INDUSTRIES OF INDIA

THE ELEVATOR

Rope, Brake, Sky



KETINENI RAMARAO

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Prologue

The Sixth Floor

> *For most of the history of cities, the best rooms were closest to the ground. Wealth lived on the first floor above the street; servants climbed to the attic. A single machine reversed the price of height, and with it the shape of every city on Earth.*

Walk the oldest quarters of Paris, Rome or New York and you walk through the world the elevator inherited. The buildings rise five or six storeys and then stop, not because masons could not build higher - medieval cathedrals had already proved that - but because legs could not climb higher. A city of stairs has a hard ceiling, and it sits at roughly the sixth floor. Beyond it, healthy adults arrive winded; the old, the injured, the pregnant and the laden do not arrive at all.

That ceiling fixed the economics of height. In the walk-up city, a building's prestige drained away as you climbed. The piano nobile, the noble floor, sat one flight above the street: high enough to escape the mud and the smell, low enough for silk stockings and bad knees. Above it, each storey was worth less than the one below, until the garret, where the ceiling sloped and the stairs were narrowest, housed the servants, the students and the poor. The mansard roof, that hat of attic rooms Paris wore into the nineteenth century, was an attempt to make the least valuable space in the building slightly less miserable.

Everything about the modern city assumes this arrangement is gone. The penthouse is the most expensive floor. The corner office looks down. A hotel sells its view by the metre, and a tower's rents rise with altitude, a gradient so familiar we forget it is an artefact. Somewhere between 1850 and 1900, in a handful of buildings in New York, Chica-

go and Paris, the gradient inverted. The floors that had been cheapest became the most desired, and the city - which had always grown outward, block by block - began to grow upward, shaft by shaft.

The machine that did this is so ordinary now that it barely registers as a machine. You step into a small room, press a number, and trust a system you cannot see: ropes you have never inspected, brakes you hope never to test, a motor in a room you will never enter, and a body of safety code written over a century by people responding, one after another, to everything that ever went wrong. The scale is difficult to measure consistently across countries: sources count journeys, passengers and installed units differently. The safety record also needs careful denominators. Passenger travel and hazardous work inside a shaft are different exposures; combining them into a single transport ranking conceals more than it explains.[2]

This book is the story of that machine as an industry - because an elevator is never just an elevator. It is a steel rope drawn from wire rod, a motor wound with copper, a microprocessor running traffic mathematics, a maintenance contract renewed for thirty years, an installer on a scaffold in the shaft, an inspector with a code book. It is Otis in Connecticut, KONE in Finland, Schindler in Switzerland, TK Elevator in Germany, Mitsubishi and Hitachi in Japan, and a vast Chinese industry that now builds most of the world's new units. It is the reason the skyscraper exists, the reason the deep mine exists, the reason a wheelchair user reaches the fourth floor, and the reason a city's most valuable real estate is in the sky.

To find all of that, begin where the book must: with the load, the rope and the pull.



The world the elevator inherited: six storeys of stairs, and a hard ceiling on the city.

Part I

The Ancient Hoist

> *Give me a place to stand, and I will move the Earth.*
>
> Archimedes, on the lever - the first theory of lifting

Chapter 1

Load, Rope, Pull

> *The elevator's ancestry is not a staircase but a crane. Long before anyone rode a lift, someone lifted a load - and the problem of lifting is where the whole industry begins.*

Every elevator that has ever existed answers one question: how do you move a weight straight up? The answers, in order of appearance, are muscle, the pulley, the winch, the water wheel, steam, water pressure, and finally the electric motor. The passenger cabin is a late addition - an afterthought that took four thousand years to arrive. For almost the whole of that history, the load was stone, grain, ore or timber, and the idea of a person trusting their body to a rope would have seemed reckless. It was.

The pulley is the oldest of the lifting answers, and it deserves respect. A single wheel changes the direction of a pull, letting a crew haul down on a rope to raise a stone. Block and tackle - pairs of pulley wheels trading distance for force - let one person lift what twenty could not. The Greek world understood these machines well enough to theorise them: Archimedes of Syracuse, in the third century BC, worked out the mathematics of the lever and is credited by later writers with compound pulleys and with the boast that a fixed point would let him move the Earth itself.[3] Whether or not he said it, the point stands: by the time of Archimedes, lifting was already a science, with ratios, not just a knack.

The Roman world industrialised it. Roman builders raised the columns and entablatures of the Forum with treadwheel cranes - great wooden wheels in which men walked like hamsters, their

weight winding a drum. A Roman treadwheel crane, rebuilt by modern engineers from contemporary evidence, could lift several tonnes, and its descendants stood on European building sites into the nineteenth century. The lifting machinery of the medieval cathedral - the wheel high in the nave of Strasbourg, the treadmill cranes on the quays of Gdansk and Bruges - was Roman in principle and barely improved in execution. Lifting was a solved problem. Safe lifting was not.

The distinction matters because it explains the elevator's long delay. A load of stone falling kills no one standing on it. The rope, the windlass, the wooden brake: all were held to the standard of a cargo, and cargo is patient. What cargo machinery lacked was not power but a guarantee - some way of answering the question every passenger's body asks before the mind does: what happens when the rope breaks? Until someone could answer that, the lift would carry everything except us.

Chapter 2

The Machinery Under the Arena

> *The most sophisticated lifts of the ancient world were built not to carry goods or people but to make lions appear as if from nowhere. The Colosseum ran on elevators.*

Under the arena floor of the Flavian Amphitheatre - the Colosseum, opened in Rome in 80 AD - lay the hypogeum: two storeys of corridors, cages, cells and machinery, invisible to fifty thousand spectators. The entertainment depended on surprise. A beast that walked up a ramp was a spectacle; a leopard that materialised in the middle of the arena, as if conjured, was theatre. So the Romans built lifts.

Archaeologists working in the hypogeum, most thoroughly the German team led by Heinz-Jürgen Beste, counted the traces of at least two dozen lifting platforms, and the evidence of capstans - the cross-armed vertical winches whose grooves are still chipped into the brickwork.[4] Each platform was a timber stage slung on ropes over pulleys, raised by crews turning capstans in the corridors below. To bring up a loaded cage of animals, a capstan gang of eight men heaved on the arms; the platform rose on guide timbers; a trapdoor in the arena floor flipped open on its own counterweight as the platform arrived; and the animal, released from its crate by a timed gate, stepped out into sunlight and noise. Some platforms carried scenery - entire painted forests rising out of the floor. The machinery could put hundreds of animals into the arena in the course of a morning.

It is worth pausing on what this means. Two thousand years ago, in the centre of a city of a million people, there existed a coordinated system of vertical transport machines - staged, guided, synchronised, worked by trained crews, maintained as permanent infrastructure. The hypogeum was, in effect, the first building with a lift system. And it already contained the elevator's defining bargain: the machinery stays hidden, the arrival looks effortless, and nobody in the audience thinks about the rope.

In 2015, Italian engineers and craftsmen completed a working reconstruction of one of the Colosseum's lifts, built from the archaeological evidence and Roman techniques, and used it to raise a wolf into the arena for the first time in fifteen hundred years.[5] The machine worked essentially as Beste's team had read it from the grooves in the walls. The Roman lift needed no rediscovery; it only needed an audience again.



The hypogeum lifts: capstan gangs, timber platforms, and theatre delivered from below.

CHAPTER 3

Monasteries, Mines and the Man Engine

> *Between Rome and the industrial revolution, lifting lived in two places that could not do without it: the inaccessible monastery and the ever-deepening mine.*

The monks of Meteora, perched on sandstone pillars above the plain of Thessaly, hauled supplies - and, on occasion, visitors - up the cliffs in nets on windlass ropes. The tradition held that the rope was replaced only when it broke, which is best read as a joke about faith, but it states the passenger problem exactly: everyone understood the rope as the weak point, and everyone who rode the net did so knowing it.

The mine was more systematic. As European mining deepened through the late Middle Ages, the problem of moving ore, water and men down and up shafts became the frontier of lifting technology. Georgius Agricola's De Re Metallica (1556), the great handbook of Renaissance mining, illustrates the machinery in loving detail: hand windlasses and horse whims, water-wheel-driven hoists, and buckets on chains.[6] The mine introduced something new to the lifting arts - depth. A cathedral crane lifts sixty metres; a mine hoist must lift hundreds. Depth multiplies everything: rope weight, winding time, the cost of an accident, and the sheer daily tonnage that must cross the shaft collar.

Depth also produced the first serious attempt to lift people as cargo, in the harrying shape of the man engine. By the nineteenth century, Cornish and German miners faced climbs of hundreds of metres down ladders at the start and end of a shift - an exhaustion so severe it was shortening working lives. The answer, patented in its mature form in the 1830s and 1840s, was a moving rod running the depth of the shaft, with small platforms at intervals, driven up and down in strokes by the steam engine above. The miner stepped on at one level and off at the next, stroke by stroke, riding the rod like a slow, segmented elevator. Man engines carried thousands of men daily; they also killed with some regularity, since a missed step between moving platforms meant the shaft. At the Levant mine in Cornwall in 1919, thirty-one men died when the connection between the reciprocating rod and beam failed.[7] The man engine is the elevator's dark cousin: proof that the demand to move people vertically existed long before the machinery was trustworthy, and a measure of what people will risk when the alternative is the ladder.

Water, meanwhile, was learning to lift in a new way. The same mine shafts that needed hoists needed pumps, and the Cornish steam engines built to drain them were the most advanced engines on Earth.

Steam would soon lift directly. But first it would lift freight, in a new kind of building that the industrial revolution was already filling with goods: the warehouse.

Part II

Steam and Water

The freight did not complain about the rope. That was the whole problem - and the whole opportunity.

Chapter 4

The Freight Hoist and the Warehouse City

> *The elevator's true birthplace is not the skyscraper but the warehouse. Steam made hoisting cheap; cheap hoisting made tall storage pay; and tall storage taught building owners to think vertically a generation before passengers would.*

The industrial revolution arrived on the ground floor and immediately ran out of room. Cotton, grain, hardware, sugar, machinery - the new economy moved physical volume on a scale no previous age had known, and it needed to store that volume near the ports and canals where it arrived. Land at the water's edge was dear. The obvious move was up: pile the goods higher. A warehouse of five or six floors multiplied the owner's land without buying more of it, provided the goods could be raised - and provided nobody had to carry them on their back.

Steam answered. A small engine in the basement, driving line-shafting and belts, could run a hoist all day for the cost of coal, lifting loads no gang of men could manage and doing it without rest. By the 1820s and 1830s, steam hoisting platforms were ordinary equipment in British and American mills and warehouses: an open platform, a chain or rope over a drum, guide timbers at the sides, a trapdoor at each floor.[8] Nobody wrote manifestos about them. They were plant, like the boiler itself. But their consequences quietly accumulated. The mill districts of Manchester and the dock warehouses of Liverpool and New York grew taller. The idea that a building's upper floors were useful - even valuable - took root in the one class of people whose opinion would soon matter: the men who owned buildings.

The freight hoist also assembled, piece by piece, the technology the passenger elevator would need. Guides to keep the platform true. Counterweights to balance the load. Indicators to show the floor. Rope drums and braking gear. And a body of bitter knowledge about failure, because hoists fell. Ropes frayed invisibly inside their lay; chains stretched at their links; a drum brake held by a man's attention failed with it. Insurance inspectors' reports from the period treat a falling hoist as a known industrial hazard, one among boilers and shafting. Freight could take the risk. The public could not be asked to. Everyone who thought about lifting people - and by the 1840s architects and speculators were thinking about it - ran into the same wall: the machine existed, but the guarantee did not.

So the stage was set with unusual clarity. Demand: cities filling, land prices rising, buildings pressing against the stair ceiling. Supply: every component of a passenger lift except one. The missing piece was not a motor or a material. It was an answer to the oldest fear in lifting - the severed rope.

Chapter 4A

The Other Elevator

> *In North America the word "elevator" names a second machine entirely: the grain elevator, the steam-age colossus that turned a harvest into a flow - and proved vertical bulk handling could run a continent's trade.*

Ask a Kansan for an elevator and they will not show you a cabin. The grain elevator is a bucket conveyor in a tower: an endless belt studded with scoops, rising through a wooden or concrete leg, lifting grain from the receiving pit to the head house, where it is weighed and

spouted into bins. Developed in Buffalo by Joseph Dart and Robert Dunbar in the early 1840s, it mechanised the one bottleneck of the grain trade - getting the harvest up into storage and out again - and it did for bulk goods what the passenger lift would do for people: replaced muscle and stairs with a machine and a shaft.[72] Buffalo's elevators made the city the hinge between the Erie Canal and the Great Lakes; the concrete grain elevator districts that followed, from Chicago to the Canadian prairies, were the tallest structures most of the continent possessed - and their stark vertical slabs so impressed European modernists that Le Corbusier and Gropius reproduced photographs of them as the architecture of the future.[72]

The two elevators share more than a name. Both are machines for moving value vertically against gravity and against time; both created their own architecture (the shaft, the silo); both turned land economics on its head - one by stacking floor space, the other by stacking a commodity. And the grain leg is still, in its bones, the same machine as the mine hoist and the passenger car: a loop, a drive, a trust that nothing lets go.

