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Vertical Transportation: The Past 50 and Next 50 Years of Development

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Abstract

No building over 200 meters tall has been voluntarily demolished. The 270 Park Avenue building in New York City (1960) will be the first such building to receive this fate; most of the 1,450-plus buildings over 200 meters that were built by the end of 2018 were expected to stand for at least 100 years. During this lifespan, all technical equipment will be refurbished multiple times, including elevator equipment, which has a lifespan of approximately 15 years. A review of how vertical transportation has evolved over the past 50 years will inform an exploration of the expected way forward for the next 50 years as a means of considering how to future proof technology to function well for 200-meter-plus buildings. A combination of ropeless and multidirectional elevators and other technologies will move the tall building industry forward in a more ecological, adaptable and flexible way.

Keywords: Adaptability, Control Systems, Future-Proofing, Multi-Use, Renovation, Vertical Transportation

Introduction

In 1969, just 50 years ago, there were only 25 buildings with a height of 200-plus meters worldwide. Only four were outside the United States, and no less than 16 were built in New York City alone. The skyscraper was an American phenomenon, born from a series of innovations efficiently implemented by a young US elevator Industry.

This has changed dramatically since then. 50 years later there are nearly 1,500 completed buildings exceeding 200 meters in height—that is roughly 60 times the amount completed 50 years ago. In 2019 the location that holds the most skyscrapers is no longer the United States, but has shifted to Asia. Nearly 90 percent of all elevators are now installed in Asia and the Middle East, and only five percent in North America and in Europe. Skyscrapers over 200 meters in height are long-term investments, and no building with a height of over 200 meters has ever been demolished voluntarily. In this height category only the original World Trade Center towers in New York City have been demolished, through terrorism. The first building over 200 meters that may undergo voluntary demolition is likely to be 270 Park Avenue in NYC (built in 1960) to make room for an even taller tower for J. P. Morgan Chase. Most of the nearly 1,500 buildings over 200 meters are expected to stand for at least 100 years.

With such a lifespan, buildings will undergo several renovations, where all technical equipment will be refurbished multiple times. The purpose of many of these buildings may even change over time. Elevator equipment with a typical lifespan of approximately 25 years will be upgraded or replaced at least four times. Though it is hard to predict the evolution of technology, one thing is certain: technology of the future needs to become increasingly future-proof to enable refurbishment.

Ancient Elevator Technology

The earliest recorded reference to an elevator is in the works of the Roman architect Vitruvius, who reported that Archimedes built his first elevator circa 236 BCE (see Figure 1). Some later historical sources mention use of early elevators as cabs on a hemp rope powered by hand or by animals. In the 11th century CE, the *Book of Secrets* by Al-Muradi in Islamic Spain described the use of an elevator-type device, used to

Figure 1. A painting of the Roman architect Archimedes by Fetti (1620).

raise a large battering ram to destroy a fortress (Al-Muradi 11th Century) In the 17th century, early types of elevators were located in palaces in England and France. Louis XV of France had a "flying chair" built for one of his mistresses at the Chateau de Versailles in 1743.

Ancient and medieval elevators used driving systems based on hoists or windlasses. The invention of a system based on the screw-drive was one of the most important steps in elevator technology since ancient times. The first screw drive elevator was built by Ivan Kulibin and installed in the Winter Palace in 1793. Several years later another of Kulibin's elevators was installed in the Arkhangelskoye near Moscow.

Inventions Preceding the Modern Elevator

The industrial revolution required the movement of a lot of materials, which led to the development of the elevator. A large number of incremental improvements followed to develop the elevator as we know it today. In 1854, Elisha Graves Otis amazed a crowd at New York's Crystal Palace, when he ordered the only rope holding the platform on which he was standing to be cut (Magical Hystory Tour 2010). The rope was severed, and the platform fell only a few inches before coming to a halt. This occurrence is still considered the start of the modern elevator. The elevator brake invention is considered one of the most crucial inventions in the elevator industry and is nowadays known as the safety brake (see Figure 2).

