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The Evolution of Elevator Technology in Tall Buildings: Race from Steam Lifts to Modern Elevators

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Abstract Vertical transportation systems are foundational to the development of tall buildings and the evolution of high-density cities. This article traces the technological advancements of elevators from early mechanical devices to today's intelligent, energy-efficient systems, emphasizing their role in increasing building height and urban complexity. Through a chronological review, it examines the high points of the elevator's trajectory of growth, including the development of the safety elevator, electric traction systems, machine-room-less (MRL) designs, regenerative drives, and the groundbreaking ropeless multi-directional elevators (MULTI) using magnetic levitation (maglev) technology. Drawing on case studies of recent skyscrapers such as the One World Trade Center in New York, Shanghai Tower in Shanghai, and Burj Khalifa in Dubai, the study highlights how vertical mobility influences tall building design, sustainability, resilience, and user experience. By synthesizing literature and real-world applications, this paper reveals the elevator's evolving role as a key enabler of vertical urbanism and anticipates future trends in elevator technology.

Keywords Vertical mobility, Safety elevator, Electric traction systems, Machine-room-less (MRL) designs, Regenerative drives, Ropeless maglev elevators

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1. Introduction

Because of the world's rapid urbanization, particularly in China and the Middle East, majestic skyscrapers have emerged in the cities. With them came the impressive innovations in elevator technology. Thus, over time, elevator technology has advanced in parallel with the evolving demands of skyscraper design. The elevator is not just an auxiliary system in tall buildings and merely a tool for moving people between floors; it is a vital prerequisite of the tall building. It is key in moving many people in increasingly towering supertall and megatall buildings.

1.1. Overview

The advent of the safety elevator, pioneered by Elisha Otis in the mid-19th century, revolutionized architectural possibilities by enabling buildings to grow vertically rather than sprawl horizontally. This breakthrough marked a paradigm shift in urban morphology, facilitating the densification of central business districts and redefining the skyline of modern cities (Walsh, 2022).

As buildings have grown taller and more complex, elevators have become increasingly sophisticated—no longer stand-alone machines, but critical infrastructural systems embedded within building performance and planning logic. Innovations in elevator design have addressed key challenges of vertical mobility: reducing wait times, improving energy efficiency, conserving floor area, enhancing safety, and ensuring accessibility for all users (Du et al., 2016).

The elevator's role extends beyond mechanical necessity. It shapes how buildings are organized, how people move, and how they experience vertical space. In supertall structures, elevator configurations influence everything from core-to-perimeter relationships to emergency evacuation protocols and inter-floor social interaction. With the advent of innovative technologies, artificial intelligence (AI), and magnetic levitation, the elevator is undergoing a new phase of transformation—becoming a digitally optimized, data-driven system that not only enables height but actively shapes the design and livability of tall buildings (Hrabovsky et al., 2021).

This review paper explores the evolution of elevator technology as an essential enabler of vertical urbanism. Tracing historical milestones, analyzing contemporary innovations, and examining case studies of emblematic skyscrapers seeks to illuminate the elevator's past, present, and likely future design in the vertical city.

The rapid vertical growth of global cities has elevated the role of elevator systems from functional building

components to critical technological infrastructures that determine the feasibility, performance, and experience of tall buildings. The present study investigates the intricate relationship between elevator technologies and vertical urban development in this context. The overarching aim is to provide a comprehensive understanding of how advancements in vertical mobility have enabled and shaped the modern skyscraper and to offer insights into the future of elevator innovation in high-rise architecture.

1.2. Research Objectives

The principal objectives of this study are as follows:

- **Chronicle the technological evolution**
  The study begins by documenting the historical trajectory of elevator technology, from rudimentary rope-and-pulley systems and hydraulic lifts to advanced electric traction elevators and machine-room-less (MRL) and multi-directional (MULTI) systems.
- **How elevators influenced skyscraper design and urban development**
  Elevators do not simply respond to architectural form and vertical urbanism—they actively shape it. This study explores how innovations in elevator systems have, amongst others, directly impacted building form, core configuration, structural strategies, and the distribution of vertical space.
- **Evaluate modern elevator systems' overall performance and safety**
  As vertical buildings grow more complex and resource-conscious, elevator systems are increasingly evaluated on multiple fronts. This study assesses how current elevator technologies address performance metrics such as travel speed, energy consumption, thermal loads, ride comfort, noise, and wait times.
- **Demonstrate current applications through case studies**
  To bridge theory and practice, this paper examines several internationally recognized skyscrapers showcasing cutting-edge vertical transportation strategies. The examples highlight the collaborative efforts of engineers, architects, and urban planners to overcome vertical mobility challenges.
- **Anticipate future trends in elevator technology**
  As supertall and megatall buildings proliferate, the emerging trends are poised to redefine the future of vertical mobility. These include amongst others development of MRL elevators, smart elevators embedded with AI and predictive maintenance tools, carbon-neutral or solar-powered lift systems, and MULTI system.

1.3. Research Methodology

In fulfilling the foregoing objectives, the study aims to contribute to scholarly and professional understanding of elevator technology, offering a multidimensional perspective on the vital yet often overlooked role of vertical transportation in shaping the built environment. The investigation adopts a dual methodological framework that combines a historical-technical literature review and analysis with selected case studies of skyscrapers. This methodology is designed to provide both breadth and depth in examining the technological evolution of elevator systems and their application in the world's most iconic skyscrapers.

A methodological component of the research involves an extensive review of interdisciplinary sources, including peer-reviewed academic articles, technical manuals, historical texts, elevator industry white papers, and institutional publications from organizations such as the Council on Tall Buildings and Urban Habitat (CTBUH). This literature base enables the study to trace the chronological development of elevator systems, from early rope and steam lifts to modern electric traction elevators, MRL, MULTI, and intelligent elevator systems. The review situates these technological advancements of elevators within the broader evolution of architectural and urban practices, highlighting how the innovation of the elevator has responded to and influenced developments in tall building design, urban density, and spatial efficiency. The literature review also engages with scholarly discussions on sustainability, performance optimization, and human-building interaction, providing a critical lens through which to assess the implications of vertical transportation technologies on environmental and user-centered design. This historical-technical synthesis sets the foundation for understanding elevators' trajectory and transformative role in shaping vertical urbanism.

The other component is to illustrate the concepts with case studies. Out of many available examples, a few representative ones from global cities are selected for analysis. These case studies provide a better understanding of the complexities of elevator technology.

2. The Background

The dual-methodological approach discussed above underlines the technical complexity behind elevator systems and highlights their socio-cultural and economic implications. By joining historical perspectives with modern technological practices, the study seeks to untangle how elevators have surpassed their useful functional role to become integral to urban life's identity and operational function. It is thus vital to delve into the historical perspective of elevators.

2.1. The Origin

The Roman architect Vitruvius first recorded the use of an elevator in the first century and attributed it to Archimedes around 235 BC (Al, 2022). The first elevator was a system of hoisting ropes wound around a drum, a block-and-tackle device consisting of two or more pulleys with a rope between them. Sources from later periods indicate elevators as cabs on a hemp rope, powered by

animals or people. The Romans used to hoist wild animals and gladiators to the floor of the Colosseum, built in the year 80, in slow-moving cages using human-powered elevators. In the 11th century, Ibn Khalaf Al-Muradi, a mathematician and engineer from Andalusia, in his *Book of Secrets,* explains a rising "fortress demolisher" that employed a rope and pulley system to expand wooden scissor-like structures to lift a mechanical pounding ram. These are the forerunners to the elevator (Torres-Garrido, 2019).

The story of modern-day vertical mobility in tall buildings begins in the mid-19th century with a transformative invention: the safety elevator. In 1852, Elisha Otis, a master mechanic at the Bedstead Manufacturing Company in Yonkers, New York, invented the first elevator, a mechanized platform that could be lifted. He demonstrated a freight elevator with safety devices in 1853. In 1854, at the New Crystal Palace Exhibition in New York City, he carried out a pioneering experiment on himself to demonstrate the first safety elevator. He stood on a platform suspended by a single rope. He then lifted himself above the observers. His assistant cut the rope with an ax, and nothing happened other than a jerk of the platform. This is a breakthrough moment when the safety elevator was born. This historic event redefined public confidence in vertical transport and catalyzed the integration of elevators into multistory buildings. With the commercial installation of the first passenger safety elevator in 1857, Otis laid the mechanical and psychological foundation for moving upward in multistory buildings. He changed the shape of cities to come (Nichols, 2018). In 1861, he patented a steam elevator.

2.2. Early Steam-Driven and Hydraulic Elevators

While the Otis's safety device solved the issue of sudden descent, early power systems presented another set of challenges. The earliest elevators were driven by steam engines, which were large, noisy, and inefficient. The first hydraulic crane using a piston in a cylinder powered by water pressure was introduced in 1846 Sir William Armstrong to lift and lower cargo. However, quieter and more reliable, hydraulic elevators had their constraints, particularly the need for a deep borehole equal to the height of travel, which limited their application in taller structures. These systems were best suited for low- to mid-rise buildings and often used in warehouses and early department stores rather than skyscrapers. In the 1870s, hydraulic elevators began to replace steam-powered elevators (Gray, 2021). Since hydraulic elevators could reach greater heights than steam elevators, they facilitated the rise of up to 10-story buildings in the 1870s (Beedle et al., 2007).

2.3. Early Applications and Challenges

Despite these limitations, engineers and architects experimented widely, and mechanical challenges and early building applications began to emerge in urban cores. Buildings such as the Equitable Life Building of 1870 in New York, which was a groundbreaking structure for being the first commercial building to employ passenger elevators and was a precursor to the skyscraper and the Home Insurance Building of 1885 in Chicago, generally recognized as the first skyscraper, relied on elevator systems to unlock new spatial and economic possibilities (Ali and Moon, 2022). Yet their implementation remained cumbersome (Escalada & Abad, 2016). Elevators were slow, prone to breakdowns, and required extensive shaft space and mechanical oversight. Safety was not yet standardized, and passenger comfort was minimal by contemporary standards.