Chapter 5

The Hydraulic City

> *Before electricity, the cleanest power in the city was water under pressure - and for half a century the finest lifts in the world ran on it, fed by pumping stations that worked like a power grid fifty years early.*

The hydraulic lift is a simple, elegant machine: a ram in a cylinder, water forced in beneath it, the platform rising on the column of water. William Armstrong's hydraulic crane at Newcastle in the 1840s

showed what pressurised water could do, and engineers were quick to apply it to lifting people. The early direct-acting plunger lifts needed a cylinder buried as deep as the lift was tall - fine for two floors, absurd for ten - but roped hydraulics multiplied the ram's travel with pulleys, and the hydraulic lift climbed to meet the growing city.[9]

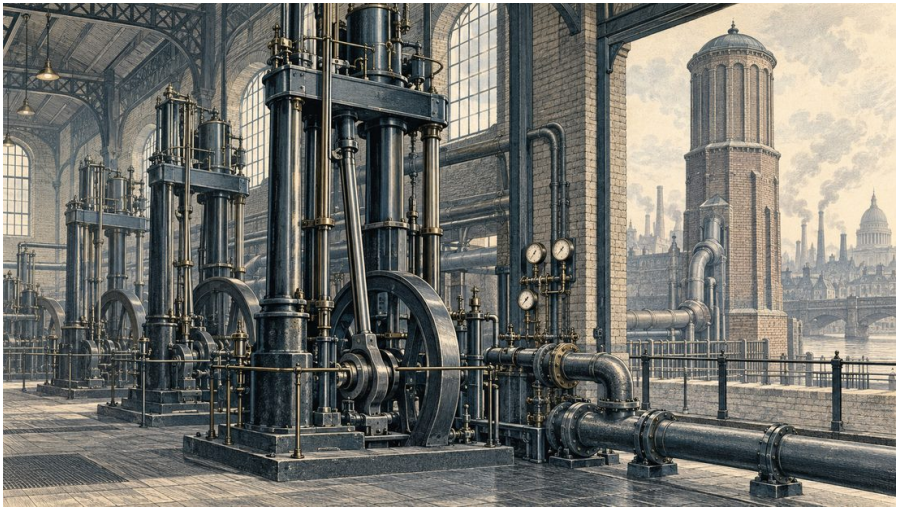
What made hydraulics an industry rather than a curiosity was the network. Instead of a pump in every building, why not pump water for a district and sell the pressure? London did exactly that. The London Hydraulic Power Company, formed in 1883 from predecessors going back to 1871, laid high-pressure water mains under the capital and sold hydraulic power the way the gas companies sold gas.[10] At its peak the network ran for well over a hundred miles of mains, feeding thousands of machines: lifts in hotels and offices, dock cranes, theatre curtains, the bascules of Tower Bridge. Pumping stations at Wapping and elsewhere kept the pressure up, and strange towers dotted the city - hydraulic accumulators, great weights riding on rams, storing pressure against demand. Paris, Liverpool, Manchester, Melbourne and Sydney built networks of their own. For a few decades, a city could be plumbed for power as readily as for water.

The hydraulic era left two legacies. The first is the machine itself: hydraulic lifts are smooth, strong and quiet, and their descendants are still installed by the hundred thousand - the roped hydraulic and the modern holeless ram remain the one established answer for low-rise buildings, and when you ride a short-rise lift, a hydraulic installation may be doing the work. The second legacy is subtler: the hydraulic network was the first proof that lifting could be a utility. Power generated centrally, distributed invisibly, billed by use - the pattern electricity would inherit.

The era's monument still stands over Paris. When the Eiffel Tower rose for the 1889 exposition, its elevators were the most demanding lifts yet built: cabins climbing the curved legs on inclined tracks, and five hydraulic machines going into service that June, with American engineers from Otis solving the hardest ascent - the long, curving run to the second level - when the tower's own builders found it beyond the available French technology.[11] The tower made the lift a public attraction in its own right: crowds queued to ride as part of the attraction. Tens of millions have done it since.



1889: the Eiffel Tower's hydraulic lifts - the first time the public queued to ride.



Pressure as a utility: the pumping station and accumulator towers of the hydraulic city.

Chapter 5A

The Plunger's Problem

> *Every hydraulic lift fights the same geometry: the cylinder must be as deep as the lift is tall. The war against that hole in the ground drove half a century of invention - and its truce still rules the low-rise world.*

The direct-acting plunger lift is the simplest machine in this book: a steel ram in a buried cylinder, water pumped beneath, the car riding the column. Simple - except the cylinder must descend the full travel below the pit, drilled through whatever the geology offers. For a two-storey shop, trivial. For a ten-storey block, a forty-metre hole lined against groundwater and settlement: expensive, slow, sometimes impossible.

The industry's answers were characteristically elegant. Roped hydraulics hung the car from sheaves on a short ram, multiplying travel two, four, six times - so a short cylinder served a tall rise, at the price of ropes and their maintenance. The water companies answered from the supply side: the accumulator, a great weight riding a ram in a tower, storing pressure so that a modest pump could serve sudden demand - the visible towers of Chapter 5's hydraulic city.[9] And when electricity arrived, the pump and motor moved into the building's basement, turning the hydraulic lift into a self-contained product any structure could order.

The modern descendant is the holeless hydraulic: telescoping rams beside the car, no deep bore at all, serving two to six storeys - the vast middle of the world's building stock. When the machine-room-less electric lift (Chapter 22) attacked that territory in the 1990s, the hydraulic did not vanish; the two divided the low-rise world between them, and the argument - oil versus ropes, basement versus shaft-top - is one every small building still settles in its own way.

Part III

The Man Who Made Falling Safe

> *All safe, gentlemen. All safe.*
>
> Elisha Graves Otis, at the Crystal Palace, 1854

Chapter 6

Mr Otis's Spring

> *The invention that created the elevator industry was not a way to make a lift move. It was a way to make it stop - a spring, two pawls, and a craftsman who understood exactly which fear he was selling the cure to.*

Elisha Graves Otis was not looking to found an industry. In 1852 he was a forty-one-year-old mechanic - a born tinkerer who had tried farming, doll-making and running a sawmill - employed to build a bedstead factory in Yonkers, New York. The factory needed a hoist to move its heavy machinery between floors, and Otis, like every practical man of his time, knew what hoists did: they dropped. His employer could afford to lose freight less than most, since the freight was the machinery itself. So Otis fitted his hoist with a device of his own.[12]

The device was beautiful in the way only mechanical answers can be. He mounted a stout flat spring - the same wagon spring that cushioned carts - above the platform, and ran the hoisting rope through it. As long as the rope pulled, it bowed the spring, and the bowed spring held two steel pawls clear of the toothed guide rails on either side of the shaft. The instant the rope went slack - cut, snapped, unshipped - the spring snapped straight and drove the pawls into the rack teeth on both sides at once, wedging the platform fast. The machine's normal state depended on the very thing that could fail; failure itself was what triggered the safety. No attendant's attention, no second rope, no vigilance was required. A broken rope did not merely stop pulling the platform up; it actively locked the platform to the building.

That inversion - making the accident operate the brake - is the true founding act of the elevator industry, and it deserves the standing it has in the history of safety engineering, beside the steam boiler's safety valve and the railway's automatic brake. Otis saw its value at once, patented an improvement, and by 1853 was selling hoists with the device from his own small shop. The company he founded dates itself from that year.[13] Orders came in ones and twos. The world did not yet believe.

What is striking, reading the story, is how completely Otis understood that his problem was not engineering but trust. The spring worked from the first day. What didn't work was persuading strangers to stand on a rope. That required theatre - and Otis turned out to be very good at theatre.

Chapter 7

All Safe, Gentlemen

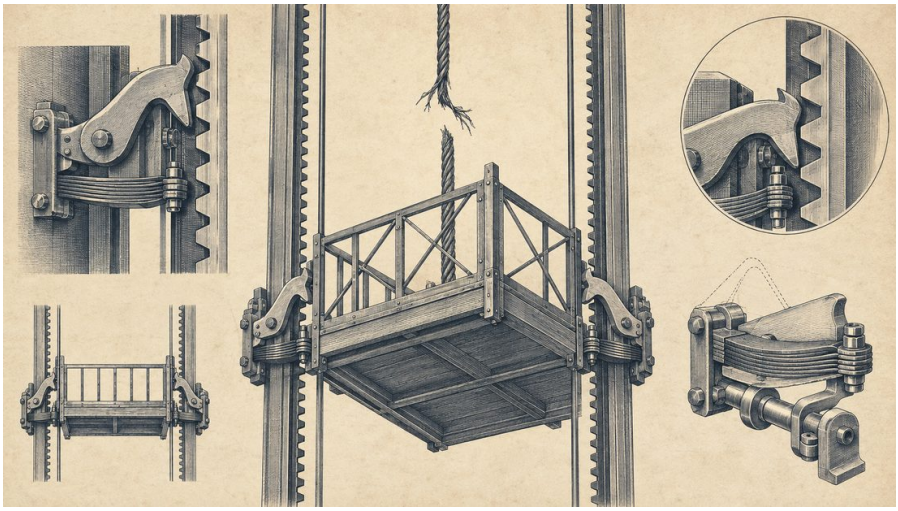
> *A defining product demonstration in elevator history took place on an open platform above a crowd in New York, and its entire script was a man, an axe, and a cut rope.*

The Exhibition of the Industry of All Nations opened in 1853 in New York's Crystal Palace, an iron-and-glass hall modelled on London's, at what is now Bryant Park. Among the machinery on show, a lanky man in his forties ran a peculiar daily ritual. He mounted an open hoist platform, had himself raised high above the crowd, and then - at the top, with the audience watching - had an assistant cut the hoisting rope with an axe.

The platform dropped the distance of a breath and stopped. The spring had straightened; the pawls had bitten into the guide rails. The man steadied himself, took off his hat, and delivered the four words that founded an industry: "All safe, gentlemen. All safe."[14]

Everything about the performance was engineered - and not only mechanically. Otis understood that the audience's fear lived precisely at the rope, so he put the rope at the centre of the stage and destroyed it in public, daily, betting his life on a wagon spring to teach the crowd what his patent claims could not: that the accident had been designed for. The demonstration did for the elevator what no specification could. It made safety visible.

He repeated the act through 1854, and the orders improved - eight elevators sold that year, fifteen the next.[13] They were still freight hoists. The passenger, the real prize, required one more step: a customer willing to put the public on the rope, and a building worth doing it in. Both arrived in 1857, on Broadway.



The safety brake: a wagon spring, two pawls, toothed rails - and the accident made to work the lock.

Chapter 8

The Passenger

> *The first passenger elevator served a five-storey shop of astonishing luxury, and its cargo was not convenience but wonder. From the beginning, the lift sold the ride as much as the floor.*

The E.V. Haughwout Building went up in 1857 at the corner of Broadway and Broome Street, in the cast-iron district of New York, to hold one of the most glamorous businesses in America: Eder Haughwout's emporium of cut glass, silver and china, supplier of tableware to the White House. Mary Todd Lincoln shopped there.[13] The building was five floors of ornate cast iron - a material that was itself teaching buildings to go vertical - and Haughwout wanted his wealthy customers to see every floor without a climb. He installed an Otis steam-powered passenger lift, Otis's first commercial passenger installation: an enclosed cab in a shaft, worked from the basement, safe by the spring and pawl.

The choice of a department store as the passenger elevator's first home was no accident, and it set a pattern that runs through the whole history of vertical transport. The elevator arrived as retail theatre. Riding it was an experience to be offered to customers, like the plate glass and the chandeliers; the store that had one drew crowds who came partly to ride. The same logic would fill the Eiffel Tower's cabins thirty years later and the observation decks of supertalls a century and a half later: vertical travel as attraction. Convenience came afterwards.

The early passenger lift was a different species from today's. It was slow - walking pace, because steam winding and Victorian nerves agreed on it. It was staffed: an attendant ran the machine, and the passenger was a guest, not an operator. And it was rare enough to be

news. Through the 1860s, lifts spread into the places that could justify wonder at a price: the grand hotels (the Fifth Avenue Hotel's "vertical railway" was itself an advertisement), the finest stores, a few clubs and public buildings.[15] Office buildings - the use that would eventually swallow all the others - had yet to move. In 1870, they did, and the city changed for good.

Otis himself did not live to see it. He died in 1861, aged forty-nine, leaving the firm to his sons Charles and Norton, who built it into the Otis Brothers company and then, through consolidation, into the Otis Elevator Company. The father's contribution was the founding insight, and it is still the industry's: the passenger elevator is a machine for manufacturing trust.

CHAPTER 8A

The Hotel's Vertical Railway

> *The grand hotel was the passenger lift's second home and its finishing school: the place where riding became part of luxury, and where the machine learned manners.*

When New York's Fifth Avenue Hotel opened in 1859 with its 'vertical railway' - a steam lift carrying guests to six floors of unheard-of convenience - the advertisements mentioned the machine by name.[15] The logic ran deep. A hotel sells comfort to strangers; stairs are the enemy of comfort, especially with trunks, corsetry and candlelight. The lift let hotels rise, pack in rooms, and charge for the upper floors' quiet. By the 1870s no first-class American hotel could open without one; European palaces followed.

The hotel also professionalised the ride. The uniformed attendant, the scheduled service, the separate service lift so that linen and luggage never met the guests - the grammar of vertical hospitality was written in these buildings, and much of it survives. The modern hotel tower is an elevator building before anything else: its brand promise (a quiet room in the sky, bags delivered ahead of you) is a lift-system specification wearing a logo.

Part IV

Wiring the Vertical

The rope was always the limit. Then electricity took hold of the wheel, and the wheel took hold of the height.