Alexander Miles improved the method of the opening and closing of elevator doors in 1887 by creating an automatic mechanism that closed access to shaft (US Patent 371, 207). Previous to his invention, elevator operators had to manually shut a door to cut off access to the elevator shaft, resulting in serious accidents. Wilhelm August Julius Albert invented the steel wire rope in 1834 (Albert 1838). In 1874 modern wire hoist ropes were first used in the mines of the German Harz Mountains. By 1880, Werner von Siemens had built the first elevator powered by an electric motor at the Pfalzgau Exhibition in Mannheim (Kiuntke n.d.). His first elevator rose 20 meters with a speed of 1.8 kilometers per hour (see Figure 3).

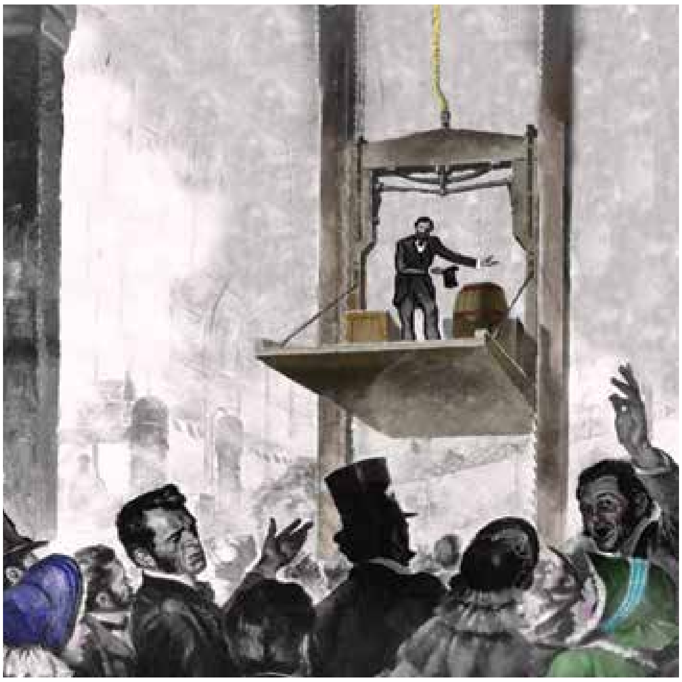

Figure 2. Elisha G. Otis demonstrates his safety brake in New York City circa 1854.

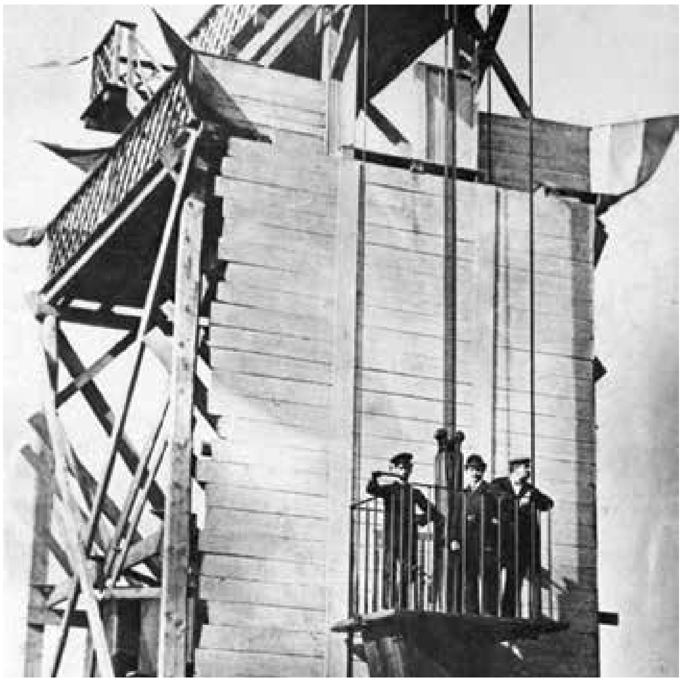

Figure 3. Image of the first electric elevator at the Pfalzgau Exhibition in Mannheim (1880). © Siemens