2.4. Limitations of Early Systems

The limitations of early systems for vertical height and reliability placed practical ceilings on building design. The maximum height a building could attain was primarily governed by its elevator's speed, dependability, and lifting capacity. Tall buildings were technically viable, but economically and operationally inefficient. As a result, vertical growth during this period remained modest, pending further advancements in traction systems, motor technology, and safety protocols (Figure 1). This early phase of elevator development thus set the groundwork for the skyscraper era but also revealed the technological choke-points that needed to be addressed to move beyond about 20 stories (Al-Kodmany, 2023a). The stage was set for electrification and traction innovations, defining the next phase in vertical mobility.

3. Advancement of Elevator Technology

The hydraulic elevator has its downsides. As stated, a borehole under the elevator was needed to accommodate the piston. The higher the elevator traveled, the deeper the hole needed to be. For taller buildings, this was undesirable. The advent of the traction elevators marked a historic moment for elevators and engineering innovation. An electric motor powers traction elevators, which are usually called an electric elevator. Innovations followed that made elevators more sophisticated, safer, and relaxing for the passengers.

3.1. Advent of Electric Elevators and Gearless Motors

In 1880, Werner von Siemens, a German engineer, built the first electric elevator and demonstrated it. However, it was not immediately suitable for practical use. Frank Sprague developed an electric elevator around the same time in the U.S., contributing positively to the refinement and implementation of this new technology. Later, he claimed these could run up to 183 meters (600 feet) per minute. His elevators could run up to 122 meters (400 feet) per minute (Gray, 2002). Later, he claimed these could run up to 183 meters (600 feet) per minute. In

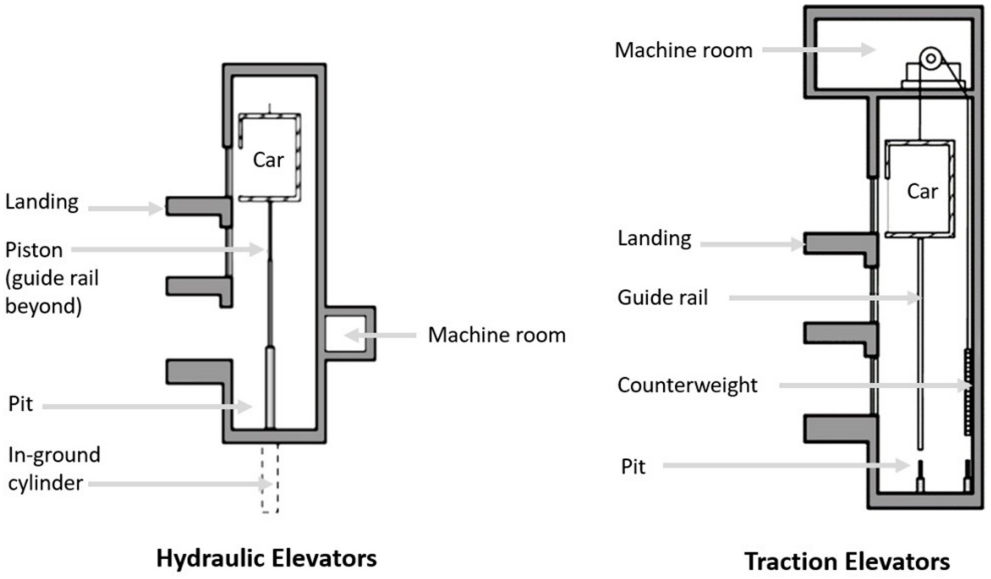


Figure 1. Schematic comparing hydraulic and traction elevator systems, emphasizing differences in operation, space requirements, and performance—factors that shaped early skyscraper design. Source: authors

1887, an American inventor, Alexander Miles, patented an electric elevator with automatic doors. Fully automated elevators became available in 1900.

These systems allowed smoother rides and significantly higher travel distances than their hydraulic predecessors. The introduction of gearless traction motors, pioneered by Otis Elevator Co. in the 1930s and refined over subsequent decades, enabled elevators to reach speeds exceeding 305 meters (1,000 feet) per minute. The gearless motors were crucial to the functioning of skyscrapers like New York's Empire State Building of 1931, where speed, reliability, and passenger volume were vital (Boyko & Volyanskaya, 2018). The full adoption of electric traction systems replaced steam and hydraulic mechanisms, allowing for faster, more reliable, heavier load carrying, and more comfortable vertical movement. With these advancements, elevators were no longer limiting elements—they became enablers of modern building height and urban density.

The 1930s and 1970s marked a pivotal era of electrification and modernization. Elevator technology matured concurrently with the global rise of tall buildings. During this period, the increased application of electric traction systems gradually replaced hydraulic systems, resulting in enhanced dependability, lifting capability, and passenger ease (Abdelrazaq, 2010). Mobility in the vertical realm became more achievable, supporting the promotion of ambitious tall building design. Although electric elevators became more common, hydraulic elevators continued to be refined and are still used for some applications, especially for low-rise buildings.

3.2. Machine Rooms

A related development results from the need for a machine room for elevators. Hydraulic elevators are often located on the ground floor or in the basement, while electric elevators are generally accessed on a rooftop, a penthouse, or through a mechanical equipment room. The machine room holds the elevator's mechanical and electrical equipment, main controllers, and drives. During the 1940s-1970s, improvements in spatial design introduced optimized machine room systems and vertical shaft integration. These advancements enabled elegant and compact building profiles by centralizing machinery within structural cores (Pai et al., 2015).

3.3. Multi-Elevator Banks and High-Rise Core Design

As skyscrapers grew in height and complexity, elevator banks and zoning systems emerged to manage passenger flows. The concept of dividing tall buildings into vertical zones, each served by its own set of elevators, was introduced to minimize travel times and reduce the number of elevator shafts needed (Al-Kodmany, 2021). The innovation of the multi-elevator is directly linked to the growth of skyscrapers for the efficient vertical movement of many people. This led to a more efficient use of floor area, particularly important as buildings surpassed 20, 40, and even 50 stories. Group control systems, a precursor to today's algorithmic dispatching, also began to appear, coordinating elevator assignments based on usage patterns.

3.4. Improvements in Safety, Speed, and Shaft Optimization

Regarding spatial design, machine room systems and vertical shaft optimization became central to architectural planning. Traditional elevators required substantial overhead machine rooms to house motors, pulleys, and controllers, often occupying valuable rooftop real estate. Architects

and engineers refined core arrangements to centralize and stack elevator machinery, enabling more elegant and compact building profiles. The mechanical and spatial integration of elevator systems into the structural core became standard in modern high-rise construction (Koçak & Bayraklılar, 2023).

4. New Technologies and Innovations

By the end of the 1970s, elevator technology had matured into a refined system capable of supporting most aspiring vertical advances. The growing degree and intricacy of tall buildings continued to push engineers toward further sophistication, leading into the era of digital integration, energy efficiency, and space-saving innovation that would define the late 20th and early 21st centuries. The globalization of elevator manufacturing began to shape our present-day (as of 2025) innovations of elevators. Companies such as Otis (U.S.), Schindler (Switzerland), KONE (Finland), ThyssenKrupp (Germany), and Mitsubishi Electric (Japan) emerged as global leaders, driving innovation and standardization across international markets (Beyer, 2009). These corporations developed proprietary technologies, expanded installation capabilities, and helped shape building codes and performance benchmarks in rapidly growing cities worldwide.

The contributions of major elevator companies have been critical in defining modern vertical mobility. Otis revolutionized skyscraper transportation with gearless traction motors, enabling faster and more reliable elevators. Schindler advanced energy-efficient and sustainable solutions, while KONE initiated MRL elevators, a breakthrough that marked a high point in elevator engineering. Thyssen-Krupp (renamed TK Elevator) has developed MULTI system using maglev technology, and Mitsubishi Electric is renowned for precision engineering and high-speed elevators catering to the world's tallest skyscrapers. These companies have driven technological expansions and supported the global urban landscape. In short, elevator technology has evolved dramatically from its hydraulic origins to revolutionary MRL and MULTI systems (Al-Kodmany, 2023b; Al, 2022).

4.1. MRL Elevators

The introduction of MRL elevators in 1996, through KONE's pioneering MonoSpace® system, marked a significant turning point in elevator technology for tall buildings. By integrating compact, gearless traction motors and control systems directly within the elevator hoist way, MRL elevators eliminated the need for a separate machine room, traditionally located above or below the shaft. This breakthrough offered a leaner, more space-efficient design that transformed elevator engineering and high-rise architecture.

MRL elevators quickly became a preferred solution for developers seeking to optimize space, reduce costs, and improve energy performance. Eliminating the machine room freed up valuable rooftop or basement areas for other uses, allowing for greater design flexibility in elevator placement and core planning (Figure 2). Their gearless motors consume 30-40% less energy than traditional traction or hydraulic systems (Al-Kodmany, 2023b). MRL systems typically require less structural reinforcement, are easier to install, and have lower maintenance costs.

Since their introduction, MRL elevators have become a global standard in vertical mobility. What began as a compact innovation for space-constrained towers has

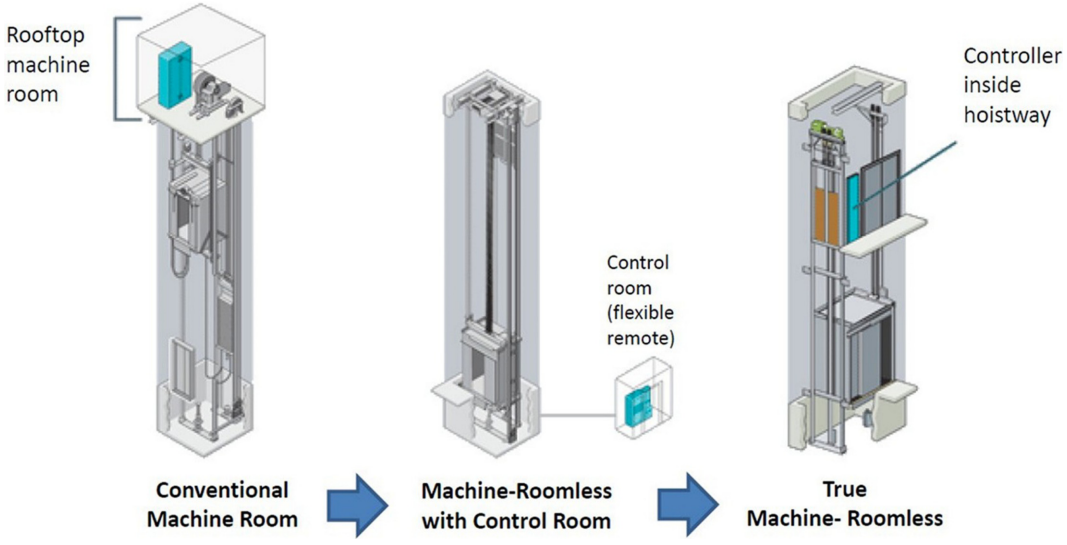


Figure 2. Diagram of the Gearless Machine-Room-Less (MRL) elevator system, which integrates the motor and controls within the hoistway. This space-saving design eliminates the need for a machine room, enhancing core efficiency, design flexibility, and energy performance in tall buildings. Source: adapted from http://www.otisworldwide.com.

evolved into a critical component of high-rise design, supporting denser urban growth through efficient and adaptable systems.