Chapter 9

The Electric

> *In 1880, at a provincial exhibition in Mannheim, Werner von Siemens put a motor under a platform and showed the future. It climbed at walking pace, and it ended the age of everything else.*

Werner von Siemens was already one of the great electrical men of Europe - the dynamo, the telegraph, the first electric railway - when he turned to the lift. At the Mannheim exhibition of 1880 he demonstrated the first electric elevator: a platform raised by a motor beneath it, working through gearing on the dynamo-electric principle. Some eight thousand visitors rode it during the show.[16] It was not fast, and it was not yet a building machine, but the principle was decisive. Steam needed a boiler and a fireman; hydraulics needed a pressure main or a pump house; the electric motor needed only wires. Any building could have one. Every building eventually would.

The 1880s and 1890s were the sorting decade, when the electric lift absorbed everything the older systems had learned and then outpaced them. Early electric machines wound the rope onto a drum, like the steam hoists they replaced - simple, but limited: a drum can only hold so much rope, so a drum machine caps a building's height at the drum's length of lay. For the ten- and twelve-storey buildings now rising in Chicago and New York, something better was needed, and it arrived by turning the oldest enemy of the machine - friction - into the worker.

Chapter 10

Rope and Sheave

> *The traction elevator does not wind its rope; it grips it. In that grip - steel wire on a grooved steel wheel - lives the whole possibility of the tall building.*

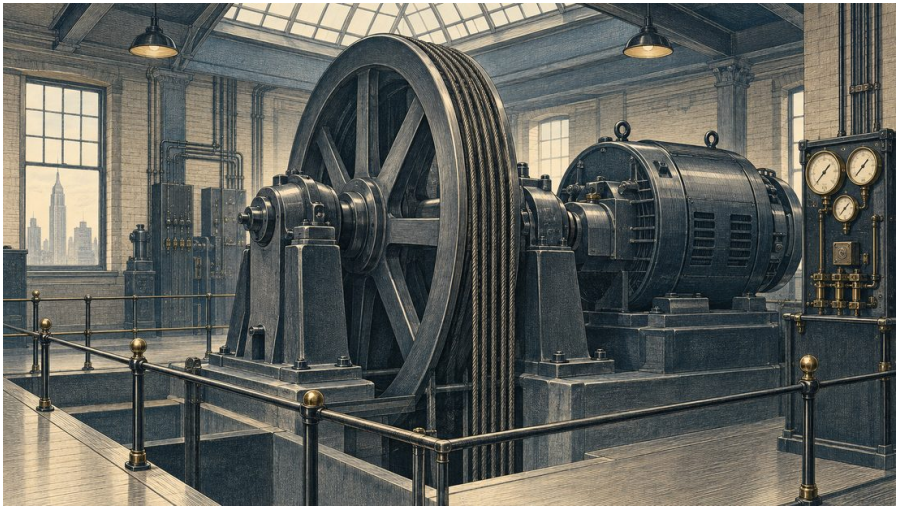
Watch a traction elevator work in your mind's eye. Over a grooved wheel - the sheave - high in the shaft, passes a set of steel ropes. On one side they carry the car; on the other, a counterweight balanced to the car plus roughly half its rated load. The motor does not reel the rope in. It simply turns the sheave, and friction in the grooves drags the ropes over it, raising one side as the other descends. The car and counterweight trade places like buckets over a pulley, and the motor only ever lifts the difference.

Each element of that sentence is an industry in itself. The rope: not a rope in the hardware-store sense but wire rope - steel wires twisted into strands, strands laid around a core, a product whose modern form was invented in the German mining districts in the 1830s and which underlies every cable-car, crane and suspension bridge as much as every lift.[17] The counterweight: an idea so old it serves in medieval drawbridges, here doing the quiet work of reducing the unbalanced load the motor must move. The sheave: cast and machined steel, its groove profile a science of its own, because traction is friction, and friction decides how much out-of-balance load the machine can lift before the ropes slip.

The theory of that grip - how the ratio of tensions on the two sides of a wrapped rope grows exponentially with the angle of wrap - was worked out for elevators in the early 1900s by the Otis engineer Fred Hymans, whose rope-traction papers became foundational texts of vertical transport.[18] With theory came design freedom: roping could

be arranged 1:1, rope straight to car, or 2:1, through a pulley on the car itself, halving car speed relative to rope speed and doubling mechanical advantage. Compensation ropes hung beneath car and counterweight kept the balance honest as the main ropes moved from one side of the sheave to the other. The traction machine was no longer a blacksmith's winch; it was applied mechanics.

One problem remained. The motors of the 1890s were happiest spinning fast, and elevator sheaves turn slowly, so a worm gear sat between them - and gears waste power, wear, whine, and cap the machine's speed. The answer was to remove the gear entirely and build a motor slow and strong enough to drive the sheave directly. When that machine arrived, the skyscraper arrived with it.



The gearless machine: a motor slow, vast and direct, with the building's height hanging over its sheave.

CHAPTER 10A

The Wire Rope: An Industry Inside the Industry

> *Every traction lift in the world hangs on a product invented for the mines of the Harz mountains in 1834 - and wire rope's own century of craft is what made Otis's promise affordable.*

Before wire rope, lifting lines were hemp (weak, rot-prone, stretchy) or chain (strong but unforgiving: one bad link fails without warning). Julius Albert, a mining official in Clausthal, twisted the first wire rope in 1834 for the Harz silver mines - steel wires laid into strands, strands closed around a core.[17] The idea spread through every lifting art on Earth: mining hoists first, then cranes, suspension bridges (Roebling built his Brooklyn cables on wire-rope craft), cable railways, and finally the passenger lift. The rope solved a subtle problem: strength with flexibility, so the line could wrap a drum or sheave thousands of times a day; and graceful failure, since wires break one at a time, visibly, on the surface - a rope announces its retirement to any inspector who runs a rag along it. That inspectability is a safety feature as real as Otis's spring, and the modern code mandates rope retirement criteria based on counted broken wires.

The elevator rope of today is a precision product: eight-strand, high-carbon steel, drawn and closed by specialists; multiple suspension ropes share the load, with safety factors specified by the applicable code. Its twentieth-century refinements - independent wire-rope cores, preforming, plastic-impregnated cores - all came from the hoisting trades. And its twenty-first-century successor, the carbon-fibre tape of Chapter 20, is the first credible challenger in 180 years. When the rope changed, the height limit changed. That is what a component industry looks like when it matters.

Chapter 11

The Machine That Removed the Ceiling

> *In 1902 Otis built an electric elevator machine with no gearbox at all. Installed from 1903, the gearless traction drive made height itself a solved problem - and it still runs the tallest buildings on Earth.*

The gearless traction machine is exactly what its name says: the motor's armature and the driving sheave turn on the same shaft, with nothing between. No worm, no gears, no oil bath - just a large, slow, immensely strong DC machine, built like a mill engine, with the ropes passing over its sheave. Otis developed the design in 1902 and put the first commercial installations into service from 1903.[19] The gain was total. Speeds that worm gears could not sustain became routine; heights that drums could not wind became ordinary; efficiency, smoothness and durability all improved at once. The machine room of a high-rise - that cathedral of a slow-turning giant, humming at the top of the shaft - was born.

It is one of the quiet facts of technology that the core of this machine has never been displaced. A century of refinement - better steels, variable-voltage drives, permanent-magnet motors, digital control - has not altered the arrangement: sheave, ropes, car, counterweight, and a direct-drive motor at the top. The lifts in the Empire State Building and the lifts in a new Mumbai tower are, in principle, the 1903 machine. Few technologies earn that sentence. The gearless traction drive is one of them.

Height now ceased to be an elevator problem and became a traffic problem. A single shaft could serve any practical rise, but a tall building cannot give every passenger an express ride from the lobby - the shafts would eat the floor plate. The industry's next century would be

spent managing that arithmetic: zoning, sky lobbies, double-deck cars, destination control. The machine had removed the ceiling. What remained was the queue.

And a framework of fear, now industrialised into rules. As lifts multiplied, so did the codifiers: governors to catch overspeed, oil buffers at the pit floor to absorb a falling car, interlocks to hold the landing doors shut against an absent car. Each device answered an accident that had happened to someone. The elevator was becoming what it remains - a machine whose safety depends on coordinated technical and regulatory systems.

Chapter 11A

The Governor, the Buffer, the Interlock

> *Three unglamorous devices complete the safety stack. None of them ever does anything - that is the job.*

High in the machine space, a small wheel turns with the car, spun by its own steel rope: the overspeed governor. If the car ever runs away, the governor rope races with it; centrifugal flyweights fling outward at a set speed - as specified for the particular machine and applicable code - and jam the rope. The jammed rope, still tied to the car's safety gear, drags the safeties into the guide rails and wedges the car fast. It is Otis's spring, generalised: a complete second machine whose only purpose is to detect failure and call the brake.[49]

At the bottom of the shaft stand the buffers: oil cylinders or springs rated for specified impact conditions - the pit's last mercy. And at every landing, the interlock: the electromechanical marriage of door and controller that Alexander Miles's 1887 patent began, which will not let the car move until every door is proved closed, nor let any

door open until the car is proved present.[26] Governor, buffer, interlock: detection, absorption, prevention. Between them and the ropes' redundancy, the falling car of the public imagination has become an event so rare that when one occurs anywhere on Earth, it makes news worldwide. The devices' quiet is the loudest statistic in transport.

Part V

The Vertical City

Rent is the shape of the city, and the elevator redrew it floor by floor.

Chapter 12

Eight Floors That Changed Rent

> *In 1870 a New York insurance company built an office block around its lifts, and discovered that with the stairs gone, the top of the building was the best of the building. The economics of height have never recovered.*

The Equitable Life Assurance Society's building at 120 Broadway, completed in 1870, was seven storeys plus a mansard - not tall by later standards, but revolutionary in arrangement: the first office building designed from the start around passenger elevators.[20] Contemporary accounts credit its success with changing what an upper floor was worth. Where the walk-up office had discounted every flight of stairs, the Equitable's lifts made the upper floors not merely acceptable but desirable: quieter, lighter, above the street. Tenants paid premiums to rise. The building was such a commercial triumph that its successors kept raising the bet, and New York's newspapers soon noticed the new arithmetic of the skyline: height paid.

Pause on the inversion, because it is the elevator's deepest effect. For five thousand years the vertical gradient of value ran downward: live low, climb poor. The lift reversed it in a generation. By the 1920s the penthouse - the roof-level floor that in the walk-up world had been the servant's attic - had become the most expensive address in the building, a word that still carries the inversion in its bones. Every modern city prices its altitude. The view, the quiet, the light, the status of the high floor: all of it is rent on the elevator's reliability. When the

machine is trusted, height is an asset; where lifts fail, as any resident of a broken-down tower block knows, the old gradient reasserts itself overnight, and the sixth floor becomes the cheap floor again.

The elevator did not merely serve the tall building, then. It repriced it - and in repricing it, created the economic engine that would drive buildings higher than any architect's ambition could have justified on its own.

CHAPTER 12A

The View Becomes the Product

> *Once the lift could be trusted, altitude itself became merchandise - the observation deck, the rooftop restaurant, the penthouse premium: an economy of height with no ceiling but engineering.*

The Equitable's lesson generalised into whole business models. The Eiffel Tower's lifts made altitude an admission ticket in 1889; the Empire State Building turned its 86th floor into one of the most visited places on Earth; today the observation decks of the supertalls - the Burj Khalifa's At the Top, Shanghai Tower's, One World's - sell access to a view, and every one of them is an elevator ride sold.[11] The restaurant trade followed altitude up: the revolving restaurant sold the view with dinner. Hotels put their prices in their floors' numbers.

The residential market completed the inversion. The penthouse - once the servant's garret under the leaking roof - became by the mid-twentieth century the most expensive floor in the building, and the super-prime towers of the present sell altitude at rates that would have baffled the walk-up world: height as luxury good, underwritten by the reliability of a machine the buyer will never see. When the machine fails - a stalled tower-block lift is a story this book takes seriously - the

premium collapses instantly, which is only the same fact read backwards: the view was never the product. The lift is the product. The view is its dividend.

Chapter 13

Steel Frames and the Arithmetic of the Sky

> *The skyscraper has two parents. The steel frame made it structurally possible; the elevator made it financially rational. Neither alone builds tall.*

Histories of the skyscraper usually begin with the frame: William Le Baron Jenney's Home Insurance Building in Chicago (1885), skeleton construction, curtain walls, the Bessemer process's cheap steel. All true - and all inert without the lift. A steel frame can stand twenty storeys, but it cannot lease them. The chain of logic runs the other way: elevator trust made upper floors valuable; valuable upper floors made tall buildings profitable; profitable tall buildings made steel frames worth erecting. When the early skyscraper men argued for height, they argued from rent rolls, and the rent rolls ran on Otis.

The frame and the lift then grew up together in a ratchet. Each lift improvement - the electric machine, traction, the gearless drive of 1903 - raised the height at which a tower still made sense; each new height record - the Metropolitan Life and Woolworth towers of 1913 at 241 metres, for seventeen years the world's tallest - normalised altitude for tenants and cities. By the 1920s, Manhattan was zoning for towers and Chicago was arguing about whether to. The elevator had become what economists would call general-purpose infrastructure: the technology inside every other technology of the vertical city, from the high-rise hotel to the multi-storey hospital to the department store's upper floors.