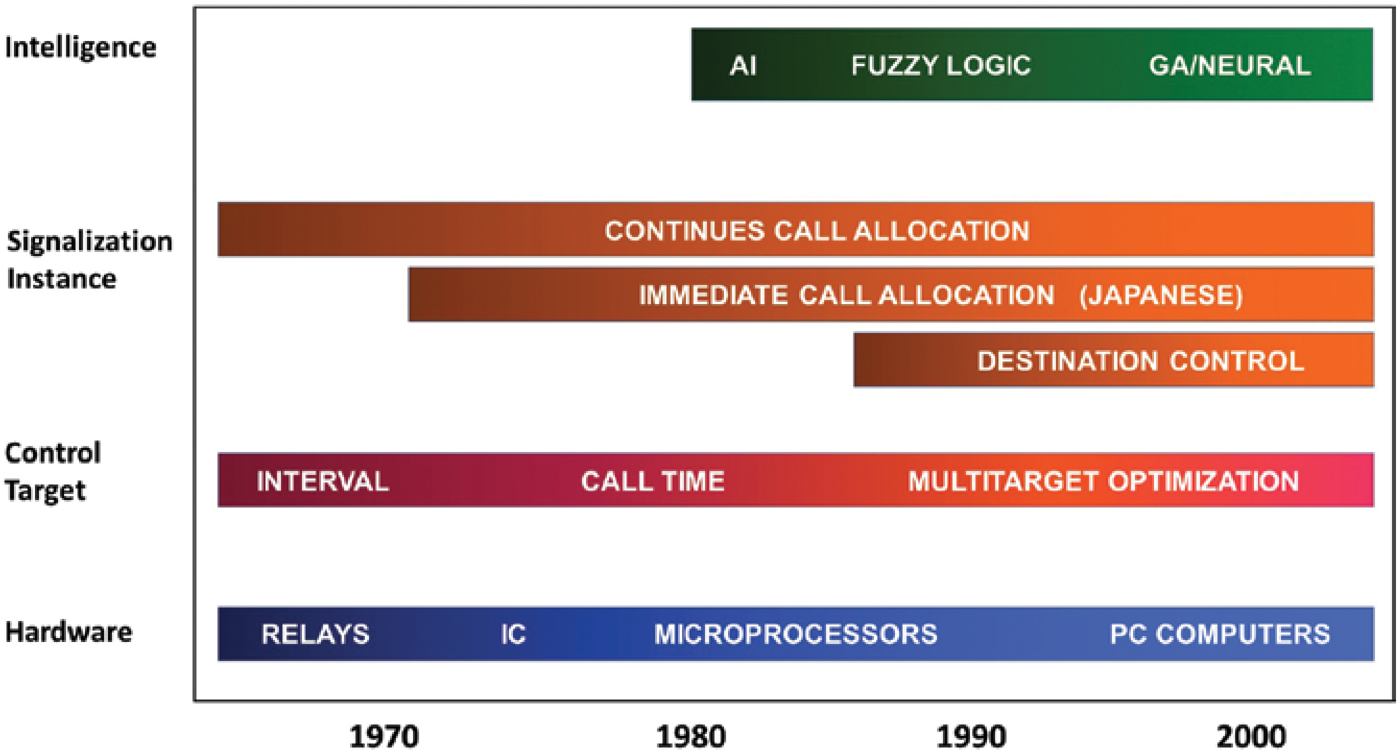

Figure 4. Diagram showing the history of modern elevator control. © Elevating Studio

Frank Sprague developed the Sprague-Pratt Electric Elevator in 1892 and significantly enhanced the safety and speed of electric elevators (Greller 2014). The company developed floor control, automatic elevators, acceleration control, safety measures and several freight elevators. The Sprague-Pratt elevator ran faster and with bigger loads than existing elevators. By 1892 some 584 elevators had been installed worldwide.

In England in 1904, Joseph Richmond/Carey came out with the "press button" control. Just three years later in 1907 the first "collective push-button control" was installed by Otis. Another 17 years later, Otis installed the first automatic signal control in New York City, eliminating the need for elevator attendants. The first American elevator and escalator codes were implemented in 1925 as a response to the growing popularity of vertical transportation in buildings. In 1931, Otis came out with the first Double Deck Elevators in New York City. Between 1931 and 1969 there were a large number of smaller incremental inventions, but the elevator has remained largely unchanged since then.

Status of the Elevator 50 Years Ago (1969)

Fifty years ago (1969) the modern elevator was approaching its current state. In 1969, the elevator already used automated control. It was controlled by pushbuttons on landings to call the elevator, and pushbuttons in the car indicated the desired floor. Most elevators provided today still use the same pushbutton control principle.