4.2. Turning Elevators into Energy Contributors

A tremendous advance in elevator technology over the past few decades has been the integration of regenerative drives, which allow elevators to consume energy and produce and return it to the building's electrical grid. First introduced into commercial elevator systems in the late 1990s and early 2000s, these systems adapt regenerative braking—a principle long used in trains and industrial machinery—to the vertical demands of high-rise structures. Leading elevator manufacturers such as KONE, Otis, and Schindler played a pivotal role in adapting this technology for elevators, aligning it with the broader push toward energy-efficient and sustainable buildings. A significant milestone came with KONE's EcoDisc motor system, which incorporated regenerative components and signaled a new era of intelligent, environmentally conscious vertical mobility. By the 2010s, regenerative drives had become standard in many mid- and high-rise projects worldwide (Gu, 2014).

In traditional elevator systems, energy generated during braking, such as descending with a heavy load or ascending with a light one, is typically dissipated as heat. This wastes potential energy and increases the load on the building's HVAC systems due to the added thermal load in machine rooms. Regenerative drives address this inefficiency by capturing the kinetic energy produced during these movements, converting it into usable electricity, and feeding it back into the building's power supply (Figure 3). The benefits are particularly significant in tall buildings where elevator use is constant, making the opportunity for energy recovery both frequent and substantial. When

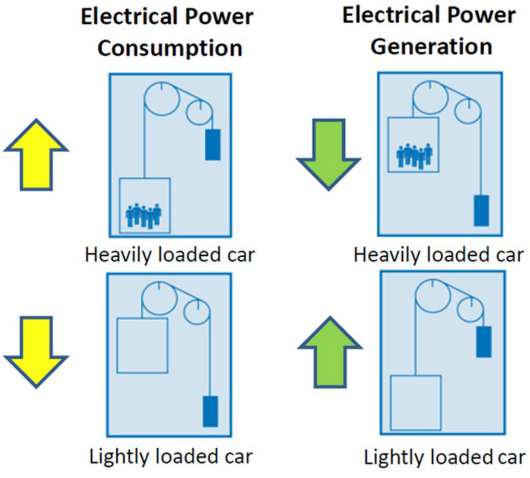


Figure 3. Illustration of a regenerative drive system that captures braking energy and converts it into electricity, feeding it back into the building's grid. This technology improves energy efficiency, reduces heat waste, and supports sustainable high-rise design. Source: Adapted from otisworldwide. com

operating in generator mode under optimal conditions, elevators equipped with regenerative drives can reduce overall energy consumption by as much as 70% (Parker & Wood, 2013).

In addition to direct energy savings, regenerative systems lower operational costs, reduce carbon emissions, and extend the life of elevator components by minimizing heat-related stress. They also contribute to building sustainability targets and green certifications such as LEED. Although initial installation costs are higher than those of conventional systems, the long-term advantages of regenerative drives—economically and environmentally—make them a compelling investment. As cities grow vertically and strive for net-zero carbon goals, regenerative elevator systems stand out as a vital component of intelligent, future-ready buildings.

4.3. Integrating LED Lighting

Integrating LED (light-emitting diode) lighting in elevator systems marks a significant breakthrough in the broader movement toward energy-efficient building technologies. It imparts efficiency, longevity, and environmental integration. While elevator cabins and machine rooms traditionally relied on incandescent, halogen, or fluorescent bulbs, the transition to LED lighting began in the early to mid-2000s, with widespread adoption accelerating throughout the 2010s as LED technology became more affordable, reliable, and architecturally mainstream.

LED lighting is now a standard feature in newly constructed tall buildings and is increasingly being retrofitted into existing elevator systems. Its appeal lies in converging energy savings, environmental performance, and operational reliability (Yao et al., 2022). LEDs consume about 80% less electricity than conventional lighting and emit significantly less heat, an essential consideration in the confined spaces of elevator cabs, where excessive heat can impact rider comfort and increase cooling loads. LED lighting is among the most effective contributors to reducing a building's overall elevator energy consumption, especially when integrated with motion detectors that dim or switch off lights during inactivity.

The longevity of LED lighting translates into lower maintenance costs and fewer disruptions for service, especially important in high-rise environments with heavy elevator usage (Makar et al., 2022). LED technology has become integral to sustainable elevator systems. Whether incorporated into new high-rise projects or used to modernize aging infrastructure, LED lighting reflects a shift toward more resilient, cost-effective, and sustainable vertical transportation.

4.4. Innovative Braking Systems

While braking mechanisms have been a fundamental part of elevator technology since Elisha Otis introduced the safety brake in 1854, advanced braking systems ensuring precision, redundancy, and safety as we know

today began to surface from the late 1990s to early 2000s, coinciding with broader advances in motor control, regenerative drives, and digital automation. These modern systems are no longer limited to simple mechanical friction brakes; instead, they incorporate precision control, multiple redundancies, and energy-efficient operation, making them indispensable in the operation of high-rise elevators (Eberle, 2001).

Elevators in tall and supertall buildings must handle increased speed, weight, and dynamic forces. As such, braking systems have evolved to meet more rigorous demands. Unlike conventional designs that relied solely on friction and mechanical engagement, contemporary braking systems integrate electromagnetic braking, digital sensors, and real-time monitoring. This allows for precise deceleration, smoother stops, and responsive adaptation to variable loads and emergency conditions. In particular, innovative braking systems can modulate braking force in real-time to maintain ride comfort and system stability at high speeds.

Manufacturers such as Otis, Schindler, KONE, Mitsubishi Electric, and TK Elevator have pioneered these technologies, often aligning brake innovation with new gearless motors, MRL configurations, and regenerative drive systems developments. For example, braking systems are now routinely integrated into energy recovery loops, allowing kinetic energy from braking to be converted back into electricity, thereby improving overall system efficiency.

Another hallmark of modern braking systems is redundancy. In tall buildings, where elevator failure could disrupt the flow of thousands of occupants, multiple braking layers ensure operational continuity and safety. Brakes are designed to activate automatically in case of sudden power failure, overspeed detection, or system glitches. Many elevators now include self-diagnostic protocols that continuously test brake performance and send alerts if wear thresholds are approached, thus supporting predictive maintenance.

4.5. Computerized Roller Guides

A principal technological innovation in achieving smoother elevator ride has been the development of computerized roller guides, also called *active* or *smart roller guides*. These systems began emerging in the early 2000s, with significant refinement and deployment throughout the 2010s, especially in high-rise applications where elevators operate at speeds exceeding 305 meters (1,000 feet) per minute (Wang et al., 2021).

At their core, computerized roller guides serve as real-time shock absorbers that enhance ride quality by minimizing vibrations, jolts, and lateral motion. They use intelligent sensors and pressure-adjusting mechanisms to adapt dynamically to track irregularities, improving passenger comfort and mechanical durability (Lewis & Holt, 2011). This capability is especially critical given that elevator rails must be installed in short segments—typically around 5 meters (16 feet)—which introduces multiple joints along the shaft. These joints and external factors like wind sway and thermal expansion and contraction create alignment challenges that can degrade ride quality if not addressed.

A notable example of these systems is the One World Trade Center (One WTC) in New York (see Section 8). Designed by TK Elevator, the building features automatic computerized roller guides that counteract structural sway and rail misalignments. These guides exert pressure opposite the direction of motion, dampening shocks and ensuring continuous contact between the elevator car's wheels and the guide rails. Polyurethane rollers further absorb vibrations, and a feedback-controlled mechanism minimizes the effects of even minor rail defects.

This innovation functions analogously to a driver avoiding potholes. When irregularities are sensed on one side of the rail, the system subtly adjusts position in the opposite direction, ensuring a seamless ride. As a result, express elevators at One WTC achieve much faster speeds than those in the original Twin Towers and deliver exceptional quietness and smoothness, even under high loads and rapid transit conditions.

5. Double-Deck, TWIN Systems, and Early Digital Controls

A central innovation around 2000 was the deployment of double-deck elevators and the TWIN system to optimize space efficiency and passenger throughput in tall buildings. As skyscraper height increased, so did the spatial burden of elevator shafts, which consumed valuable floor area on every story.

5.1. Double-Deck Elevators

The first double-deck (DD) elevators were invented and installed by the Otis Elevator Company in 1931, specifically in the Cities Service Building (renamed 70 Pine Street) in New York City. Comprising two vertically stacked cabs, this issue was addressed by serving two floors simultaneously: one cab for even-numbered floors and the other for odd-numbered ones. This configuration made them especially suitable for shuttle services in supertall towers, where efficiently moving large volumes of people was essential (Figure 4).

However, DD elevators presented particular operational challenges. First, they required passengers to understand that each cab served only specific floors, which could be confusing, particularly for first-time visitors. Second, even if only one cab needed to stop, both had to come to a halt, reducing efficiency. Third, the inter-floor distances had to remain uniform across the building. Toshiba introduced height-adjustable double-deck elevators in response to this constraint, granting architects more design flexibility (Cortes et al., 2021).