There is a quieter arithmetic the lift also fixed: the core. Every floor of a tower must give some of its area to shafts, and as buildings rise, the shaft count rises with them, because more people need more lifts. There is a height - different in every era, set by the lift technology of the day - at which the core would eat the building. Managing that arithmetic is the hidden design problem of every supertall, and the industry's answers - zoned banks, sky lobbies, double-deck cars - are chapters of this book. The skyscraper looks like a story about steel. Read the floor plans, and it is a story about shafts.



1913: the Woolworth era. The frame made the height possible; the lift made it pay.

Chapter 14

Sky Lobbies and Stacked Cities

> *The World Trade Center's engineers reached the elevator's wall - shafts eating the tower - and solved it the way railways solve distance: express lines, local lines, and stations in the sky.*

By the 1960s the arithmetic of the core was closing in on the supertall. A conventional all-local lift system for a 110-storey tower would have required so many shafts that the lower floors would have been more core than office. The Port Authority's team for the World Trade Center, led on the engineering side by figures like Guy Tozzoli and working with Otis, adopted instead an idea that had floated around the industry for decades: the sky lobby.[21] Express lifts - big, fast cars running non-stop from the ground - flew to transfer floors at the 44th and 78th storeys. There, passengers changed to local banks serving the floors above, exactly as a subway rider changes from express to local. Crucially, the expresses and locals could share the same vertical shaft space, stacked: the tower was, in effect, three shorter towers piled on top of one another, and the shafts for the upper zones never reached the ground.

The saving was enormous - the system cut the core's appetite for floor area by a wide margin and helped make the towers' vast, column-light floor plates leaseable at all.[22] The sky lobby has been standard practice in supertalls ever since: the Sears (Willis) Tower, the John Hancock Center, and every kilometre-chaser of the present century runs on express-local logic. The Burj Khalifa, the Shanghai Tower, the Guangzhou CTF - all are stacked cities with stations in the sky.

Emergency lift operation is a separate design problem from ordinary passenger service. Firefighters' lifts and specially designed occupant-evacuation systems have defined protection, power and control re-

quirements. They are not a reason for a passenger to ignore posted fire instructions or to use an ordinary lift during a fire. NIST's research catalogue records the long-running investigation of elevators in emergency egress.[62]

CHAPTER 14A

Double Decks and Twins

> *When shafts are the scarcest thing in the building, put two cars in each: the double-deck cabin and the twin-car shaft are the industry's answers to its own geometry.*

The double-deck elevator is exactly what it sounds like - one car frame, two cabins stacked, serving two floors per stop, doubling a shaft's morning capacity at a stroke. The catch is choreography: passengers must enter from two lobby levels, odd and even floor travellers sort themselves at the escalator-fed sky lobby, and the building's floor heights must stay regular enough for the deck spacing to land true. That is why double-deck systems live where the pressure justifies the ritual: the supertalls. The Shanghai Tower's fastest shuttles are double-deck machines - the 2016 Guinness record recognised the fastest double-deck lift as a class of its own.[29]

Two cabins can also be arranged independently in one shaft, subject to controls that maintain safe separation. They cannot pass through one another: their order is fixed. This differs from a double-deck frame, whose cabins move together, and from a rope-less circulating loop. Each approach trades mechanical or control complexity for a different use of shaft space.

Part VI

The People of the Shaft

Every automatic machine was once a person's job, and the elevator remembers its people in its design.

Chapter 15

The Operator

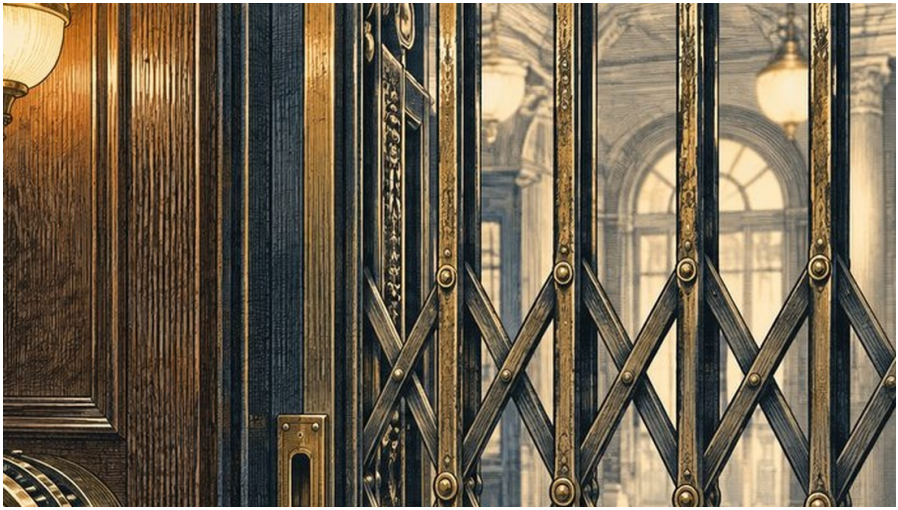
> *For much of the passenger elevator's early history, many riders entrusted the trip to an operator: the operator, hand on the lever, the machine's living interface - greeter, driver, doorman and traffic controller in one uniform.*

The early passenger elevator did not stop itself. Landing the car level with the floor - neither a step up nor a trip down - was a skill, worked by feel through a hand lever or car switch that fed power to the motor. Operators learned their building: its load of people, its floors' quirks, the exact braking point in rain and in cold. They opened the collapsible gate and the landing door, announced the floor ("Fourth floor - ladies' wear"), watched feet and skirts, decided who fit and who waited, and ran the express-local pattern of a busy bank of cars by eye and bell signal. In the great department stores and hotels the operator was part of the service; in the office towers, part of the machinery. At mid-century, American elevators were worked by tens of thousands of operators - in New York alone, approximately fifteen thousand building-service workers, including elevator operators, would walk out together in September 1945.[24]

The trade had its culture: the uniform and white gloves, the stool for quiet hours, the operator's perch at the car's corner. It was also, visibly, a window on the workforce of its century - an early occupation open to women (the "elevator girls" of the department stores and of wartime), to Black workers shut out of other skilled trades, and to immigrants arriving in the vertical city. When department stores in Ja-

pan later professionalised the role into the white-gloved lift attendants who announce each floor in set phrases, they were refining a profession the whole industrial world had once shared.

Yet the operator sat on top of a contradiction that the industry's engineers were already exploiting: the machine did not need a driver. Automatic levelling, push-button control and automatic doors all existed by the 1920s. What the machine lacked was not automation but acceptance - riders who would trust it, and owners willing to pay for the change. The operator survived as an act of trust-management. The strike exposed a dependence that would strengthen the commercial case for automation.



The control and folding gate: the fittings of a skilled trade in a moving box.

Chapter 16

September 1945

> *When New York's elevator operators struck at the end of the war, the world's tallest city discovered it could not go home without them. A truce came after five days; automation would subsequently reshape the occupation.*

On 24 September 1945, approximately fifteen thousand New York elevator operators, doormen, porters, firemen and maintenance workers walked off the job.[24] The city's vertical economy stopped with them. Office towers that could be climbed by the young and determined were climbed; everyone else stayed away or went home. Mail, freight and business stalled on the lower floors. The strike was part of the great postwar strike wave, and like the rest of that wave it was settled in days - about five, in this case. The operators returned to their levers. But building owners had been shown something they could not unsee: their buildings' dependence on a workforce that could be withdrawn in an afternoon.

The strike did not invent automatic operation, nor does its timing alone prove why an occupation declined. It did expose the dependence of building owners on staffed lifts. NPR's later history describes the stoppage as a catalyst for the industry's effort to win public acceptance of operatorless cars.[25] Modernisation then spread through a combination of technical improvement, operating cost and changing expectations.

The pattern is worth naming, since it repeats through this book and far beyond it. The technology arrives early; the transition waits for a forcing event; and the forcing event is usually about trust, cost or power between people, not about whether the machine works. Otis

had proved the safety brake in 1852 and still had to cut a rope in public. The automatic elevator was proved by the 1920s and still had to wait for September 1945.

Chapter 17

Push-Button Nerves

> *Riders did not fear the automatic elevator's machinery; they feared its doors, its indifference, its box. The industry answered with a decade of human-factors design - much of it now invisible because it worked.*

The early operatorless elevators of the 1950s met a resistant public. People missed floors, panicked at stalls, and above all did not trust the doors - the heavy, closing edge of a machine with no one watching. Newspapers ran stories of doors closing on arms and cars leaving floors early. The industry's answer was systematic. Doors gained electric eyes and sensitive edges that reversed on a touch. Closing speeds were limited; reopening buttons were made real; emergency stop switches, alarms and telephones put a voice in the box; braille plates and floor chimes made the car legible to more of the public. Attendants were posted in lobbies of early automatic buildings purely as reassurance. Riding instruction became advertising: the elevator companies taught the public to drive.[25]

Behind the doors' etiquette stood a deeper safety system, and behind that, a man the industry was slow to honour. In 1887, Alexander Miles of Duluth - a Black inventor and businessman - patented an improvement that linked the elevator car to the opening and closing of the shaft doors, addressing the horrific accidents of the open-shaft era, when a door left unlatched could open onto emptiness.[26] Miles's pat-

ent is a landmark in the logic of the interlock: the door must not open unless the car is there; the car must not move unless the doors are closed. That logic, extended through the twentieth century into electromechanical and then electronic interlocks, is what makes the modern shaft a sealed system. The code requires it; inspection tests it; and the horror story it was built against has become rare enough to be news - which is the whole point.

By the 1960s the nerves had calmed. The operatorless elevator was simply the elevator, and the small rituals of the automatic car - the button's light, the chime, the doors' pause - had become the universal etiquette of vertical travel, so familiar that a child can run the machine. The trust Otis had built with an axe was now carried by design so quiet that no one noticed it. That, too, is what the industry is for.

Part VII

The Science of Moving People

The machine lifts the car. The mathematics lifts the crowd.

Chapter 18

The Arithmetic of the Morning Rush

> *An office tower at 8:50 in the morning is a queueing problem with a heartbeat. Solving it made a science of its own: vertical transportation, where the machine meets the crowd.*

Every working day, the same test is set. A tower holds thousands of people; nearly all of them want to go up in the same forty minutes; the lifts are finite. Whether the building works - whether the lobby clears or floods with impatient tenants - is decided before the first car moves, at the design desk, by the mathematics of elevator traffic. The core measures have names: interval, the average wait between car departures; handling capacity, the percentage of the building's population the system can move in five peak minutes; round-trip time, the seconds a car needs to collect a lobby load, deliver it up the building, and return.[27] From those three numbers flows the whole layout: how many shafts, of what size, at what speed, grouped in which zones.

The science was built by a small guild of specialists, and its bible for two generations has been George Strakosch's Vertical Transportation handbook - the text that taught engineers to count passengers per car (not the rated load but the realistic crush), stop probabilities (how many times a car actually halts on a run), and the merciless arithmetic of up-peak.[27] The numbers rule design with a quiet absolutism. A building that under-elevatores is crippled on day one and nearly impossible to cure - shafts cannot be added after the fact, which is why the traffic consultant's fee is among the best-spent money on a tower.

Control is where the arithmetic meets the machine. Early group supervisory systems simply answered calls in order. Modern ones dispatch by predicted cost: which car, already going where, can take this call with the least total waiting added to the whole system. And at the frontier sits destination control, which asks the passenger to declare their floor before boarding - at a lobby terminal - and then assigns a specific car, grouping everyone bound for the same floors together. The queue is sorted before it forms; each car makes fewer, denser stops. Schindler's Miconic 10, the pioneering commercial destination system of the 1980s and 1990s, spread the idea through thousands of buildings, and its descendants - with keypads, badges and phones as the interface - are now the standard brain of the high-rise bank.[28] The passenger experiences it as a small oddity ("which lift is mine?") that quietly halves the morning's chaos.

CHAPTER 18A

The Consultant

> *Between the architect's ambition and the maker's catalogue stands a small profession most people have never heard of: the vertical transportation consultant, who decides how many lifts the building gets - and therefore whether it works.*

Every tower's lift system is specified before it is sold. The developer's team must answer, years before opening: how many shafts, what capacity, what speed, what zoning, what control system - decisions set in concrete, literally, and nearly unchangeable afterwards. The answers come from traffic analysis (Chapter 18), and the people who perform it are the consultants: independent engineers, a specialist profession, who carry the building's vertical destiny in their spreadsheets. Their

deliverable - the vertical transportation specification - is the document the majors bid against, and its quality decides whether the finished building clears its morning lobby or drowns in it.[27]

The trade's leverage is outsized and its errors permanent. Under-specify, and the building suffers forty years of queues with no cure short of carving new shafts through occupied floors - effectively impossible. Over-specify, and the client bought shafts and machine rooms it never needed, floor area worth millions given away. The consultant walks that edge with the handbook's mathematics, population models of the tenancy, and hard-won rules of thumb. When this book calls the lift the skyscraper's hidden infrastructure, the consultant is its hidden profession: the industry inside the industry that no passenger will ever know exists.