Developments Over the Last 50 Years (1969–2019)

Early control technology was mainly based on the use of telephone relays, allowing only basic control principles. Before 1945, when transistors were not available, the industry had to cope with fragile vacuum tubes, which would ultimately wear out during service, while tubes also took time to warm up. Elevators hardly used these tubes; they were simply not reliable enough and occupied too much space. When transistors first came to the market after 1945, the introduction of these new electronics started influencing the control technology of elevators (see Figure 4).

Relay elevators controlled the average time between departures of elevators from the main lobby, called the Interval. When the first integrated circuits (ICs) came on the market around the 1970s, the control principles of the relays were copied into ICs. With an exponential increase of transistors on a chip and therefore the calculation power of the ICs, it became possible to use more intelligence. Instead of interval, the industry could now also start checking call time. Call time being the time from when a button was pressed until the time the elevator arrived at the floor. With more information one could even estimate the number of people waiting behind each call. Floors needing more attention could now get that attention. The continuous allocation process already used with relays became faster, allowing elevators to become more efficient and accurate.

Japanese manufacturers started focusing on elevator comfort and this focus continued in their control algorithms. They introduced immediate call allocation, signaling immediately which elevator would arrive next at a floor. Passengers would thus wait in front of the next arriving elevator. Western companies did not adopt this until much later.

Computing power increased with improved hardware efficiency, changing from ICs to microprocessors to computers. This rapidly increasing calculation power affected the algorithms used, and more sophisticated algorithms were introduced into elevator controls. Control intelligence made great leaps as well. Artificial Intelligence (AI) was introduced in the early 1980s, Fuzzy Logic during the 1990s and genetic algorithms and neural networks in the late 1990s and early 2000s. This increase in intelligence is ongoing with new mathematical algorithms being explored every year. Elevators have turned into complex computerized systems, where a large group can run as much software as a modern jetliner.

Major Breakthroughs of the Last 50 Years

Even with more complex algorithms the capacity of elevators only slowly increased, which was a similar phenomenon experienced in the airline industry: new airplane models hardly increased in speed or range. The elevator industry needed a major breakthrough; a jet-engine-like invention to find a clear improvement in capacity.

Destination Control

Destination Control, invented by Leo Weiser Port in Sydney in the late 1960s, would eventually become incredibly impactful to the elevator industry, but was difficult to implement successfully with available technologies at the time. The reintroduction by Schindler of Destination Control circa 1975 with microprocessor control advanced the elevator industry significantly as Destination Control could handle 20–25 percent more traffic than previous elevator systems. Soon both major and smaller suppliers were implementing the technology. With Destination Control, the passenger already enters his destination at the landing outside the elevator (de Jong 2014). To enable input outside the elevator an input device is needed at the landing. This destination operation panel (DOP) provides the elevator with both the source floor and the destination floor of the passenger. This device also indicates to the passenger which elevator they should use (see Figure 5). Destination Control can combine people with same destinations into the same car, thus reducing the amount of stops and the length of each journey (see Figure 6). With traditional pushbutton control, elevators can only drop people off in sequence of travel, resulting in unnecessarily lengthy trips.

In general, one can expect 20–30 percent more capacity with Destination Control depending on the group size. Simulating traffic patterns at different times of day is important to ensuring there are adequate numbers of elevators. Lunch traffic, for example, peaks less than rush hour due to the more random

Figure 5. A Destination Control operation panel provides an elevator with information such as the destination floor of the passenger. © Schindler