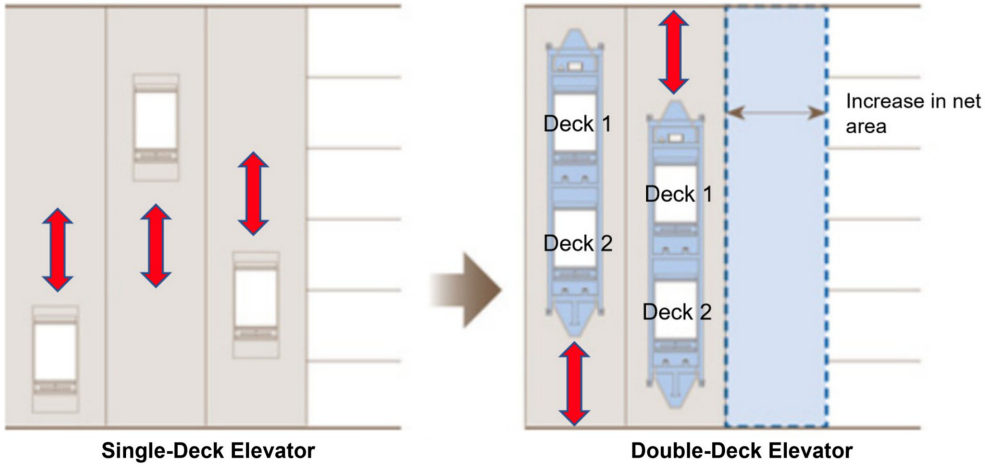


Figure 4. Schematic comparing single-deck and double-deck elevators. The double-deck system uses two vertically stacked cabs in one shaft, reducing shaft count and enhancing spatial efficiency—ideal for high-traffic supertall buildings. Source: Adapted from hyundaielevator.com

Super DD elevators, an advancement of the standard DD elevator, introduced by TK Elevator, are designed to maximize efficiency and adaptability in modern skyscrapers. These elevators include height-adjustable cabins allowing architects and engineers greater design flexibility, accommodating varying floor-to-floor heights without compromising operational efficiency. These elevators are outfitted with advanced control systems that augment passenger flow, ensuring smooth coordination between the two cabins while reducing wait times. These are perfect for tall buildings with complex plans. Moreover, their innovative mechanisms address traditional inadequacies, such as the need for concurrent stops, thereby increasing energy efficiency.

5.2. TWIN System

Building on shared shaft logic, TK Elevator's TWIN system—launched in 2003—offered a more flexible alternative (Figure 5). Unlike double-deck elevators, the TWIN features two independent cabins with their own motors operating within a single shaft, each capable of moving separately. This innovation increased efficiency and saved up to 30% of core space compared to conventional systems. An advanced control system ensures safe spacing between the cabs and optimizes assignments based on passenger demand, minimizing wait times and conserving energy (Smith, 2005).

5.3. Early Digital Controls

The late 20th century marked a pivotal shift in elevator technology, as microprocessors, sensors, and software logic transformed elevators from purely mechanical devices into intelligent systems. A significant breakthrough was the development of Destination Dispatch Systems (DDS) in the 1990s, building on advances in microprocessor technology from the previous decade (Barney & Al-Sharif, 2015). Instead of pressing generic "up" or "down"

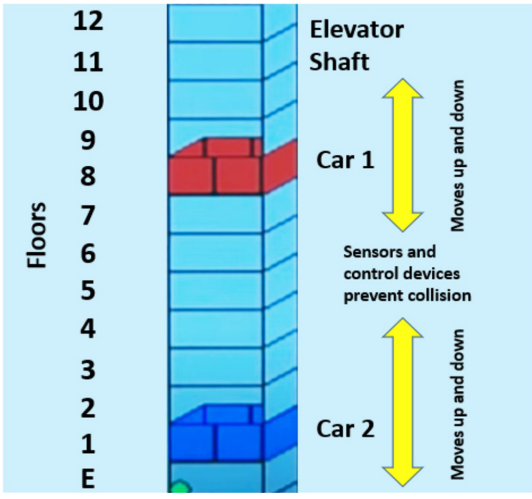


Figure 5. The TWIN elevator system by TK Elevator features two independently operating cabins in a single shaft, each with its own motor and controls. This design improves efficiency, reduces shaft count, and saves up to 30% of core space in high-rise buildings. Source: Adapted from youtube.com/watch?v=DMfqwhj_S3U

buttons, users entered their destination at a lobby terminal, allowing the system to group passengers traveling to similar floors and assign them to specific elevators (Figure 6). This reduced wait times, minimized stops, and improved energy efficiency, cutting average wait times in one 16-story building from 138 seconds to 13 seconds (Xu et al., 2018). Some DDS algorithms even adjusted elevator speed during off-peak hours to conserve energy.

In parallel, early predictive maintenance tools emerged, using basic sensors and onboard diagnostics to monitor performance, detect anomalies, and prevent breakdowns, setting the stage for more sophisticated AI-based systems introduced in the 2010s. These developments aligned with increasing demands for energy-efficient, cost-effective,

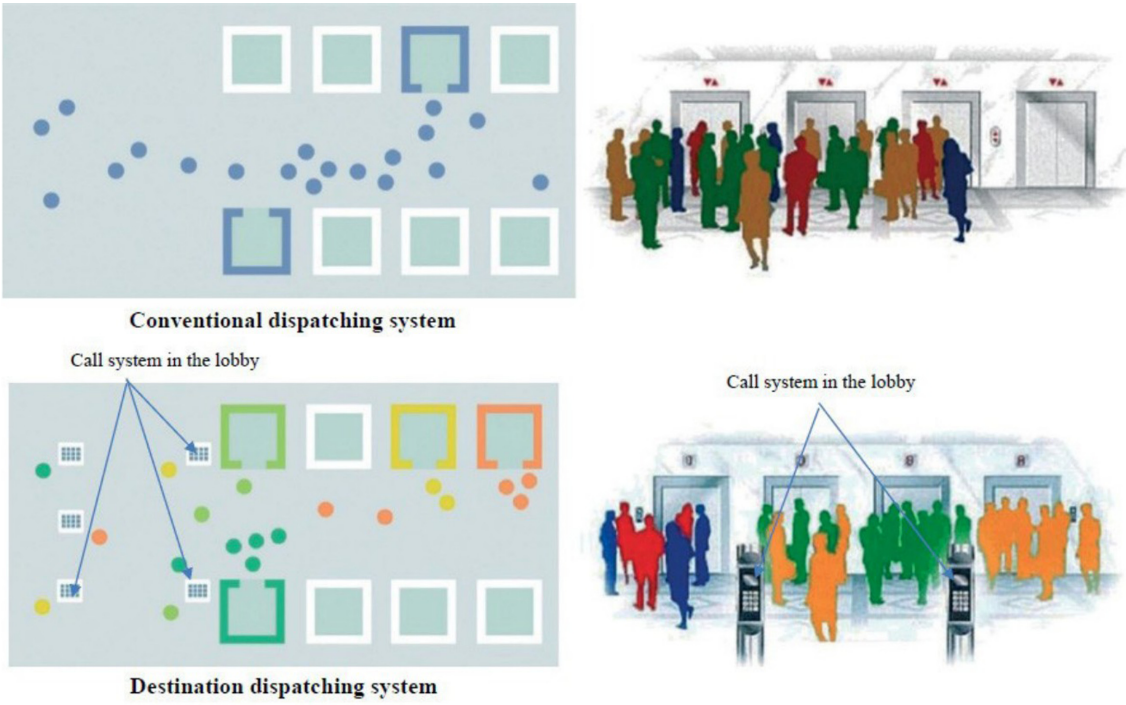


Figure 6. Comparison of conventional dispatching (top), where users select up/down calls, and destination dispatch systems (bottom), which group passengers by floor to optimize assignments, reduce stops, and improve efficiency. Source: Adapted from ThyssenKrupp.com

and high-performance building systems. As green certifications like LEED gained traction, elevators became critical to achieving sustainability benchmarks through reduced idle times, more innovative scheduling, and improved operational efficiency.

By the early 2000s, elevators in tall buildings had become digitally orchestrated systems—responsive, predictive, and essential to the seamless functioning of modern high-rises. These foundational innovations laid the groundwork for the intelligent vertical transportation networks of the supertall era.

6. Advanced Technologies and Sustainable Elevators

The global push for environmental sustainability was strongly reflected in elevator design during the 2010s-2020s era. Systems began incorporating standby modes that reduced energy consumption by shutting down lights, ventilation, and display panels when not in use. Regenerative drive systems converted kinetic energy from descending elevators into usable electricity and became standard in many new installations. Manufacturers also began exploring solar-powered elevator systems, particularly in mid-rise buildings in sunny climates, as part of broader net-zero building goals. These innovations were cost-saving and aligned with growing regulatory and market demands for energy-efficient infrastructure.

6.1. The UltraRope Revolution

Historically, one of the most critical limitations to vertical mobility in supertall buildings has been the weight of elevator ropes. In extremely tall towers, nearly 70% of an elevator's total moving mass is attributed to the hoisting cable, which adds considerable mechanical strain, accelerates energy consumption, and presents serious maintenance concerns. As travel distances exceed 500 meters, traditional steel ropes become inefficient and structurally impractical—at such lengths, their weight can exceed the loads they are meant to lift. For instance, as Johannes de Jong of KONE noted, the total weight of steel ropes for a 2,000-kilogram (4,400 pounds) elevator cab traveling 500 meters (1,640 feet) can approach 27,000 kilograms (59,400 pounds), significantly increasing the energy needed for acceleration and deceleration (Ming et al., 2018).

These excessive loads also pose safety risks and long-term structural challenges. In past supertalls such as the original World Trade Center Twin Towers, elevator ropes swayed significantly in high winds, gradually wearing grooves into the shaft walls. Several manufacturers have pursued lighter alternatives to address these risks: Otis developed a polyurethane-sheathed cable belt, Mitsubishi engineered concentric-layered steel wire ropes, and Schindler introduced aramid fiber solutions. While each offered incremental improvements, the most groundbreaking leap came from KONE's development of UltraRope.