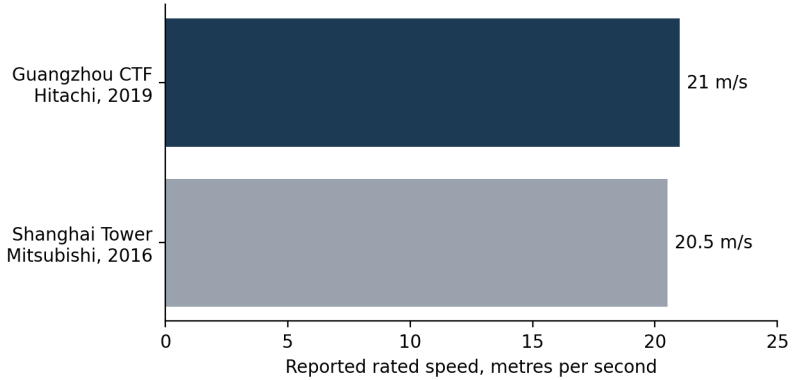
CHAPTER 19

Speed and the Body

> *The world's fastest production lifts now rise at twenty-one metres per second - faster than a galloping horse, straight up. The obstacle was never the motor. It was the passenger's ears.*

A lift at full speed is a pressure vessel moving through a chimney. Rising a kilometre changes the air pressure on the eardrum by amounts the body feels acutely; exceed the ear's comfortable rate and the ride becomes pain. That, more than any limit of power, is why ultra-high-speed lifts took so long. The modern record machines solve it bodily: the car is sealed and its internal pressure actively controlled as it climbs; aerodynamic shrouds smooth its passage; active rollers and vibration damping keep the cabin still enough to stand a coin on edge. When Mitsubishi Electric raised the Shanghai Tower's shuttles to 1,230 metres per minute - 20.5 metres a second - for the building's

2016 opening, taking three Guinness records for fastest, tallest and fastest double-deck lifts, the engineering story was as much otolaryngology as electricity.[29] Hitachi answered in 2019 at the Guangzhou CTF Finance Centre: 1,260 metres per minute, 21 metres a second, ground to the 95th-floor lobby in about 42 seconds, and a Guinness title announced in September 2019.[30]



Selected reported speeds, historical installations, 2016-2019. Sources: company announcements and Guinness records cited in this chapter.

Comfort has its own physics, codified over a century. Acceleration is limited not by strength but by sensation: the body reads the push of a starting car and the lightness of a stopping one, and comfort lives in keeping those changes gentle - in technical terms, limiting jerk, the rate of change of acceleration. The old operator smoothed starts by hand; the modern drive shapes its acceleration curve in software, an S-curve so polished the floor seems to rise to meet you. Speed records make news; the industry's real achievement is the opposite - that a ride at ten metres a second feels like nothing at all.

And the body sets one more limit, this one on descent: a falling car of air above a descending lift compresses, and a car dropping fast down a tight shaft rides its own piston effect. Shaft pressurisation, bypass vents and aerodynamic car design all answer it. The ultra-fast lift is less a vehicle than a small, vertical airliner.

CHAPTER 19A

The Shake: Lifts in Earthquake Country

> *Seismic regions place additional demands on lifts. Earthquake operation - detecting the tremor, parking the car, protecting the rope - is vertical transport's hardest branch of engineering.*

An earthquake tests a lift in three ways at once. The building sways, and the ropes - long pendulums in the shaft - sway with it, risking tangle and collision with shaft equipment. The rails can distort, trapping the car. And passengers, worst of all, can be caught mid-flight. Japan, which lives with all of this, built the answers that much of the world now buys. Seismic sensors distinguish the fast-arriving P-wave from the destructive S-wave that follows seconds later; on detection, the lift's controller abandons its schedule, moves to the nearest floor away from the tremor, opens the doors and parks.[71] Rope-sway detectors watch the long ropes of tall buildings; counterweight guides are reinforced against derailment; after the event, inspection regimes decide what runs again. Japanese practice, hardened by Kobe in 1995 and Tohoku in 2011, has been exported wherever the map is seismic - from San Francisco's code requirements to the towers of Istanbul, Manila and Santiago.

Chapter 20

The Weight of the Rope

> *Every traction lift carries its rope as cargo. Beyond five hundred metres the rope weighs more than the car can spare - the single-lift limit that ruled the supertall for a century, until someone changed the material.*

Here is a strange and beautiful constraint. In a tall building the hoisting ropes must be strong enough to carry the car, the passengers - and the ropes' own length. Strength grows with the rope's cross-section, but so does weight; past a certain travel, adding rope to hold the rope consumes the whole machine. Practical engineering put the ceiling for a single lift run at roughly five hundred metres of travel with conventional steel ropes.[31] Buildings taller than that - and the modern era builds much taller - had to be stacked: sky lobbies, shuttle expresses, second and third lift systems riding on the first, each eating rentable floors for its shafts and machine rooms. The rope's weight was the hidden tax on altitude.

KONE's answer, unveiled in 2013, was to change what a rope is. UltraRope replaced the steel core with carbon fibre: a tape with carbon-fibre strands in a polymer jacket, about a tenth the weight of equivalent steel rope.[32] A rope that no longer spends its strength holding itself can travel far higher: KONE announced single-lift travel up to a kilometre, with large energy savings on the moving mass besides.[32] The kilometre-high building - the Jeddah Tower project and its successors - was designed around exactly this capability. Material science, not motors, moved the elevator's ceiling; the carbon age reached the shaft.

The rope's story closes the loop with the book's beginning. Otis's machine existed because ropes failed; three generations of wire-rope craft made failure rare; carbon fibre now makes the rope light. The load, the rope and the pull are still the whole machine - the pull just got taller.

CHAPTER 20A

The Door

> *The most used machine in your building is not the lift. It is the lift's door: sliding panels, asked to be gentle, fast, silent and incapable of error, 200,000 times a year.*

Engineer a demand like that and every part earns its keep. The panels hang from hangers running on tracks, kept captive below by gibs in a sill groove so they cannot be kicked off; a small motor - the door operator - drives them through belts or linkages, tuned to accelerate hard, travel fast, and arrive soft. Between the panels rides the safety system: a mechanical edge or an invisible curtain of infrared beams across the opening, any touch or break reversing the doors. At every landing, the car's operator must wake the floor's own doors through a clutch, and the interlock (Chapter 11A) must prove everything closed before the car may move.

The door is where the elevator meets its public - where fingers, prams, suitcases and impatient shoulders test the engineering daily. It is also, in the trade article cited here, where over seventy percent of trouble calls are attributed to worn components.[74] Which makes the door the perfect emblem of this book's argument: the glamorous engineering - the speed, the height, the records - matters less to the rider than a sliding panel opening on time, every time, for thirty years.[77]

Part VIII

The Industry

Nobody buys a lift. Everybody rents one, for the life of the building - and the industry is built on that sentence.

Chapter 21

Otis: The House That the Spring Built

> *From a one-man Yonkers shop to a company that moves the equivalent of the world's population every few days, Otis is the industry's founding firm - and its history is the industry's, in miniature.*

The company Elisha Otis founded in 1853 grew through his sons into Otis Brothers, and then, in 1898, through consolidation with fourteen rival makers into the Otis Elevator Company - a pattern of roll-up that the industry has repeated ever since.[13] The twentieth century made it global: the Eiffel Tower's difficult lifts, the Empire State Building's bank of gearless expresses, the World Trade Center's sky-lobby system. Otis equipped the defining towers of each era and became the an internationally recognised name in vertical transport.

In 1976 the firm was bought by United Technologies, the American industrial conglomerate, and for four decades it lived inside a corporation better known for jet engines and air conditioning. Then, in April 2020, UTC separated: Otis was spun off to shareholders and listed on the New York Stock Exchange under the ticker OTIS - returning, as its own announcement put it, to life as an independent public company for the first time in nearly half a century.[33] The numbers it reported as it stood alone describe a mature giant: 2024 net sales of about $14.3 billion, of which the large majority - and nearly all of the profit - came not from selling new lifts but from servicing the ones already installed.[34] Its service portfolio, approximately 2.4 million units under

maintenance at year-end 2024, is the largest on Earth, and its 2024 results reported growth in both maintenance portfolio and modernisation orders.[34]

The pattern of those numbers - modest equipment sales, vast service annuities - is not a quirk of Otis. It is the shape of the whole industry, and Chapter 25 is about why. First, the other houses.

Chapter 22

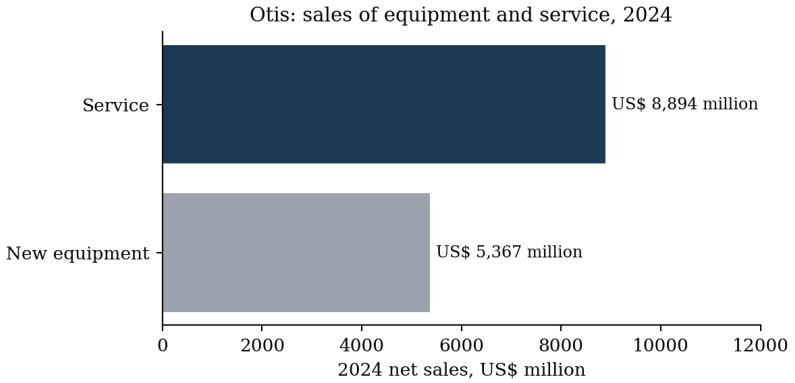
The European Houses

> *A Finnish engineering shop, a Swiss mountain-village works and a German steel colossus grew into three of the four giants - each carrying a national style of engineering into the shaft.*

KONE began in Helsinki in 1910 as a machine shop, sold its first lifts after the First World War, and spent its life as a family-influenced firm - the Herlin family has steered it for four generations.[36] KONE's genius has been the industry-changing product, twice over. In 1996 it introduced the MonoSpace, the world's first machine-room-less lift: the hoisting machine flattened into a disc - the EcoDisc - small enough to live inside the shaft itself, abolishing the rooftop machine room that buildings had needed for a century.[37] The MRL design swept the low- and mid-rise world within a decade; today machine-room-less designs have become widespread in low- and mid-rise buildings, and every rival sells one. Then, in 2013, came UltraRope's carbon-fibre hoisting tape. KONE's 2024 sales were approximately €11.1 billion, and its AGM review sizes the world elevator and escalator market at over €80 billion a year, with China taking roughly 450,000 of the world's new units and the rest of the world about 400,000.[38]

Schindler is the Swiss house, founded in 1874 in Lucerne by Robert Schindler and Eduard Villiger - and still anchored there, still family-influenced, listed on the Swiss exchange.[39] Where KONE led on hardware, Schindler led on brains: its Miconic 10 made destination dispatch a commercial reality, and its PORT descendants run the lobbies of thousands of towers. Schindler's 2024 revenue was CHF 11.2 billion.[40]

TK Elevator is the newest name and the oldest lineage: the elevator division of ThyssenKrupp, the German steel and engineering group, sold in 2020 to private-equity owners (Advent and Cinven) and reborn as an independent company - a large industrial carve-out.[41] It inherited the German heavy-engineering tradition and its moonshot, the rope-less MULTI. Its fiscal 2023/24 sales were €9.3 billion.[42]



Otis's 2024 sales mix. Source: full-year results; service US$8,894m and new equipment US$5,367m.

Together with Otis, these four are the industry's oligopoly - four firms with long memories, global service armies, and a habit of absorbing challengers.

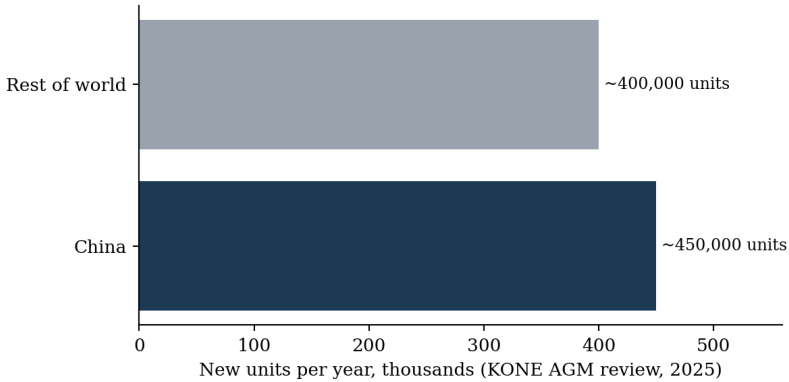
Chapter 23

Japan Builds the Speed, China Builds the Volume

> *The industry's centre of gravity has moved east twice: first to Japan's precision houses, then - overwhelmingly - to China, which now installs most of the world's new lifts and owns nearly half the installed base.*

The Japanese makers came to lifts through electrical engineering, and it shows. Mitsubishi Electric, Hitachi, Toshiba and Fujitec built their reputations on the hard end of the craft: ultra-high-speed gearless machines, the world's fastest cars (Shanghai Tower, Guangzhou CTF), seismic detection that parks lifts safely at the first tremor, and double-deck shuttles. Fujitec, the specialist of the group, is lifts and escalators only; the others are divisions of vast electrical houses. Japan's home market - dense, vertical, seismic and aging - became a laboratory the rest of the world now studies: earthquake operation, barrier-free design, and home lifts for a greying population all matured there early.

Then came China, at a scale with no precedent. China's construction boom made it the industry's demand centre: roughly 450,000 new units in the market estimate presented at KONE's 2025 AGM against approximately 400,000 in the rest of the world, and an installed base approaching 11 million units - about 43 percent of all the lifts and escalators on Earth.[3843]



KONE's market estimate presented in 2025: approximately 450,000 new units in China and 400,000 elsewhere.