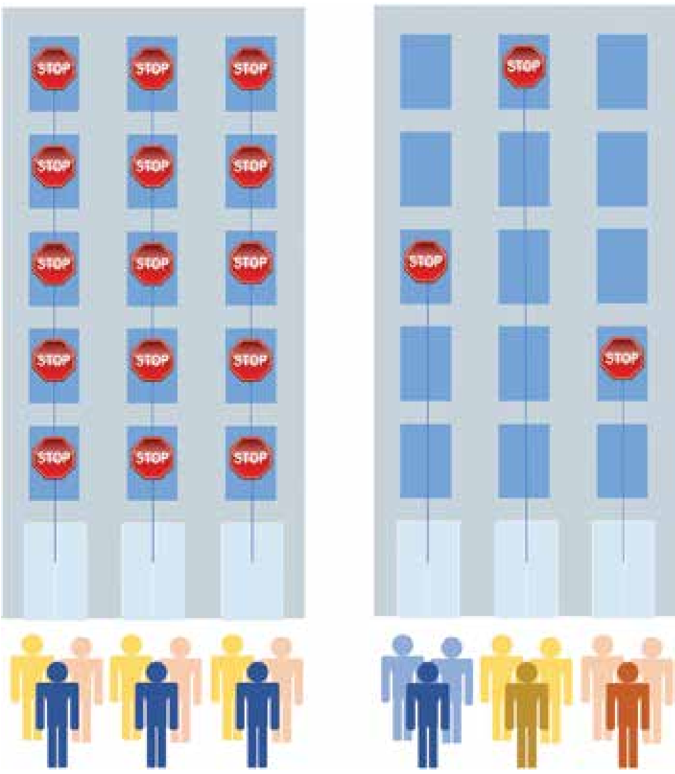

Figure 6. Destination Control elevator technology can reduce the time a trip takes by combining passengers with the same destination into the same elevator. © Schindler

Figure 7. Permanent Magnet Synchronous Motor (PMSM) technology used by an MRL elevator. © KONE

Figure 8. The TWIN elevator system could accommodate two elevator cars in a single shaft, reducing the amount of space dedicated to elevator shafts in a tall building. © thyssenkrupp

nature of this traffic. Destination Control works especially well in offices where the morning peak traffic is dominant, and works less well where traffic ebbs and flows throughout the day. Therefore, it is less commonly used in residential applications.

Elevators Without Machine Rooms

In 1996 KONE was the first elevator to introduce a Machine-Room-Less (MRL) Elevator on the market (de Jong 2014). This product was focused on the volume market and covered a large part of geared and hydraulic production. It did not dramatically change the way elevators were built, but simply placed the machine inside the hoistway and thus eliminated the need for the "hump" on the building. Where there were height restrictions, it often added an extra floor on the building and increased construction efficiency.

The motor applied by KONE used high-efficiency Permanent Magnet Synchronous Motor (PMSM) technology and reduced energy consumption by at least 50 percent (see Figure 7). Later improvements adding regeneration of energy and low energy standby technology reduced energy consumption by up to nearly 75–80 percent compared to earlier technologies. Nowadays 40–60 percent of all elevators provided globally use the MRL concept and it is delivered by practically all suppliers. MRL elevators are available with speeds of up to three meters per second.

TWIN Elevators

In 2003, thyssenkrupp came out with a system that could place two elevators in the same shaft one above the other. This innovation was called the "TWIN" (see Figure 8). TWIN was enabled by Destination Control. Because the system knows where passengers are located and where they are going, it is possible to control multiple cars in the same shaft. TWIN applies two separate roped elevators where both have their own car and counterweight. A complex safety system ensures no collision between cars is possible. TWIN has found its own segment, but as the solution requires special arrangements from the building and as there are no other suppliers, the use of TWIN is somewhat limited. TWIN can however be considered a crucial foundation for multi-car systems that may revolutionize the future elevator world.

UltraRope

Not only did the number of 200-meter-plus buildings increase exponentially between 1969 and 2019, their height also increased exponentially. This increase in height encountered a height limit for elevator suspension ropes at around 650 meters. Rope weight increases dramatically with increased distances, resulting in ropes being unable to support their own weight at a certain point. Currently, it is possible to reach a maximum elevator run height of 650 meters with the most modern steel ropes. In 2013, KONE Introduced the

UltraRope, a new lightweight, carbon-fiber rope (De Jong 2014). UltraRope enables travels exceeding 1,000 meters, (see Figure 9). These ropes have already been applied in several skyscrapers globally. CITIC Tower, the tallest building in Beijing, serves as an UltraRope reference. With these capabilities, buildings can now be built over one kilometer in height, and some are already being planned.

Multidirectional Elevators

In 2017, thyssenkrupp expanded on the idea of the TWIN and came out with a multiple-car elevator system without ropes (Jetter & Gerstenmeyer 2015). Instead of ropes, a linear motor system propels each car around a looped shaft, (see Figure 10). The MULTI system features multiple cars in a loop similar to the old Paternoster elevator. An ingenious system of exchangers moves the cars through a path of vertical and horizontal tracks, and also allows for the passing of cars which have either stopped for loading or unloading or need to be replaced or repaired. This system no longer has a height limit as there are no ropes needed to move the cars. There is a lane for upward traffic and a lane for downward traffic, with the exchangers shifting the cars from one lane to the other. The more cars are placed on the lanes, the bigger the capacity of the loop. If one loop does not provide enough capacity, a second or even a third loop can be introduced. The higher the number of loops, the bigger the total capacity. MULTI provides a second path to increase elevator height far beyond the 650-meter steel rope limit.