Introduced in the 2010s, the UltraRope is a carbon-

fiber-based hoisting solution that radically redefines elevator design. It consists of a carbon-fiber core with a high-friction coating, is significantly lighter than steel, and provides high tensile strength. UltraRope is very light compared to conventional steel ropes. This reduction in rope mass substantially reduces the total moving load, resulting in lower energy consumption. Maintenance and replacement cycles are also shortened, given the material's durability and ease of handling.

According to de Jong (2018), UltraRope represents "the biggest change in elevators since 1853." It eliminates many of the height and performance barriers that have constrained elevator technology for decades and opens the door to a new generation of ultra-tall buildings, perhaps even realizing long-imagined visions such as Frank Lloyd Wright's One-Mile-High Illinois Tower (Baker & Pawlikowski, 2015). With its combination of lightness, strength, and energy efficiency, UltraRope enables greater height and supports leaner, greener elevator systems that align with contemporary sustainability goals.

The UltraRope is slated for use in the Kingdom Tower (Jeddah Tower) under construction, which will exceed 1,000 meters (3,281 feet) in height, making it the tallest building in the world. With this integration, UltraRope may soon become the enabling technology for a new frontier in vertical urbanism, marking a definitive step toward realizing the full architectural potential of the vertical city.

6.2. Standby Modes to Conserve Energy During Inactivity

As tall buildings grow increasingly complex and energy-conscious, elevator systems have evolved to include high-performance motors and drives, and intelligent standby modes designed to conserve energy during periods of inactivity. These standby solutions—also referred to as "sleep modes"—represent a crucial component of innovative elevator technology, helping reduce operational costs and environmental impact without compromising user experience (Patrão et al., 2009; Rashed et al., 2024).

Standby modes power down non-essential elevator functions when the system is idle. Through the use of in-cab sensors and intelligent software, the elevator can detect when it is unoccupied and automatically deactivate features such as:

- Interior lighting,
- Ventilation fans,
- Multimedia screens (e.g., advertisements or news tickers), and Music or audio cues.

One common scenario involves weight sensors detecting the absence of passengers, triggering a sequence in which lights may dim or switch off after as little as 40 seconds of inactivity. In some systems, touch panels and floor displays may also enter low-power states, further cutting energy consumption.

The impact of these strategies is significant. Standby modes can reduce total elevator energy use by 25% to 80% depending on building type, elevator configuration, and usage patterns. For example, switching from incandescent to LED lighting paired with intelligent shut-off mechanisms yields significant reductions in electricity and heat load.

These efficiencies are especially valuable in tall buildings with multiple elevator banks operating around the clock. During off-peak hours—such as late nights or weekends—standby functionality ensures that energy isn't wasted maintaining unused systems. Standby solutions reflect a broader shift toward responsive, energy-smart infrastructure. As part of an integrated approach to sustainable design, these features help tall buildings achieve energy benchmarks, reduce operational costs, and align with green building certifications. In doing so, standby modes advance the evolving role of elevators—not just as vertical movers, but as key contributors to environmental performance in vertical urbanism.

6.3. "Net-Zero" Solar Elevator

As cities worldwide intensify efforts to decarbonize their infrastructure, solar integration in elevator systems has emerged as a promising frontier in pursuing energy-efficient, sustainable high-rise development. s are traditionally seen as energy consumers, but recent technological advancements are transforming them into energy-neutral or even energy-positive components of building systems.

A significant compelling innovation is the net-zero solar energy elevator, which is designed to produce as much energy annually as it consumes. This concept combines renewable power generation, ultra-efficient components, and intelligent power management. Among the pioneers in this field is TK Elevator, whose prototype Synergy Elevator integrates several advanced techno−logies to dramatically lower energy consumption. These include (Leung et al., 2024):

- Regenerative drive systems,
- LED cab lighting,
- A deep-sleep standby mode controller, and
- Auto power-down features that shut off lights and fans when the elevator is idle.

The Synergy Elevator is paired with a 3.75-kilowatt rooftop photovoltaic (PV) array to achieve net-zero status, generating around 4,000 kilowatt hours per year in climates like Boston. This prototype was tested at Boston's Center for Sustainable Energy (CSE) headquarters, showcasing its applicability in temperate, urban environments.

Similarly, Schindler has introduced its solar-powered solution—the Schindler Solar Elevator. This system employs rooftop solar panels and a Hybrid Energy Manager (HEM) to store energy in battery units, enabling operation independent of the grid during power outages. Key features of this elevator include (Leung et al., 2024):

- A Schindler 3,300 gearless MRL elevator,
- A frequency converter with energy-efficient standby

modes, Soft start technology to avoid energy spikes during trips; and
- Automatic LED lighting and car control systems that optimize energy use.

Schindler's system claims up to 100% solar-powered operation, significantly reducing peak energy demands and offering resilience in power-restricted settings. Further, this gearless elevator model is approximately 60% more energy-efficient than traditional hydraulic elevators, according to Samion et al. (2021).

Collectively, these systems represent a shift in thinking—from elevators as passive, high-consumption components to active contributors in sustainable building design. While challenges remain in scaling such systems across varying climates and building types, the trajectory is clear: solar-powered elevators are becoming viable in achieving net-zero and carbon-neutral urban environments.

An emerging enhancement in this space is the integration of Virtual Reality (VR) diagnostics. Using VR headsets, technicians can perform detailed inspections of elevator machinery without physically entering shafts or accessing elevated motor rooms. This innovation improves technician safety and enables immersive, 3D "walkthroughs" of elevator systems, allowing crews to locate and address issues with unmatched spatial clarity. VR-assisted diagnosis can simulate component failure scenarios, map out repair workflows, and direct less-experienced personnel through complex troubleshooting tasks.

6.4. Hygiene and Accessibility Technologies

The COVID-19 pandemic of 2020 and onward spurred a pivotal shift in elevator design, catalyzing the rapid integration of hygiene-centered and accessibility-enhancing technologies, particularly in tall buildings where use is frequent and essential. As concerns about viral transmission via high-touch surfaces grew, manufacturers introduced a new generation of touchless control systems to reduce physical contact within elevator cabins. These systems include voice-activated interfaces, gesture recognition panels, foot pedals, and smartphone-based apps that allow users to call and operate elevators remotely. By eliminating the need to press physical buttons, these innovations have made elevators safer and more inclusive, benefiting users with mobility challenges, visual impairments, or auditory limitations (Giacomello et al., 2021).

This domain's most visually striking and advanced innovations are holographic elevator buttons—systems that project virtual control panels in mid-air. Users can activate these floating buttons by simply pointing or gesturing, combining futuristic user experience with critical public health functionality. Some systems also integrate voice-command alternatives, offering further options for hands-free interaction. Beyond hygiene, these enhancements signal a broader trend toward digital sophistication and user personalization in high-rise environments.

Manufacturers have also deployed self-sanitizing technologies to complement these control systems, most notably ultraviolet (UV) disinfection systems. When the elevator is vacant, these mechanisms activate automatically, bathing cabin interiors in UV light that neutralizes pathogens on buttons, handrails, and walls. As a passive sanitation method, UV disinfection reduces maintenance burdens. It adds an extra layer of safety, particularly in commercial towers, residential skyscrapers, and healthcare facilities with high foot traffic and frequent turnover (Giacomello et al., 2021).

6.5. Advanced DDS and People Flow Solutions

Building upon early digital scheduling systems, advanced Destination Dispatch Systems (DDS) represent a significant leap forward in optimizing vertical circulation, especially in high-occupancy tall buildings (Barney & Al-Sharif, 2015). Unlike conventional elevator operations that rely on simple up/down calls, DDS requires users to enter their destination before entering the elevator, allowing the system to group passengers traveling to similar floors and assign them to specific cars. This reduces wait and travel times, minimizes unnecessary stops, lowers energy consumption, and eases congestion during peak hours (Gensler et al., 2015). Modern DDS platforms are now integrated with artificial intelligence to learn user behavior patterns over time, improving routing efficiency.

A closely related innovation is the deployment of People Flow Solutions, which are designed to manage complex vertical and horizontal circulation challenges at an even greater scale. A notable example is the Abraj Al Bait Hotel Complex, also known as the Clock Tower Complex, in Makkah, Saudi Arabia—home to over 75,000 residents and adjacent to the Masjid Al Haram, the holiest mosque in Islam. The challenge of moving tens of thousands of worshippers to and from prayer five times a day within short windows of time required an extraordinary vertical transportation strategy. To coordinate this immense logistical task, KONE implemented a sophisticated group control system enhanced with AI, capable of learning traffic patterns and optimizing elevator dispatch in real time. This project exemplifies how advanced DDS and People Flow Solutions work in tandem to ensure seamless, high-volume vertical mobility in supertall, high-density developments (Siikonen, 2021).

6.6. Smooth Elevator Ride

In times of heavy wind and to accommodate the shaking during mild sway, Mitsubishi proposed pausing the Shanghai Tower. During extreme sways, sensors detect the shaking and stop the elevator at the nearby floor, allowing the passengers to leave the elevator safely. To eliminate any other lateral shake, engineers devised a roller system in which sensors near the cabin detect horizontal movement and counter it by moving in the opposite direction, canceling most of the shake. This elaborate system ensures a smooth elevator ride (Al, 2022).

Engineers also solved the problem of passengers' ear-popping at great height because of low air pressure by installing a system to control air pressure, allowing more time for the ear to adjust.

7. Futuristic Elevator Systems

As cities worldwide continue to densify and tall buildings reach ever greater heights and programmatic complexity, elevator technologies are poised for a dramatic transformation beyond the 2020s. The next frontier of innovation is defined by efficiency, flexibility, sustainability, frictionless movement, minimum sensory perception, and intelligent systems capable of adapting in real time to urban life's spatial and progressive dynamics. Until 2035, a convergence of technologies—including artificial intelligence, electromagnetic propulsion, and robotics—promises to redefine the design, function, and experience of vertical mobility in tall buildings.