A domestic industry rose with the boom: hundreds of Chinese makers, of which Canny and SJEC are the listed flag-bearers, alongside vast Chinese operations of all four giants. The boom has now cooled - Chinese new-equipment demand fell sharply from its peak - and the industry's Chinese chapter has turned to modernisation and service of the immense base already built.[44] What China became in thirty years - the place where most lifts are made, installed and soon serviced - is a warning against extrapolating one country's construction cycle into a universal pattern.

Beyond China is another vast market, rising on the same urban logic: India is now the world's second-largest market for new lifts, with annual demand estimated at 125,000 to 150,000 units in the industry estimates cited here.[45] Otis installed its first Indian lift in Calcutta in 1892; the industry's Indian century is only now arriving.[46]

Chapter 23A

The Modernisation Decade

> *China built more lifts in thirty years than the rest of the world combined. Now they are ageing together - and the industry's biggest single market of the 2030s is the renewal of what the 2000s built.*

A lift's design life is twenty to thirty years for its brain and muscles, longer for its rails and shaft. China's installed base - approaching eleven million units, most installed after 2000 - is therefore marching toward a simultaneous mid-life.[43] The majors saw it coming: their Chinese strategies have pivoted from chasing new-tower orders to winning the service and modernisation of the base they themselves installed. Roland Berger's market outlook describes the same turn industry-wide: new-equipment growth flattening, modernisation and service becoming the growth engine.[44]

Modernisation is a craft of its own - the lift rebuilt around the passenger, in an occupied building, a floor's work at a time: new controller, new drive, new doors, refreshed cabin, old rails and car frame retained. It is also where the independent service firms fight the makers hardest, since a modernised lift need not remain loyal to its badge. The modernisation decade will test everything in this part: the annuity model, the data lock-in, and the industry's claim that only the maker can safely renew the machine.

Chapter 24

Inside the Box: The Component Trades

> *A lift is an assembly of industries: ropes from wire makers, drives from motor houses, doors, controllers, fixtures - a supply chain most passengers never know exists.*

Strip a modern lift and the giants' nameplates come off quickly. The wire ropes come from rope specialists - firms like Tokyo Rope or the world's wire rope houses - drawn from high-carbon wire rod. The drive may come from the lift maker or from an electrical giant; the geared and gearless machines of the mid-market are often built by specialists such as Italy's Montanari or Sicor. Doors - the hardest-working part of any lift, opening and closing hundreds of times a day - are a trade of their own: Wittur of Germany and Sematic of Italy supply door systems, cars and complete components to much of the industry, including to makers whose badges ride on the car.[47] Controllers - the lift's brain, the board that schedules, drives and supervises - come from both the majors and a tier of independent control houses that also supply modernisation projects.

Two structural facts follow. First, the "lift industry" is really a layered stack: materials (steel, copper, electronics), components (ropes, machines, doors, boards), systems (the majors' products), and service (the largest layer of all). A tariff on steel or a shortage of power semiconductors travels straight down the stack into the price of a new lift and the wait for a repaired one. Second, the component trades are where much of the actual innovation happens quietly - permanent-magnet gearless machines, belt drives, LED fixtures, slim door operators - before being absorbed, standardised and sold as the majors' next generation. The industry looks like four names. It is hundreds.

CHAPTER 24A

The Belt and the Disc: Two Machines That Rebuilt the Mid-Market

> *Between the hydraulic ram and the skyscraper gearless giant stands most of the world's building stock - and two product revolutions decided who lifts it.*

The first revolution was KONE's, told in Chapter 22: the 1996 MonoSpace and its flat EcoDisc machine, which put the motor inside the shaft and abolished the machine room for low- and mid-rise lifts.[37] Architects regained rooflines, owners regained penthouse space, and every competitor had to follow; machine-room-less designs became an important alternative to the separate machine room.

The second revolution was Otis's Gen2, launched in 2000, which changed the hoisting medium itself: in place of wire ropes, flat coated-steel belts - thin steel cords sealed in polyurethane - running over small sheaves.[70] Belts allowed much smaller machines (sheave diameter is limited by rope stiffness, and a belt is flexible), ran quietly enough to hang beside a bedroom, and needed no lubrication - a maintenance and environmental gain the industry had chased for a century. Gen2 became Otis's best-selling machine family, passing a million units sold, and belt-drive designs spread across the industry into home lifts and mid-rise work alike.[70] The pattern of both revolutions is the industry's in miniature: the component changes, the machine shrinks, the building regains space, and within a decade the new thing is simply what a lift is.

Chapter 24B

The Works

> *A lift is the rare machine that is never finished in a factory. The works makes kits of precision; the building makes the machine. Inside the industry's manufacturing - and its cathedrals of testing.*

Walk a lift maker's works and you find not assembly lines of elevators but lines of parts: traction machines wound and machined in one hall, doors and operators in another, controllers racked and burned-in, car walls folded from steel sheet, guide rails manufactured and straightened to hairline tolerances. The product leaves as engineered kits, containerised for a specific shaft. A building lift is not a complete working installation when it leaves the factory, because its longest dimension is the building's. The factory's real product is tolerance: parts that will align, kilometres from the works, into a machine safe to ride.

What the works cannot test, the test tower can. The industry maintains some of the strangest structures in engineering for this purpose: Otis's 117-metre test tower at Bristol, Connecticut; KONE's high-rise laboratory sunk 350 metres into a working limestone mine at Tytyri, Finland - the world's deepest elevator test shaft, where long travel distances permit high-speed testing; TK Elevator's 246-metre Rottweil tower with its twelve shafts.[64,75,76] Here new machines are run to destruction, safeties are dropped on command, and doors are cycled hundreds of thousands of times against their 200,000-cycle year.[74] The test tower is the industry's answer to a problem its founders would recognise: you cannot rehearse a failure on the public.

A third site completes the manufacturing story: the shaft itself, where the kit becomes the machine - the subject of the next chapter.

Chapter 25

The Service Business

> *Sell the lift once; service it for thirty years. The industry's economics are an annuity disguised as a machine - and that explains nearly everything about how the business behaves.*

A lift can serve a building for decades through maintenance and modernisation - and through all of it, someone must inspect it, grease it, adjust its doors, answer its entrapments, and periodically modernise its brain and muscles. Whoever installs a lift has the inside track on that income: the maintenance contract. The result is an industry whose profit pool sits overwhelmingly in service rather than new equipment. Otis's accounts say it plainly: in 2024, service provided about 62 percent of sales and the great majority of operating profit, and the pattern holds, with variations, across all four giants.[34] New lifts are sold keenly, at thin margins, because each installation seeds decades of high-margin service. The lift business is the razor-and-blades business, standing on end.

This shapes everything. It explains the majors' appetite for acquisitions - buying a regional service firm buys its portfolio of units under contract, annuities in a box. It explains the long trench war over independent service providers, the thousands of local firms that maintain lifts built by others, and the majors' counter-moves: proprietary diagnostics, encrypted controllers, and bundled modernisation. And it explains the industry's digital turn. If profit lives in service, then knowing a lift will fail before it fails is money. So the shaft got sensors and a cloud connection: KONE's 24/7 Connected Services, built with IBM, streams vibration and performance data from the machine to predictive algorithms; Otis ONE does the same across its portfolio.[48]

The promise to the building owner is fewer entrapments and planned, not panicked, repairs; the value to the maker is a service contract that renews itself.

The installed base is the moat. Every year roughly a million new units join the tens of millions already running, and every one of them will need its thirty years of attention. That is why four patient firms, and their hundreds of suppliers and rivals, can plan in decades. The city is not finished going vertical; it is barely begun.

CHAPTER 25A

The Service Call

> *What does a maintenance visit actually maintain? Follow the technician through a routine call - the craft underneath the annuity.*

The visit starts at the doors, because the doors are where lifts live and die. A working passenger door opens and closes on the order of 200,000 times a year, and one Elevator World upgrade article reports worn door components as the cause of over 70 percent of trouble calls.[74] The technician checks the operator's tune, the hanger rollers and gibs that keep the panels captive, the tracks' cleanliness, the closing force and the protective edge or light curtain that must reverse the doors on a touch. Doors collect the building's abuse - trolleys, shoes, held hands, dust - and pass it straight to the machine.

Then the machine room and the shaft: ropes inspected for broken wires and equal tension (an untensioned set wears itself and the sheave), governor tested on its tripping speed, brake wear measured, lubrication renewed, controller fault logs read like a patient's chart.

The pit gets its sweep and its buffers a look. Everything found goes in the log - the document the inspector will read and the record the next technician inherits.

And sometimes the call is an entrapment. Rescue is a task for trained, authorised personnel following the procedure for that specific installation, with communication, electrical safety and car position all accounted for. It is not a task for the passengers themselves: the self-rescue attempt, climbing between car and shaft, is how entrapments turn lethal, and it is why the industry's first instruction to a trapped rider is the hardest: stay put. The service call, routine or emergency, is the annuity's real substance - and the reason the connected lift of Chapter 36 is genuinely valuable: every fault predicted is one of these visits that never has to happen at midnight.[77]

Part IX

Rules of the Shaft

> *Every clause of the code is an accident that happened to someone.*
>
> A saying of the safety profession

Chapter 26

The Code

> *The elevator is the most thoroughly ruled machine in ordinary life, and its rulebook - a century of ASME A17.1 and EN 81 - is a fossil record of everything that ever went wrong, answered in advance.*

By the early twentieth century, lift regulation differed among cities and states. ASME's first national elevator safety code appeared in 1921. Its successor, A17.1, is revised over time and addresses installation, operation, maintenance and inspection. In Europe, the EN 81 family provides a separate standards framework. National adoption and legal obligations must be checked in the relevant jurisdiction; publication of a standard alone does not establish a universal legal deadline.[49]

Read the code closely and it reads like a history of accidents, answered one by one. The governor that must seize the car at overspeed answers the falling car. The interlock that bolts the landing door until the car arrives answers the open shaft. The buffers in the pit answer the overtravelled car; the final limit switches answer the runaway; the emergency light, the alarm, the firefighters' service with its recall to the lobby - each a chapter written after something happened. Fire protection, hoistway integrity and emergency communication add further requirements beyond the original falling-platform problem.[51] This is not bureaucracy. It is the industry keeping its founding promise - Otis's promise - one clause at a time.

The code also quietly fixes the industry's structure. Compliance is expensive, inspection is constant, and liability is severe - conditions that favour large, patient firms and long service relationships, and that

make the lift a very different purchase from any other machine in the building. You do not buy a lift the way you buy an air conditioner. You enter a regulated relationship, for the life of the building, under a code neither of you wrote.

CHAPTER 26A

The Inspector

> *The code is only paper until someone witnesses the safeties bite. The inspector - witnessing tests, reading maintenance logs, condemning cars - is where the rulebook becomes the record.*

Inspection requirements vary by jurisdiction. A regulated installation can require at installation (the acceptance test, where the safeties are deliberately triggered and the buffers witnessed), and periodically thereafter - annually in much of the world, on cycles the code sets. The inspector's craft is a strange one: part engineer, part auditor, part police. They ride the car with the maintenance manual, check the governor's calibration tag, drop-test the safeties, verify the door's closing force and reopening, confirm the alarm rings somewhere staffed. What they find goes on a certificate in the car - that small framed document behind the glass, which most passengers never read, is the visible tip of the entire regulatory iceberg.[49]

The system's strength is its independence: the inspector answers to the code and the authority, not the building or the maker. Its weakness is capacity - the same skilled-labour shortage of Chapter 33 bites here too, and inspection backlogs are a quiet scandal in fast-growing markets. But the principle has held for a century and it is the industry's deepest institutional achievement: vertical travel is not trusted to the market. It is witnessed.

Chapter 27

Safety Is a System

> *The passenger experiences one machine. Its safety depends on several systems, on their interfaces, and on people who maintain and inspect them.*

A modern traction lift combines suspension, a service brake, overspeed detection, rail-gripping safety gear, door interlocks, terminal stopping devices and buffers. These do different jobs. A buffer is not a substitute for safety gear; an overspeed governor is not the suspension rope. Calling everything a brake can hide the paths by which a fault reaches the passenger.

The redundancy is engineered, not magical. Multiple suspension members share load; factors of safety, permitted wear and replacement rules depend on the design and code. A claim that any single rope on every lift can support the fully loaded car is not a safe general rule. Neither is a promise that a modern car cannot fall. The Empire State crash in the next chapter illustrates a common-cause event that damaged more than one system.[53]

Historical US accident reports distinguish passenger incidents from work on and around equipment. Those data matter, but mixing elevator and escalator totals, old injury estimates and an unrelated journey count does not establish a defensible worldwide safety ranking. The proper conclusion is more useful: routine riding and servicing a shaft are different risk environments, and both require the protections intended for them.[2]

The practical public rule is simple: do not force landing doors or attempt to climb out of a stopped car. Use its emergency communication, report the location and wait for authorised assistance. For an

owner, maintenance records, inspection obligations and communication reliability are part of the transport system, not administrative extras.

Chapter 28

The Day a Bomber Hit the Empire State

> *On 28 July 1945 a bomber struck the Empire State Building. Betty Lou Oliver survived a catastrophic lift fall. Her survival should not be mistaken for proof that its normal safety system worked.*

Fourteen people died when a B-25 struck the building in fog. Elevator World's technical retrospective describes an engine entering the shaft of elevator number six and damaging both the governor rope and the hoisting ropes. It reports a fall of 75 floors and the survival of its operator, Betty Lou Oliver.[53]

The governor rope is a separate line that moves with the car. If overspeed makes the governor grip that line, its relative movement actuates the car's safety gear. In the crash, that actuation path was destroyed before the suspension failed. Several protections were exposed to the same extraordinary event. This is a common-cause failure, not the successful operation of an intact safety chain.