Figure 9. UltraRope enables elevator runs 1,000 meters and beyond, potentially decreasing rentable area occupied by elevator shafts. © KONE

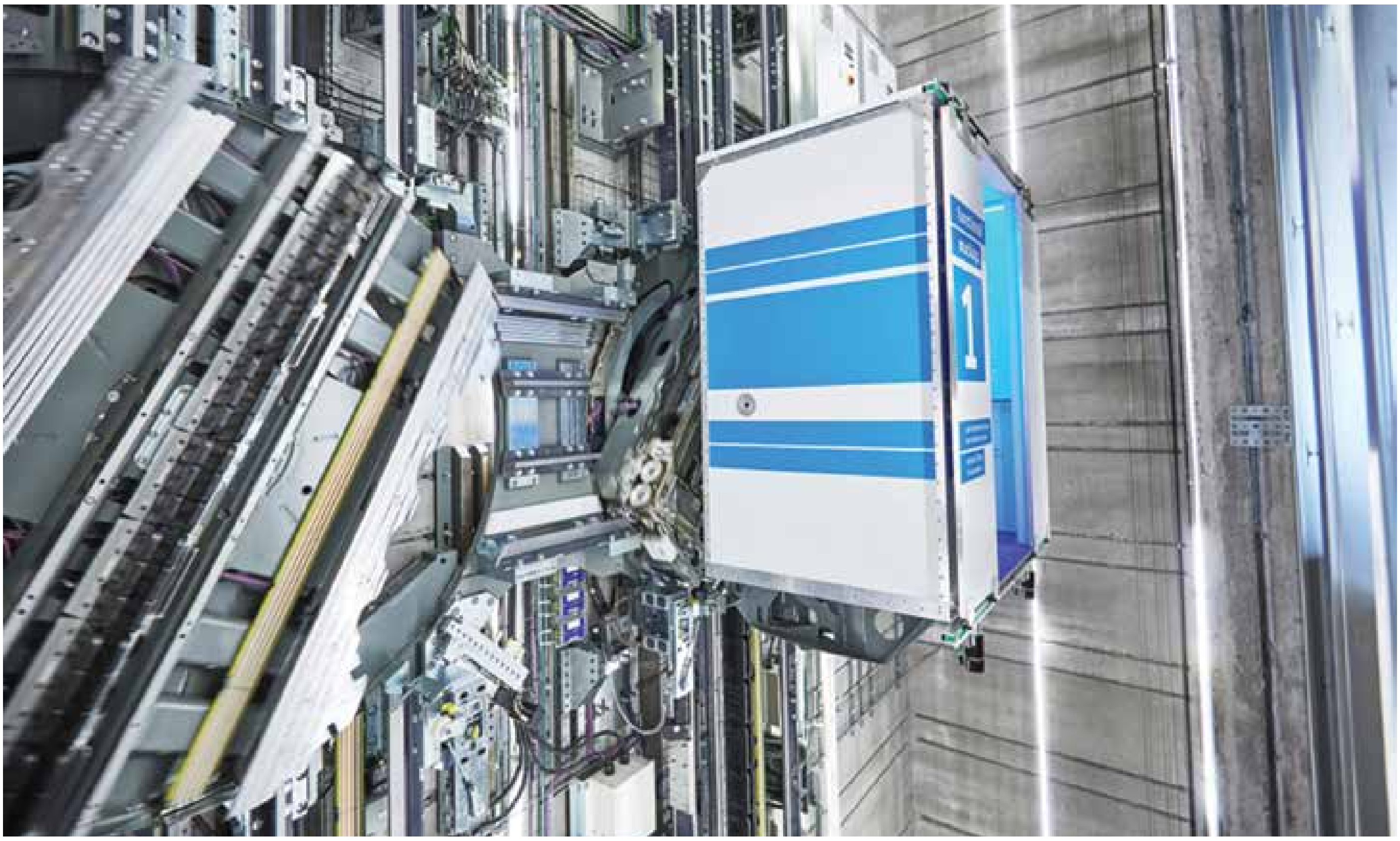

Figure 10. MULTI is set to be the world's first ropeless elevator. © thyssenkrupp

Figure 11. Rendering of an elevator traveling into outer space.