7.1. A Paradigm Shift in Vertical Mobility

Ropeless elevators represent a groundbreaking mobility system that departs from traditional vertical transportation technology, freeing elevator systems from the usual constraints of cable and pulley mechanisms. These advanced systems, such as MULTI, utilize maglev technology to propel elevator cabins smoothly and efficiently. Departing from the rope system, TK Elevator has developed a radical mobility system called MULTI, which can go horizontally, sideways, longways, slantways, and any other way. Unlike conventional elevators, which rely on mechanical ropes to move cabins vertically, ropeless elevators operate using opposing magnetic fields. Linear induction motors drive the cabins, enabling frictionless motion along tracks extending vertically, horizontally, or diagonally across a building's internal landscape. This engineering breakthrough transforms elevator shafts into dynamic mobility corridors and offers a new model for spatial planning and flexible architectural design (Lu et al., 2016; Al, 2022).

MULTI is one of the first to operationalize maglev principles in elevators. MULTI cabins are driven by linear induction motors, the same technology used in maglev trains (Figure 7). This propulsion method allows multiple cars to move within a single shaft, following looped paths that include vertical, horizontal, or angled segments. A rotating exchanger can move the MULTI elevator from one track to another, like a train, and allows several cabins to share tracks instead of the single rope and shafts dedicated to each conventional hoisting elevator. Using numerous MULTI elevators in a single shaft for new buildings will allow for a more cost-effective space utilization. It will also reduce wait times for passengers (Al, 2022). These elevators will improve energy efficiency by about 60%, provide quieter rides, allow skyscrapers to attain extraordinary heights, have a low maintenance cost, and have fewer system failures.

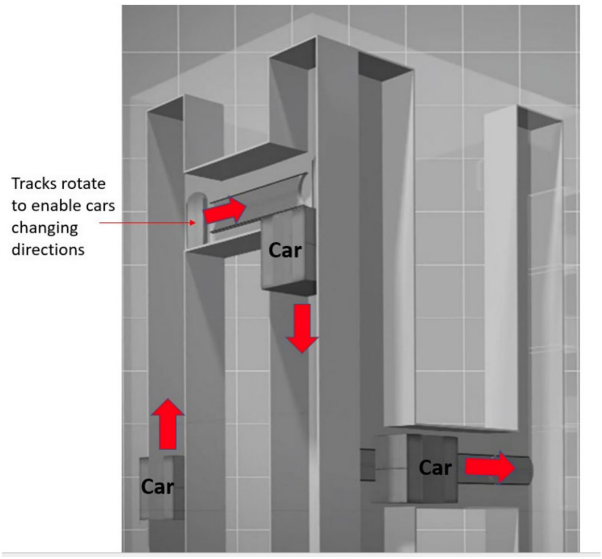


Figure 7. The MULTI ropeless elevator system by TK Elevator enables vertical and horizontal movement using linear induction motors and maglev technology. Eliminating ropes allows multiple cabins to operate in a single looped shaft, enhancing space efficiency, reducing wait times, and offering new design flexibility. Source: authors.

A completely operative MULTI prototype has been installed and tested in the innovation test tower in Rottweil, Germany. Also, the first commercial application of the MULTI system is planned for the East Side Tower in Berlin, demonstrating its changeover from conception and testing to practical application. These examples demonstrate that MULTI is not just a theoretical idea, but a definite technology being tested and implemented in practical applications to face challenges in urban mobility and transportation inside buildings.

A benefit of MULTI is that skyscrapers could seamlessly integrate with underground metro stations, with magnetic cabins proceeding from subway tunnels into buildings, dropping off passengers at their office floors. Moreover, buildings could be interconnected with sideways elevators, creating a network of skybridges and faster travel. In addition, people with disabilities could readily move around buildings (Al, 2022). The possibilities are almost limitless.

Maglev-based elevators are expected to become more economically viable as production scales and component costs drop. Their potential to reduce space usage, extend building height, and improve long-term performance makes them an ideal solution for the future of supertall structures. As these technologies mature, they will likely underpin a new era of high-rise mobility defined by fluidity, resilience, and adaptability.

7.2. Circulating Multi-Car Elevators Within Closed Shafts

The concept of circulating multi-car elevators marks a radical shift in vertical mobility, drawing direct inspiration

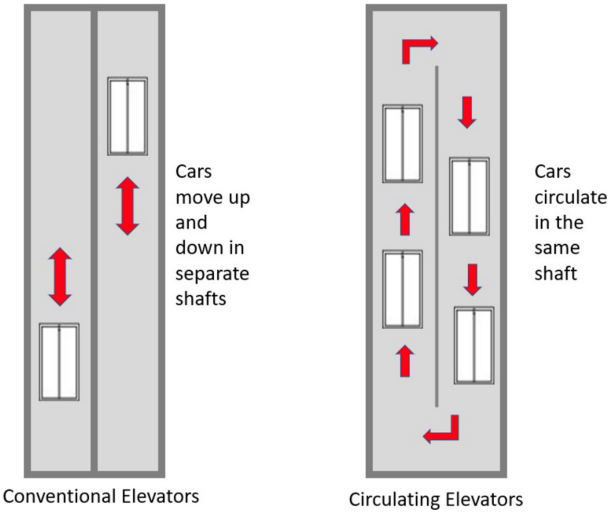


Figure 8. Comparison of a conventional elevator system (left), with one cabin per shaft, and a circulating multi-car system (right), where multiple autonomous cabins move in a continuous loop. Inspired by mass transit, this advanced model enhances capacity, reduces wait times, and maximizes space efficiency through synchronized, high-frequency vertical mobility. Source: authors.

from mass transit systems. Instead of treating elevators as discrete point-to-point rides with idle waiting times, this model envisions a continuous loop-based circulation system where multiple autonomous cabins travel within a single shaft in synchronized motion, much like a vertical subway (Figure 8). The key innovation lies in transforming elevator shafts into dynamic corridors capable of handling high volumes of passengers with greater frequency, reliability, and efficiency.

Hitachi has also entered this frontier, developing a one-tenth scale prototype to validate the feasibility of such a system. While the model has successfully demonstrated fundamental capabilities, it will require additional refinement to comply with international safety and building code standards before large-scale deployment can be realized (Gerstenmeyer, 2018).

As AI advances, circulating elevator systems are expected to leverage real-time traffic prediction, automated cabin scheduling, and adaptive routing, further enhancing system responsiveness. These attributes make circulating multi-car elevators particularly suitable for next-generation megatall buildings and urban super-hubs, where managing vertical flow is as critical as horizontal movement in traditional cities.

7.3. Robotic Installations and Drone-Assisted Monitoring

The future of elevator technology in tall buildings is not limited to what happens inside the shaft—it also extends to how elevator systems are installed, monitored, and maintained. Recent advancements in robotics and aerial drone technologies are revolutionizing these processes by improving efficiency, safety, and precision, especially in complex, high-altitude construction environments.

One of the most promising innovations is deploying autonomous robotic systems for elevator installation. For instance, Schindler has developed a fully autonomous, self-climbing robot that ascends elevator shafts and uses AI and advanced sensing to perform tasks with millimeter-level precision. The robot is designed to measure and drill anchor bolts required for securing elevator guide rails, one of the most time-consuming and error-prone tasks when done manually. By automating this process, the robot significantly reduces the risk of human error, enhances worker safety in tight shaft conditions, and accelerates the construction schedule (Babel et al., 2022). This innovation marks a critical shift toward robotization in vertical infrastructure, allowing for consistent quality and fewer delays.

Complementing robotic systems, drones are increasingly being used for elevator shaft inspections and construction monitoring. With high-resolution cameras and lidar sensors, drones can swiftly capture geometric measurements, detect irregularities, and visually inspect difficult-to-reach areas in real time. During installation and maintenance phases, drones enable faster data collection, enhanced documentation, and more frequent performance checks without requiring technicians to enter dangerous or confined spaces physically. Studies suggest that drone-assisted workflows can reduce elevator installation times by 21%-26% and lower costs by up to 11%, mainly by streamlining survey and inspection tasks (Marani et al., 2022).

Robotic installation and drone-assisted monitoring represent a new paradigm in elevator construction and lifecycle management that prioritizes precision, safety, speed, and cost-effectiveness. As tall buildings grow taller and more complex, these technologies will be essential for maintaining efficiency in an era where traditional construction methods struggle to keep pace with the scale and sophistication of vertical urbanism.

7.4. AI-Enhanced Systems

AI is rapidly transforming elevator technology, offering unprecedented capabilities in autonomous flow regulation and predictive functionality. Static scheduling systems often fall short in high-rise environments where elevator demand varies significantly throughout the day. AI-enhanced elevator systems respond to this challenge by leveraging real-time sensor data, building occupancy trends, and behavioral analytics to optimize vertical movement dynamically (Goldsworthy, 2018). These systems learn from daily usage patterns—such as morning rush hours, lunchtime peaks, and post-event surges—to anticipate passenger demand and adjust real-time dispatching strategies. Rather than waiting for user input, AI-powered elevators proactively send cars to floors where demand is likely to occur, minimizing wait times and reducing energy consumption through more efficient routing.

AI also plays a key role in predictive maintenance,

ensuring continuous, reliable operation. Intelligent algorithms monitor elevator performance through Internet of Things (IoT) devices connected to the controller, gathering granular data on component wear, temperature fluctuations, vibration anomalies, and other operational parameters. These data points are processed by machine learning–based applications that diagnose emerging faults before they escalate into breakdowns, thus preventing costly outages.

Ultimately, AI-enhanced elevator systems mark a shift from reactive operation to proactive, adaptive mobility management. In tall buildings—where hundreds or even thousands of people rely on vertical transport daily—AI's ability to fine-tune elevator dispatch, anticipate passenger loads, and maintain service continuity is critical to vertical urban environments' livability, efficiency, and resilience.

8. Case Studies

Advanced elevator systems have been installed in several supertall and megatall skyscrapers. The best-case scenario would be to review several of these project examples. Yet, because of space shortage in a single article, the authors selected three buildings and elaborated on them. Due to its symbolic significance to the U.S., One World Trade Center in New York received more attention throughout its design and construction than any other skyscraper. Thousands of workers, citizens, experts, engineers, and architects assisted in bringing this structure to the cutting edge of technology. In addition, the building's owners and authorities wished to use it as a model for future construction (Ming et al., 2018). Similarly, Shanghai Tower in Shanghai is a tower with an elaborate and perfected sensor system of the elevators that ensures that the passengers' ride to the top is as smooth as possible. Burj Khalifa in Dubai being the tallest building of the world is a remarkable achievement by architects, engineers, and other professionals who worked on this extraordinary project; its elevator system warrants an insightful analysis of its own.