The retrospective attributes cushioning to compensating cables piling in the pit and air compression in the close-clearance hoistway. Oliver sustained serious injuries and spent months recovering. Those circumstances were exceptional; they were not a designed or repeatable rescue method. The article describes subsequent attention to positioning safety equipment farther from the building's exterior.[53]

The engineering lesson is sobering. Redundancy works only insofar as its supposedly independent parts are not all defeated by one cause. A safety history should preserve that lesson rather than turn a survivor's experience into a reassuring legend.

Part X

Lifting Everything

The passenger lift is the famous one. Its brothers lift the world.

Chapter 29

The Freight World

> *Goods move vertically before people do, and long after: the freight lift is the unglamorous giant that stocks the mall, feeds the hospital and supports industrial work.*

Every supply chain ends in a shaft. The shopping mall's stock rises from the loading dock in goods lifts; the hospital's meals, laundry, sterile supplies and waste each ride their own circuits (the dumbwaiter, the smallest lift of all, is a whole parallel industry); the automated warehouse is essentially a building-sized elevator system, its stacker cranes lifting pallets to racks forty metres high. Freight lifts are built to different rules - slower, stronger, indifferent to comfort, sized for forklift trucks and ISO pallets - and they account for a quiet, durable slice of the industry's order book, tied to logistics rather than to towers.

Chapter 29A

The Hoist That Builds the Building

> *Before the tower's own lifts run, another machine climbs its raw concrete: the construction hoist - the temporary elevator that builds the permanent ones' home.*

Every tall building under construction wears a rack-and-pinion hoist on its flank: a cage climbing a bolted mast, driven by pinion gears on a toothed rail, extended floor by floor as the structure rises. It carries

the workforce, the tools, the rebar bundles and the morning shift - the tower's first vertical transport, months or years before the permanent shafts take over. It is a distinct industry segment (specialist rental fleets, its own safety code clauses, its own brutal duty cycle), and its economics are simple: every minute of hoist time is paid construction time, so capacity and reliability price the whole project.

The rack-and-pinion principle deserves its note: no ropes at all, the motor climbing a fixed rail - the same independence from rope and depth that Chapter 35's rope-less cabins promise, in rough industrial form, since the mid-twentieth century. The construction hoist is also a safety landmark of the sobering kind: its accidents, when mast ties fail or cages overrun, are among construction's worst, and its inspection regime is correspondingly fierce. The temporary machine is held to the permanent standard.

CHAPTER 30

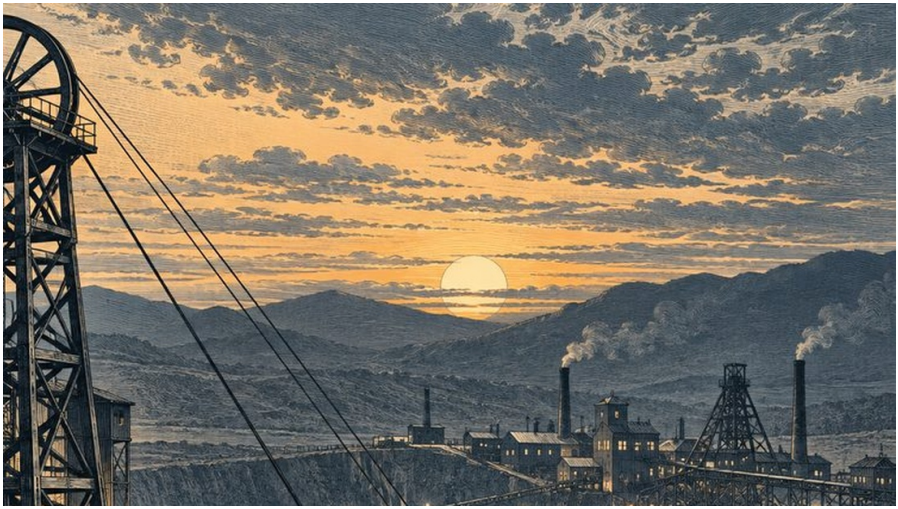
The Deep

> *The longest single lift on Earth does not serve a tower. It runs three kilometres down into a South African gold mine - and the mine hoist is the passenger elevator's oldest and hardest sibling.*

Reverse the direction and the elevator becomes the mine hoist: the machine that moves people, ore and materials through shafts deeper than any building is tall. The physics is the traction problem under maximum load: a winding drum or a friction (Koepe) winder, steel ropes kilometres long, cages and skips running on guides at highway speeds. Suspension weight is a major consideration here too, although mine-hoist designs and duties differ from building lifts, and the industry's answer has been staged winding - or, at the extreme, one astonishing single lift. The deepest belongs to the South Deep gold mine

in South Africa: a single-lift shaft 2,991 metres down, the deepest continuous lift on Earth, sunk for one of the richest ore bodies ever found.[57] Down it go crews by the hundred; up it comes the ore.

The mine hoist is also where lift safety grew some of its hardest lessons. The rope problem, the overspeed problem, the emergency brake, the depth indicator, the signal code between banksman and winder driver - all were matured in mining, where the cost of failure is measured in crews. The Levant man-engine disaster of 1919 (Chapter 3) is the grim marker of the era before that maturing was complete. Modern mine winders are among the most instrumented machines anywhere: multi-rope, automatically braked, governed and interlocked to a standard the passenger industry would recognise as family. It is no coincidence that wire rope itself was born in the mines; the deep shaft has been the elevator industry's laboratory since Agricola.



The headframe: above it a wheel, below it three kilometres of rope, cage and dark.

Chapter 31

The Moving Staircase and the Rosary Lift

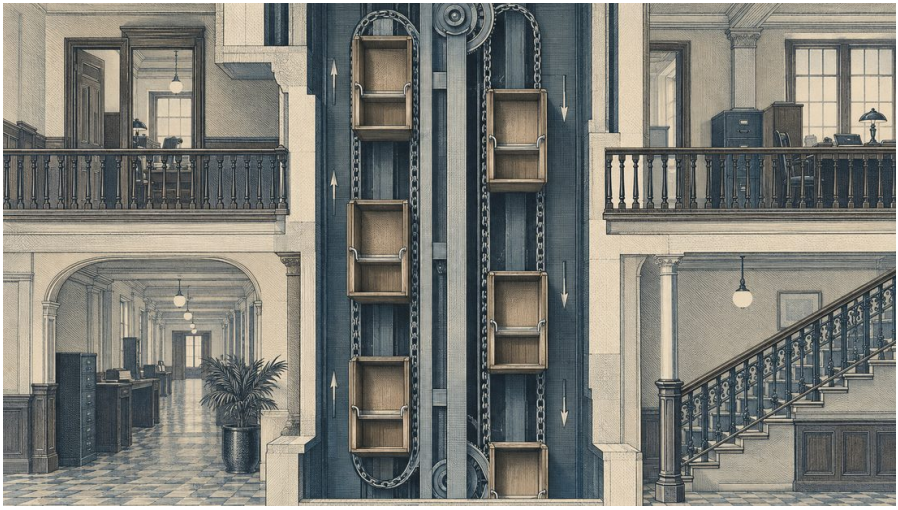
> *Two cousins complete the family: the escalator, which made vertical movement continuous, and the paternoster, the doorless loop that Europe loved and regulation is slowly retiring.*

The escalator is the elevator re-imagined as a river: instead of batching passengers into cars, move the stairs themselves. Jesse W. Reno built the first working "inclined elevator" in 1896 at Coney Island - a seven-foot rise that fifty thousand riders tried in its fortnight; George Wheeler's patents and Charles Seeberger's partnership with Otis produced the recognisable moving staircase, shown to the world at the Paris Exposition of 1900.[58] The machine was department-store gold: stairs that carried shoppers upward without effort turned upper floors into equal territory, and retail has run on them since. So has transit: the metro systems of the twentieth century, from the London Underground's deep tubes onward, are unbuildable without the escalator. Today the giants report their order books in "elevators and escalators" as a single business - the two are one industry, sharing factories, service armies and code committees (A17.1 covers both).

The paternoster is the road regulation closed. A chain of open two-person cabins loops endlessly up one shaft and down the other, named for the rosary beads it resembles; you step in as a cabin passes and step off before the top, and it never stops, at all. Cheap, continuous and marvellous for short hops, it spread through early-twentieth-century Europe - and ran into the modern logic of risk: a machine you board while moving cannot meet codes written to protect everyone, including those who step late. New paternosters have been effectively banned in much of Europe since the 1970s; survivors in Germany, Britain and elsewhere are maintained as working heritage, ridden with

affection and a little ceremony.[59] The paternoster's fate is the code's philosophy in miniature: the industry chose universal safety over charming efficiency, and it chose it on purpose.

The escalator's own mechanics repay a look: a chain of steps, each riding on two pairs of wheels on two tracks, looped around sprockets at top and bottom like a tank tread laid on a staircase. The tracks' profiles flatten each step into a platform for the ride and fold it back under at the ends; the handrail is a rubber belt driven in sync, because a hand moving slower than the feet is a fall; and the comb plates at each landing - the yellow teeth the steps vanish into - are the machine's most important safety device, backed by switches that stop the staircase if anything jams at the mesh. An escalator is, in effect, an open elevator that never stops moving, and it is maintained with the same religion: daily checks, comb by comb.



The rosary lift: an endless loop of cabins, boarded in motion - efficiency the code retired.

Chapter 31A

The Hillside and the Walkway

> *The family's far cousins lift on a slope: the funicular, an established form of passenger ropeway, and the moving walkway, the lift unrolled flat - together they move millions daily where stairs and shafts cannot go.*

The funicular is the passenger lift's elder sibling: two cars on a slope, joined by one rope over a pulley, each balancing the other - the counterweight principle laid on a hillside. Monks and miners used inclined hoists for centuries; the passenger era opened with lines like the Salzburg Festungsbahn's ancestors and the great city funiculars of the nineteenth century, from Lisbon to Hong Kong's Peak Tram (1888).[73] The machine is pure elevator logic tilted: a shaft become a track, a shaft-bottom counterweight become the descending car. It still solves what it always solved - steep ground, short distance, no roads - and modern cities from Lausanne to Haifa run fully automatic metro-scale funiculars and incline lifts as public transport.

The moving walkway solves the opposite geometry: distance without height. Born as the 'travelator' piers of the 1893 Chicago world's fair and matured by the same makers as the escalator, it lives today in airports, where a terminal's kilometre legs would otherwise defeat the connection times the airlines sell. Walkway, escalator, lift: the industry sees one problem - moving people through a building's geometry - and three angles of attack. The order books agree: makers report 'elevators and escalators' as one business, and the walkways ride along.

Chapter 32

The Lift Comes Home

> *The elevator's newest frontier is the oldest building type of all: the private house. Ageing societies are turning the home lift from a luxury into one of the industry's growth engines - and quietly redrawing who gets to live upstairs.*

For most of its history, the lift belonged to institutions - shops, offices, hotels, mines. The home lift inverts that. Its driver is demography: as the world's richest societies age, hundreds of millions of people face houses designed for knees they no longer have. The industry's answers arrive in layers. At the threshold, the stairlift - a rail and a chair, the elevator reduced to its essence - carries the house's existing stairs; firms like Stannah built global businesses on it. At the next layer, compact through-floor and shaft lifts - some hydraulic, some tiny traction machines with belts, some pneumatic vacuum tubes - fit into houses never designed for them. Japan, the world's oldest large society and a lift-making superpower, treated the home lift as infrastructure early; Europe and North America are following as the boomer generation's staircases catch up with it.

Underneath the market sits a rights revolution. The modern idea that a building must be usable by everyone - wheelchair users, the blind, the deaf, the frail - is barely a generation old, codified in laws like the Americans with Disabilities Act of 1990 and its worldwide cousins.[60] Accessibility rules made the lift mandatory where ramps cannot reach, and remade the lift's interface: braille plates, audible floor announcements, door dwell times, reachable buttons, emergency communications a deaf rider can use. The elevator, born as theatre for the able-bodied shopper, has become the load-bearing element of the ac-

cessible world. When a lift in a public building fails, it is not an inconvenience to everyone equally - for some, it is the building closing. Dependence, in this book's sense, could not be more literal.



The lift comes home: vertical living for the century of the ageing city.

Part XI

The Limits

An industry's bottlenecks are its true portrait: what it cannot easily get, it truly is.

Chapter 33

Bottlenecks

> *Ask the industry what constrains it and you will not hear about motors. You will hear about people, copper, codes - and the world's enormous backlog of ageing lifts.*

People first. A lift is not delivered; it is built, on site, in the shaft, by installers whose work needs site-specific skill. The same is truer still of service: the majors' service armies number in the tens of thousands, and industry analysis identifies a recurring constraint - skilled technicians are scarce, retiring, and slow to replace.[61] In fast-urbanising markets, installation capacity - not demand - sets the pace. The elevator business, for all its machinery, is a people business wearing a machine's clothes.

Materials next. A lift is steel (the rails, the car, the counterweight), copper (every motor winding and trailing cable), and increasingly electronics (drives and boards). The majors' accounts show cost of materials as a quarter or more of revenue, and the price cycles of steel and copper pass straight through to margins and to the price of a new unit.[40] Semiconductors joined the list during the chip shortage, when lift controllers queued with cars and kettles for silicon. An industry that lifts the world's cities is pinned, at the bottom, to the same commodity curves as everyone else.

