrete, and now timber. The sentence is not finished. Somewhere tonight there is a city running out of ground, a developer

running the numbers, an engineer sketching a section through a tower that does not yet exist. The skyscraper is what happens when those three meet. They are still meeting.

Glossary

Buttressed core. The Burj Khalifa's structural system: a central concrete hexagon with three wings, each wing buttressing the others, so the tower braces itself by its own plan shape.

Bundled tube. Fazlur Khan's system for the Willis (Sears) Tower: nine square tubes side by side, stopping at different heights, acting together as one wide, stiff structure.

Caisson. A deep foundation element: a shaft sunk through weak ground to bedrock or dense soil, filled with concrete, carrying a column's load down past the made ground.

Curtain wall. A building skin that carries only its own weight and the wind, hung from the frame like a curtain - the glass and metal wall of the modern tower.

Damper (tuned mass damper, TMD). A large mass near a tower's top, mounted so it can swing against the building's motion and absorb it, cutting the sway occupants feel.

Floor-area ratio (FAR). The ratio of a building's total floor area to the area of its lot - the number through which zoning writes the city's bulk.

Framed tube. Khan's system for the World Trade Center towers: closely spaced exterior columns tied by deep spandrel beams, so the whole outer wall works as one hollow tube.

Height premium. The extra cost of building each additional floor at greater height - more structure, more core, more elevator - the reason height is bought reluctantly.

Landmarking. Legal protection of a building against demolition or alteration, administered in New York by the Landmarks Preservation Commission.

Megatall. The Council on Tall Buildings and Urban Habitat's class for a building 600 meters or taller.

Mullion. The vertical member between the panes of a curtain wall.

Outrigger. A stiff horizontal truss or wall, usually at a mechanical floor, tying the central core to the perimeter columns so both fight the wind together.

Safety elevator. Elisha Otis's 1852 device: a spring catch that locks the elevator car to the guide rails if the hoisting rope fails - the invention that made vertical transport trustworthy.

Setback. A step back of a building's upper floors from its street line, required by New York's 1916 zoning to let light and air reach the street; the origin of the wedding-cake tower.

Skeleton frame. Construction in which a frame of iron or steel columns and beams carries all loads, and the walls are mere enclosure - the structural idea the skyscraper is built on.

Sky lobby. An interchange floor in a very tall building where passengers leave the express elevators that brought them from the ground and board local elevators for the higher floors - the device that makes one hundred floors stackable.

Spire versus antenna. The Council's height rules count a spire - a permanent architectural crown - in a building's height, but not an antenna, which is functional equipment; the distinction has decided more than one tallest-building title.

Supertall. The Council's class for a building 300 meters or taller.

Transferable development rights (TDRs). The "air rights" of the New York system: unused floor area a lot may sell to a neighboring lot, letting a low landmark stay low while its allowance builds high next door.

Tube system. The family of structures - framed tube, tube-in-tube, bundled tube, diagrid - in which a tall building's exterior does the wind work, the idea that governs every supertall today.

Vanity height. The distance between a tower's highest occupied floor and its architectural top: height that wins titles but houses nobody.

Zoning. The municipal law of use and bulk: what may be built where, and how large. The 1916 New York ordinance and its successors are co-authors of the skyline.