8.1. One World Trade Center, New York City, USA

Height: 541 meters (1,775 feet)
Floors above ground: 104
Floors below ground: 5
Architect: Skidmore, Owings & Merrill
Completion: 2014

8.1.1. Building Overview

One World Trade Center is the highest building in the Americas. The tower, which serves as the property's focal point, is located on the site where the Twin Towers once existed before September 11, 2001. It integrates cutting-edge environmental and green features, such as advanced elevator systems, and establishes new architectural and safety standards. The upgraded life-safety systems go above and beyond what the New York City Building Code requires. The tower is resistant to explosions, storms, and earthquakes due to using over 50,000 tons (35,714 cubic yards) of steel and 252,000 tons (180,000 cubic yards) of concrete to construct the tower. Special safety

Table 1. Key Elevator Technologies – One World Trade Center, New York

Category	Key Features
Elevator Manufacturer	ThyssenKrupp (renamed TK Elevator)
Total Elevators	73 (5 express elevators)
Maximum Speed	10.16 m/s (33.3 ft/s), fastest in the Western Hemisphere
Travel Distance	394 meters (1,293 feet), express elevators to the 102nd floor
Capacity	1,814 kg (4,000 lbs) per express elevator
Key Technologies	Computerized roller guides, pressurized cabs, air-pressure differential solutions, and a destination dispatching system
Sky Lobbies	Express elevators to the sky lobby (64th floor), then local elevators
Ride Comfort	Elongated rail segments, automatic roller guides, and polyurethane rollers to absorb vibrations and building sway.
Air Pressure Management	Aerodynamic cab shrouds, pressurized vehicles, and fan-controlled air pressure to reduce ear-popping and noise
Safety & Security	Thick concrete core, refuge rooms, negative-pressure emergency elevator shaft, badge access, and touch screen overrides
Maintenance & Monitoring	Azure Intelligent Systems Service for predictive, real-time maintenance, dynamic models, and rapid diagnostics
Entertainment & Experience	HD monitors display the city's historical time-lapse during express rides.
Sustainability & Efficiency	Energy-saving features integrated, above-code life safety, and green systems
Unique Innovations	Real-time shock absorber roller guides, security integration, and fastest express elevators in the hemisphere



Figure 9. presents the tower itself, while Figure 10 shows the computerized roller guide system that enhances both speed and ride comfort for elevator passengers, further illustrating these innovations.



Figure 11. Shanghai Tower, the tallest building in China and the world's tallest double-skin tower, features a spiraling form that reflects the dynamic spirit of modern China. Source: authors.

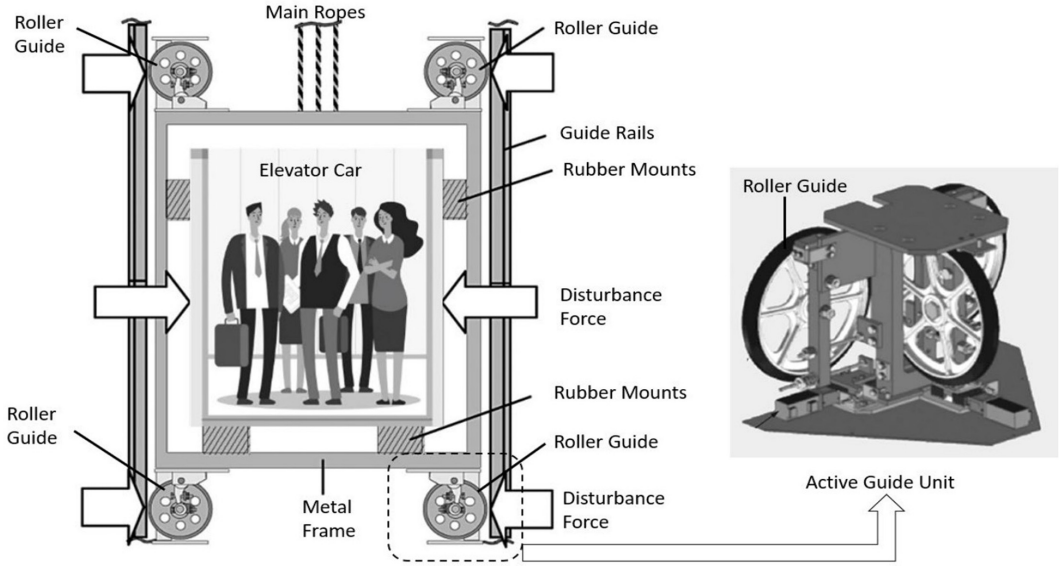


Figure 10. Computerized roller guide system used in One World Trade Center elevators. The system stabilizes the elevator car by counteracting disturbance forces through active guide units and rubber-mounted roller guides, enhancing ride comfort and safety. Source: authors.

Table 2. Key Elevator Technologies – Shanghai Tower

Category	Key Features
Elevator Manufacturer	Mitsubishi
Total Elevators	106 (3 "bullet" express, four double-deck express, multiple local and service)
Maximum Speed	18 m/s (59 ft/s), double-deck at 10 m/s (33 ft/s)
Travel Distance	565 meters (1,854 feet), basement to 119th floor, world's longest-traveling elevator at 578.5 meters (1,900 feet)
Capacity	Not explicitly specified (supports heavy mixed-use and visitor traffic)
Key Technologies	Use of sfleX-rope comprising bundles of high-intensity steel wire strands in which each is covered with plastic, offers higher intensity than conventional rope for safe operation, regenerative converters, group control system, and central computer dispatch
Sky Lobbies	Multiple, with express and double-deck elevators serving different zones
Ride Comfort	Active roller guides with electromagnetic actuators, accelerometers, and sound-insulating cages, ride to the top extremely comfortable
Air Pressure Management	Pneumatic system for ear-popping control, streamlined cab design for reduced wind noise
Safety & Security	Ceramic two-tier braking system, refuge areas, and advanced fire safety protocols
Maintenance & Monitoring	Centralized group control, real-time computer management of elevator operations
Entertainment & Experience	Quiet, smooth rides are prioritized.
Sustainability &Efficiency	Regenerative converters lower energy use by up to 30%, and energy-efficient group control
Unique Innovations	World's fastest and longest-traveling elevators, advanced braking, during extreme sways due to high wind, advanced sensor technology detects movement and automatically stops the cabin at the nearby floor

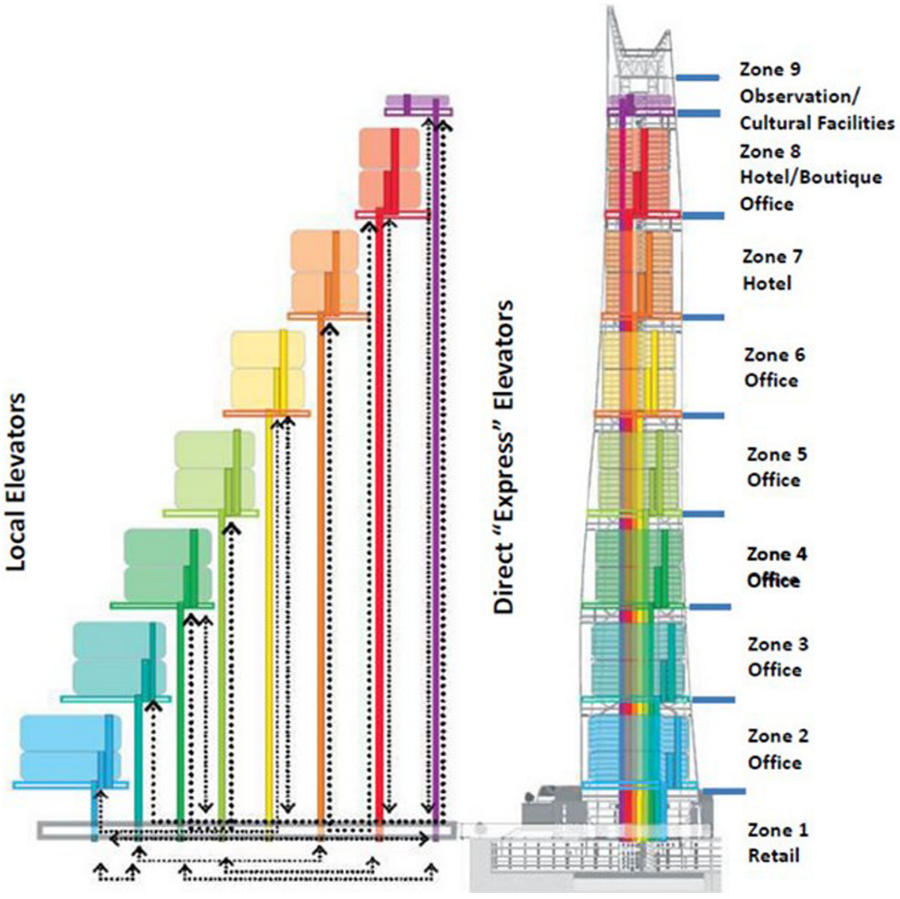


Figure 12. Shanghai Tower's elevator system, featuring the world's fastest and longest-traveling elevators, reflects the tower's vertical complexity and engineering innovation. Source: Gensler.com.

precautions include pressurized and extra-wide emergency stairs, fireproofing, and air-filtration systems for chemical and biological particles. According to the Emporis database, the building is among the most expensive in the world; One World Trade Center had a total cost of USD 3.9 billion (Siikonen, 2021).

8.1.2. Key Elevator Technologies

The elevator systems at One World Trade Center exemplify the latest advancements in vertical transportation technology for supertall buildings. Combining high-speed performance, passenger comfort, and robust safety measures, these elevators set new benchmarks for efficiency and resilience. Table 1 summarizes the main features and technological innovations of the building's elevator systems (Yao et al., 2022; Makar et al., 2022; Parker & Wood, 2013; Lewis & Holt, 2011; Barney & Al-Sharif, 2015; Ming et al., 2018).