Then the patchwork of codes. ASME A17.1 governs North America, EN 81 the European sphere, national standards in India, GB standards China - overlapping but not identical rulebooks. A global maker must engineer every model against multiple codes, and approval in one jur-

isdiction does not automatically establish compliance in another. Harmonisation inches forward, but the industry's map of regulations still looks like its map of a century ago: national.

Finally, the backlog. The world's installed base - tens of millions of units - is ageing; Europe's and North America's stocks include lifts past their fortieth year running on relay logic and open contacts. Modernising them is the industry's biggest single opportunity and its slowest work: each is a bespoke project in an occupied building. The Chinese base, built rapidly over recent decades, creates a substantial future modernisation workload.[44] The lift the world most needs in the next thirty years, in other words, has already been installed - and needs rebuilding in place.

CHAPTER 33A

The Installation

> *Work inside an open shaft, with surveying instruments and torque wrenches: installation is where the industry's promises are physically made - and where its labour bottleneck bites hardest.*

An installation begins with the shaft as the concrete trade left it - never quite as drawn. The installer's first instruments are the oldest: plumb lines the full height of the building, checked against laser plummets, because the guide rails must run true within millimetres over a hundred metres or the car will shudder forever. Brackets go into the walls, rails are lifted, aligned and clipped; the machine is set and levelled; ropes are paid out, tensioned and terminated; the travelling cable - the car's umbilical, looping down the shaft - is hung; doors are fitted at every landing, each with its interlock proved. Modern scaffoldless installation works from the car platform itself, riding the growing rail stack upward.

Then comes the quiet craft of adjustment: door operators tuned for speed and gentleness, levelling set to the millimetre, acceleration curves shaped, landing zones verified floor by floor. Finally the acceptance test, witnessed by the inspector (Chapter 26A): rated load in the car, safeties deliberately dropped, buffers proven, brakes loaded, every interlock defeated and caught. Only then does the building get its certificate. The applicable code and inspecting authority determine the tests and their witnessing requirements. They cannot be reduced to one universal procedure for every type of lift.

It is also the industry's pinch point. Installation needs trained people at the building itself. Factory capacity cannot substitute for site skill, and training requirements differ across trades and countries.[6177]

CHAPTER 34

The Kilometre Problem

> *A one-kilometre tower is not a taller five-hundred-metre tower. It is a different species - and the elevator, more than steel or wind, decides whether it can exist.*

Stack the constraints of this book and they converge at altitude. The rope's weight caps a single run (Chapter 20), so the kilometre tower must be staged - but every stage costs shafts, and shafts cost floors, and floors are the product. Passengers cap the staging: nobody will change lifts four times to reach an office, so expresses must be fast - and speed meets the ear (Chapter 19). The moving mass of a kilometre of rope, car and counterweight is so large that accelerating it dominates the energy bill. Wind sways the tall shaft enough to slacken and whip the ropes, so supertalls close their fastest lifts in storms. And evacuation rules - written for buildings people can walk out of - strain

at a kilometre, which is why some tall buildings incorporate refuge provisions and specially designed evacuation systems, with hardened shafts, backup power and priority control.[62]

The industry's answers have been incremental and brilliant in aggregate: double-deck cars doubling shaft capacity; destination dispatch thinning the queues; sky lobbies stacking towers into towers; carbon-fibre rope (Chapter 20) moving the single-run limit toward the kilometre; machine-room-less machines returning rooftop space to the building. Each answer buys height and spends something - floor area, energy, complexity, code exemptions. The kilometre tower, when it is finished, will stand as a structure requiring exceptionally demanding vertical-transport planning: a building whose core is, in essence, a vertical railway with rooms attached. The limit of the tall building was never steel. It is, and remains, the lift.

Part XII

What Comes Next

The rope made the lift safe, then tall. The next century asks what the lift is without it.

Chapter 35

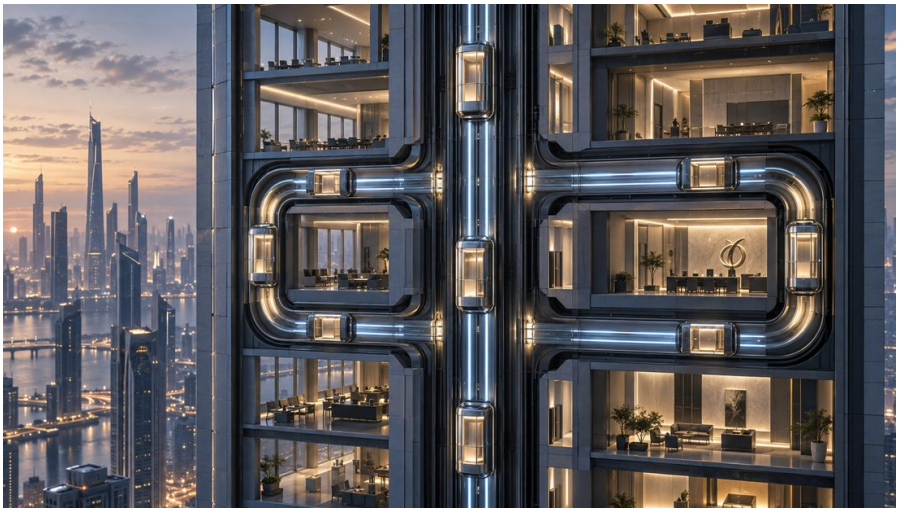
The Rope-less Car

> *In 2017, in a German test tower, a cabin went up, slid sideways, and came down another shaft - the first lift in 165 years with no rope at all.*

The rope has been the elevator's essence since the Colosseum. Traction lifts hang from suspension members; direct-acting hydraulic lifts instead support the car on a ram. MULTI pursues another arrangement. TK Elevator's MULTI cut the cable. Instead of ropes, linear motors - the maglev principle, cousin of the high-speed train - drive cabins along their shafts; cabins can queue in one shaft like a metro line, and at the top and bottom they move sideways to a second shaft for the return trip. A loop of shafts becomes a circuit; many cabins share it; the system moves horizontally as easily as vertically.[63] The prototype ran in 2017 in TK's 246-metre test tower at Rottweil - twelve test shafts in one concrete stalk, built precisely for this kind of experiment - and the system took the first rope-free lift records.[64]

The prize is the one from Chapter 34: the shaft problem. Rope-less cabins sharing loops could change the relationship between shaft count and passenger capacity, and could finally serve building shapes the vertical shaft forbids - horizontal megastructures, deep underground cities. The difficulties are equally real: switching mechanisms that must never fail, coordinating propulsion, switching and safe separation, emergency evacuation from a cabin stopped between shafts, and a cost curve still finding its way down. MULTI's first commercial installations have been slow to arrive; the industry watches the way it watched KONE in 1996. Rope-less may do to the twenty-first century

tower what machine-room-less did to the twentieth-century block. The experiment that matters has already run; commercial deployment must also resolve cost, certification, reliability and evacuation.



The loop replaces the rope: cabins circulating like trains through a building's veins.

CHAPTER 36

The Thinking Lift

> *Sensors in the shaft, algorithms in the lobby, a service van that arrives before the fault: the lift is becoming a node in a network - and its industry is becoming a data business.*

The mechanical elevator reached maturity generations ago; what changes now is its mind. In the lobby, destination dispatch (Chapter 18) sorts crowds before they board, and its next turn is personal: your badge or phone tells the system your floor as you walk in, and accessibility needs - a wheelchair's space, a blind rider's voice announce-

ments - can be attached to the call automatically. In the shaft, the connected lift reports itself: door cycles, ride quality, vibration, levelling error, brake wear, streamed to the maker's cloud, where models flag the component likely to fail and dispatch the technician with the part before the breakdown.[48] KONE's tie-up with IBM and Otis's ONE platform are the flagships of a shift every major and most independents have joined. The commercial goal is to anticipate more faults and plan more interventions, not to promise that failures are impossible.

Energy is the other frontier of the thinking lift. A traction elevator is a perfect candidate for regeneration: a loaded car descending or a light car rising is a generator being pushed. Regenerative drives capture that braking energy and return it to the building's grid instead of burning it off as heat in a resistor - and since lifts can account for a measurable slice of a tall building's electricity, the savings matter at city scale.[65] Add standby intelligence (dark cars, sleeping LEDs, fans off between trips) and the modern lift sips where its grandfather gulped.

Underneath it all runs a quiet standard-setting contest with large stakes: whose data model, whose cloud, whose service contract. The lift that reports to its maker renews its maker's annuity (Chapter 25); owners and independents push for open data; regulators are beginning to ask who owns the shaft's information. The next chapter of the industry's trench wars will be fought over APIs. The machine got smart; the business model noticed.



Destination dispatch: the queue is sorted before it forms, and the lobby becomes a timetable.

CHAPTER 37

The Longest Ride

> *Every idea in this book - the rope, the brake, the climber, the traffic problem - reappears, scaled by ten million, in the boldest lift ever proposed: the elevator to orbit.*

In an 1895 proposal inspired by the Eiffel Tower, Konstantin Tsiolkovsky imagined a tower built up to the sky - a "celestial castle" reached by a spindle climbing to geostationary height.[66] In 1960, another Russian, Yuri Artsutanov, turned the physics right-side up: not a tower standing on the ground (no material could bear its own height) but a ribbon hanging from orbit - a cable anchored at the equator, weighted past geostationary altitude, held taut by the Earth's own spin, up which electric climbers could ride to space for the price of

electricity. Jerome Pearson independently developed the concept in the 1970s; Arthur C. Clarke carried it to the public in The Fountains of Paradise (1979).[67]

The obstacle is the one this book knows best: the rope. A space elevator's tether must carry its own weight across 36,000 kilometres, and the required strength-to-weight ratio defeats every bulk material ever made. Carbon nanotubes and graphene reach the numbers in single filaments; nobody yet spins them into a macroscopic cable at anything near laboratory strength. Around that central problem orbit a hundred others that are, recognisably, elevator engineering: climber power and braking (the regenerative descent!), oscillation and sway (the skyscraper in wind), traffic scheduling (one-up-one-down logistics), and safety cases for the worst fall imaginable. Japan's Obayashi Corporation - a builder of towers - keeps a space elevator on its public roadmap, with a stated ambition around 2050, as much declaration of direction as schedule.[68]

Whether or not the ribbon is ever anchored, the idea has already earned its place in the elevator's story. It is the pure form of the industry's founding bet: that a machine for moving vertically is worth inventing a material for. Otis bet an industry on a wagon spring. The space elevator people are betting a century on a molecule. The pattern is the same; only the height changes.



The tether and the climber: the elevator's founding bet, scaled to the sky itself.

CHAPTER 37A

What the Lift Feeds

> *Every IOI study ends at the map: an item is an industry, and it feeds a hundred others. The elevator's branches run from the copper mine to the insurance office - and cross almost every book in this library.*

Upstream, the lift is a metals order. Steel: the guide rails, car frame, counterweight filler - a mid-rise lift carries tonnes of it. Copper: the motor windings, the trailing cable that feeds the moving car, the building's wiring to the machine room. The wire rope industry (Chapter 10A) draws on the same wire rod as the bridge and crane trades. The motor and drive belong to the electrical industry that Werner von Siemens was building when he stopped to invent the electric lift.[16] Semiconductors: the modern controller and drive are power electronics, which is why the chip shortage reached the shaft.

Sideways, the lift is a design constraint traded between professions: architects (the core), structural engineers (the sway), fire engineers (evacuation), insurers (the risk schedule), and the code committees where all of them argue. Downstream, it is the enabler of everything vertical: the skyscraper (this library's Skyscraper study), the deep mine, the high-rise hospital, the apartment towers of the urbanising world - and through them, the shape of the modern city itself. The banknote financed it; the transistor runs its controller; the copper industry supplies its motor windings; the hydroelectric dam's power turns its sheave. S&P placed Otis in its Industrial Machinery sub-industry at the 2020 spin-off.[78] The current GICS name for code 20106020 is Industrial Machinery & Supplies & Components.[79] The map is a filing aid: every small component is its own industry, and the lift is where a dozen of them meet.

EPILOGUE

The Machine That Stacked the World

> *Cities are humanity's greatest artefact, and the elevator is the hinge they turn on. The most ordinary machine of the modern world made the modern world possible.*

Consider what the small room carries. It carries the skyscraper, which is to say the modern economy's preferred shape of organisation - the stacked office, the vertical campus, the city within a plot. It carries the deep mine, and with it the metals the rest of the industrial world is made of. It carries the hospital's floors, the hotel's rooms, the mall's levels, the apartment tower's homes. It carries the old to their front doors and the wheelchair user to the meeting. Its scale is expressed in ordinary dependence: apartments reached, patients moved, goods delivered and journeys that would otherwise be impossible.

And it carries all of this on the slenderest of trusts: a rope nobody sees, a brake nobody tests, a code nobody reads, and a stranger who presses 7. The elevator's history is the story of how that trust was manufactured - by a spring in Yonkers, an axe at the Crystal Palace, a code book in 1921, a strike in 1945, a carbon ribbon in 2013 - and of an industry that Roland Berger valued at US$107 billion in its market outlook,[69] that maintains the promise one inspection at a time.

The material thinker looks at a city and asks what it is made of. The answer is not steel or glass or rent. It is the willingness of millions of people, every day, to step into a small hanging room and be lifted. The elevator raised the buildings. Its industry must keep earning the trust that makes them usable.