MULTI has the potential to provide architects with flexibility never before seen in building circulation systems. At present it still has limitations, but as the technology matures, we may see elevators moving in all three dimensions, horizontally, vertically, over a bend or curve etc.

What to Expect from the Next 50 Years

The next frontier of elevator travel is difficult to predict. Might it include space travel? (see Figure 11).

Under no circumstance will this chapter be an exact outcome of the future or will it predict what the future elevator will look like, but by looking at the different trends affecting the elevator industry one can say with some certainty how these important megatrends will shape the industry (see Figure 12).

Urbanization

CTBUH statistics show exponential increases in the number of high-rise buildings and also a clear increase in their height. This is largely driven by an influx of the global population to the world's cities. Not even a financial crisis will be enough to stymie this trend toward urban living. Market demand for vertical transportation equipment will remain high, with fierce competition between the suppliers for their share of the market.

As elevators and escalators are assembled as kits, the need for skilled installation workers will continue growing. The same is also expected for maintenance due to the growing installed base. The numbers will cause a large shortage in skilled labor, a trend already being observed. Elevator suppliers and maintenance providers will experience major challenges in keeping their clients happy.

Serving more units with a limited labor force can only be achieved through innovation or automation of these jobs. Automation is already ongoing in manufacturing, and is also needed on the installation and maintenance front.

Demographic Changes

Changes in demographics will alter the age trends of most countries towards a higher age. This will further aggravate the shortage of labor, even if partially countered by a raise in retirement age. Without automation, a shortage in the labor force caused by demographic changes could present some obstacles. Even jobs requiring higher education skills may need to be automated depending on circumstances.

Climate Change

The elevator industry has been one of the best performers in reducing overall carbon footprint. Since 1996, with the launch of the MRL, there has been a large increase in gearless applications, improving the efficiency of elevators dramatically. Highly-efficient PMSM technology was implemented and is replacing less efficient synchronous motor technology, also in the high-speed range.

In the early 1990s, the elevator industry introduced regenerative variable-voltage/variable frequency (VVVF) drives. Whenever the heaviest part of the elevator brakes to slow the load against gravity, the motor acts as a generator. A regenerative drive system then recovers the energy of a braking motor and reuses this energy by feeding it to the same riser as used to feed the elevator motor. This energy is used in the building and reduces the energy consumption of a building. Regeneration reduces energy consumption by as much as 30–40 percent compared to similar technology without regeneration. Standby energy of elevators has also improved significantly over the last few years—modern elevators can be up to 75–80 percent more efficient compared to elevators built before the 1990s.

Elevator Safety

Elevators are extremely safe, and are the safest mode of transportation available nowadays. Safety threats are now mainly related to the operative environment. For companies, safety against harmful individuals or effects is nowadays the top security concern, be it through the loss of Intellectual Property Rights (IPR) information, bodily harm or even loss of life through criminal acts or climatic events.

Requirements to protect against criminal acts will grow and demands for increased access control will become greater in turn. The future will require more sophisticated access

Figure 12. Megatrends affecting vertical transportation over the next 50 years. © Elevating Studio

control systems where those with access rights will not even notice being checked. They may not even need to enter their destination as their mobile calendar will place the necessary elevator calls. The journey of those users will be unobstructed and access at all locations will be automatically granted.

Users without access rights will not be able to continue their journey and must apply for access rights. Elevators will know whether there are unauthorized users inside a car, and will be able to automatically halt a journey and ask that the person exit. Vertical transportation monitoring will become more predictive, which will improve both quality and safety for the users by quickly addressing breakdowns in service or other threats to operations or passengers. Safety will improve, especially on escalators and moving walkways through the introduction of 3D camera technology, which can detect dangerous situations very quickly and will stop escalators before such situations occur.

Digitalization

According to Gardner Research, digitalization is the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business. The Internet of Things (IoT), the interconnectedness of physical devices, smart devices, buildings, and other items is at a stage where the Internet was 20 years ago. Digitalization is therefore moving from an innovative trend to a core competency for every enterprise, including vertical transportation, in the coming decades. Many of the impacts or potential challenges of vertical transportation megatrends will be countered through digitalization.

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