Figure 9 presents the tower itself, while Figure 10 shows the computerized roller guide system that enhances both speed and ride comfort for elevator passengers, further illustrating these innovations.

8.2. Shanghai Tower, Shanghai, China

Height: 632 m, 2,073 feet
Floors above ground: 121
Floors below ground: 5
Architect: Gensler
Completion: 2015

8.2.1. Building Overview

Shanghai Tower, a new iconic landmark in the ever-evolving Shanghai skyline, displays an evocative, curved facade and spiraling form that symbolizes the dynamic emergence of modern China. It is the world's second-tallest tower (next to Burj Khalifa); the tallest building in



Figure 13. Burj Khalifa, Dubai, UAE—the world's tallest building—serves as the centerpiece of a large-scale mixed-use development. Source: authors.

Table 3. Key Elevator Technologies – Burj Khalifa

Category	Key Features
Elevator Manufacturer	Otis
Total Elevators	57 (including two double-deck express, 25 machine-room-less, others zoned/local)
Maximum Speed	10 m/s (33 ft/s), double-deck express elevators
Travel Distance	504 meters (1,654 feet) express to observation deck, highest landing at 638 meters (2,080 feet)
Capacity	Double-deck: 12–14 people per cabin, service elevators up to 5,500 kg (12,110 lbs) (emergency/evacuation)
Key Technologies	Gen2 machine-room-less elevators (polyurethane belts, gearless drives), computerized destination dispatch, sway sensors
Sky Lobbies	Zoned by sky lobbies at 43F, 76F, 123F; local/express system
Ride Comfort	Roller guides, sway sensors, vibration and noise reduction, air pressure management
Air Pressure Management	Streamlined cabs and shaft air control to reduce pressure and noise
Safety & Security	Lifeboat elevators (fire-resistant), refuge areas every 25 floors, multi-alarm sensors, manual camera/joystick control
Maintenance & Monitoring	Predictive maintenance systems and sway sensors are used for elevator shutdown during high winds
Entertainment & Experience	LCDs and entertainment features in observation elevators
Sustainability & Efficiency	Gen2 reduces energy use up to 50%, requires no lubrication, and minimizes environmental hazards
Unique Innovations	The highest observation deck, lifeboat elevators, a zoned express/local system, and the world's tallest

China; and the world's tallest double-skin building (Figure 11). It contains over four million square feet of above-grade space and one and a half million square feet below grade. The tower houses offices, hotel accommodations, commercial facilities, convention halls, exhibition halls, restaurants, and culture and tourism facilities (Al-Kodmany, 2015; Xia et al., 2010).

8.2.2. Key Elevator Features

Shanghai Tower features one of the world's most sophisticated elevator systems, designed to transport large numbers of users at record-breaking speeds efficiently. Its

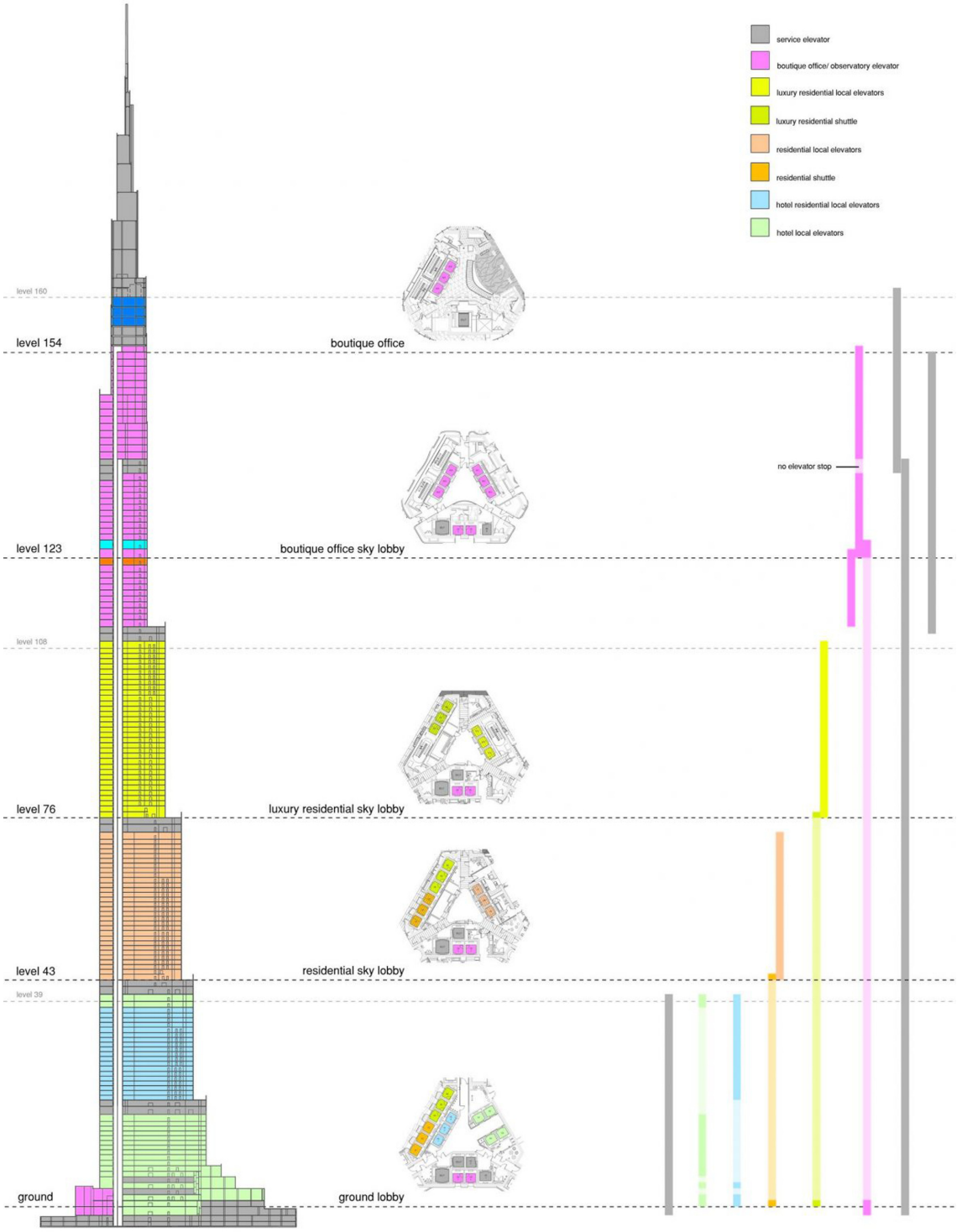


Figure 14. Burj Khalifa's elevator system, showing the internal organization and routing of express and local elevators within the tower's vertical circulation network. Source: The Skyscraper Museum.

elevator technologies focus on energy efficiency, safety, and passenger comfort, leveraging cutting-edge engineering solutions. Table 2 concisely overviews these elevator innovations and their operational features (Gensler et al., 2015; Gu, 2014; Al-Kodmany, 2015).

Figure 11 shows the tower's distinctive architectural form, while Figure 12 highlights the complexity of its elevator system, which includes the world's fastest and longest-traveling elevators.

8.3. Burj Khalifa, Dubai, UAE

Height: 828 meters (2,717 feet)

Floors above ground: 163

Floors below ground: 2

Architect: Skidmore, Owings & Merrill Completion: 2010

8.3.1. Building Overview

Burj Khalifa is the tallest building in the world (Figure 13). The tower was designed as a centerpiece of a grand plan for a significant mixed-use development that will contain up to 30,000 homes, nine hotels, 19 residential towers, the Dubai Mall, 3 ha (7.5 acres) of parkland, and a 12-ha (30-acre) artificial lake, among other functions and uses. The tower can hold up to 35,000 people. It contains swimming pools, 900 private apartments, 144 residences in the Armani section, 49 floors of corporate office suites, restaurants, sky lobbies, an observation deck, and the world's most advanced computerized "dancing fountain" on the lake (Aldred, 2010; Baker & Pawlikowski, 2015)

8.3.2. Key Elevator Systems

As the world's tallest building, Burj Khalifa incorporates a highly innovative elevator system tailored for extreme height and large occupant capacity. Its elevators employ a combination of speed, safety, and energy-saving features, including machine-room-less designs and advanced monitoring systems. Table 3 outlines the key technological characteristics and unique aspects of Burj Khalifa's vertical transportation (Abdelrazaq, 2010; Baker & Pawlikowski, 2015; Goldsworthy, 2018; Beyer, 2009).

Figure 13 offers a view of the Burj Khalifa's exterior, while Figure 14 illustrates the internal organization of the elevator system and its routing within the tower.

9. Conclusions

The story of tall buildings is inseparable from the story of elevators. The paper traces the transformative process of how elevator technology has progressed from its inception to the present. The elevator has come a long way since the creation of the first elevator using a block-and-tackle device. Since the invention of the latter-day safety elevator in the mid-19th century, elevators have advanced to today's cutting-edge AI-driven, rope-less, and regenerative systems, and vertical transportation has fundamentally shaped the trajectory of cities and their skylines. Each technological breakthrough—whether the electrification of systems, the introduction of MRL configurations, the development of smart software for crowd optimization, and the revolutionary MULTI—has extended vertical urbanism's architectural, socio-economic landscape.

Elevators are far more than utilitarian machines moving people up and down; they are the imperceptible infrastructure that animates high-rise living and working. As tall buildings have evolved into complex vertical ecosystems—housing residences, offices, hotels, cultural venues, and transit nodes—the elevator has transformed from a point-to-point lift into an integrated mobility network. Its evolution reflects broader shifts in how cities balance efficiency, sustainability, accessibility, and resilience.

Looking forward, the elevator will remain an essential instrument of urban innovation, particularly as cities adapt to growing populations, climate change, and new models of hybrid spatial use. Future elevator systems—autonomous, green, and embedded with predictive intelligence—will enable more equitable access and energy performance and inspire new forms of spatial imagination. As the skyscraper becomes more sophisticated, elevators will serve not merely as connectors of floors but as shaping the experience, identity, and functionality of the built environment in the century to come. The future of skyscrapers is partly dependent on next-generation elevators. It is also associated with the evolution of cities.

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