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**ARTICLE**

# Smart Elevator Systems

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## ABSTRACT

Effective vertical mobility is a crucial element in the design and construction of tall buildings. This paper reviews recent "smart" developments in elevator technologies and analyzes how they affect the construction and operation of tall buildings. In an approachable and non-technical discourse, it maps out, arranges, and compiles complicated and dispersed information on various elements of elevator design. It discusses hardware-based innovations, such as AC and gearless motors, machine-room-less (MRL) elevators, regenerative drives, elevator ropes, and LED lighting, as well as software-based solutions, such as destination dispatching systems, people flow solutions, standby mode, and predictive maintenance applications. Future vertical transportation models are also discussed, including multi-directional elevators and circulating multi-car elevators. Lastly, the paper suggests fruitful avenues for further studies on the subject, such as robotics, 3D printing, and the impact of the COVID-19 pandemic on elevator design.

***Keywords:*** Energy efficiency; Energy conservation; Long distances; Hardware; Software; Applications

## 1. introduction

### 1.1 Overview

Cities all over are expanding vertically. The main forces behind building upward are population expansion (driven by natural population growth and major rural-to-urban migration), rapid urban regeneration, soaring land costs, active agglomeration, and globalization. Project owners have even purchased excess development rights from surrounding structures to build a taller structure. Some builders, building owners, and tenants may have personalities that push them to build taller than their competitors or have their condo or business address in a supertall structure. Many consider cities with skylines comprised of tall structures to be progressive and suc-

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cessful. Moreover, tall buildings have shown to be magnets for new growth, attracting additional firms and boosting the local economy. After completion, several tall buildings find up in the portfolios of investment and insurance companies, giving economic rewards for more than just the developer.

At any rate, according to the United Nations, 70% of the world's 9.7 billion people will live in cities by 2050, up from 51% in 2010 [1,2]. To accommodate our expanding population, buildings are multiplying and rising higher. Thus, we need to start considering the most effective strategies to reduce consumption and the urban energy footprint. Buildings use 40% of the energy in the world; and therefore, they should be given priority in cities' efforts to minimize their carbon footprints as the fight against climate change gains steam [2,3].

As tall buildings proliferate in cities and test the limits of height, elevator design faces new challenges. Architects, engineers, and developers prioritize elevators throughout the phases of building design. The building's core, or "the backbone of a tall building", is made up of the elevator and stairs. This core determines the construction of the building and the floor layouts of the surrounding units. Simultaneously, engineers are working diligently to reduce the required space and energy to operate elevators, decrease the environmental impact, while improving safety, and comfort [2,4].

### 1.2 Goals and objectives

In tall or supertall buildings, any improvement in elevator design and manufacturing will have far-reaching effects on the costs, user comfort, and the environment. This paper traces recent developments in the elevator industry with the purpose of educating masses of architects and engineers. It delves into the "smart" evolution of elevator technology and examines its implications for the building and maintenance of skyscrapers. It organizes and gathers complex and dispersed knowledge on numerous areas of elevator design in a comprehensible and non-technical manner. Recent technological breakthroughs are put into perspective by analyzing their implementation in large-scale undertakings. The concept of "smart" is increasingly being used as a benchmark for modern engineering. Therefore, the discussion gives helpful information for choosing "smart" decisions when it comes to including elevators in high-rise buildings. Overall, the paper intends to provide an educational coverage of smart technologies, energy-efficient, space -saving elevator systems, and new elevators that generate "clean energy".

## 2. Energy-efficient hardware

### 2.1 DC and AC motors

The switch from traditional brushed DC (direct current) motors to more efficient AC (alternating current) motors is one of the most significant advancements in elevator technology. Before the 1990s, elevator systems relied on DC motors because it was easier to control elevator acceleration, deceleration, and stopping with this form of power. AC power was usually only used in freight elevators, where speed and comfort are less critical than in passenger elevators. By the late 1990s, however, more elevators had moved to AC machines because motor controller technology had advanced enough to regulate AC power, enabling smooth stopping, acceleration, and deceleration. DC motors were great when they first came out. Still, newer AC gearless motors are better in terms of performance, energy efficiency, and the ability to send extra power back into the building's electrical system [4-6].

### 2.2 Geared and gearless motors

Elevators in high-rise buildings are primarily traction elevators, which can either be geared or gearless. Because they lack gears, gearless elevator motors can be up to fifty percent more compact than their geared counterparts. As a result of the engine being scaled down, all of the other components will likewise be reduced in size. In machines that use gears, the electric traction motor rotates a reduction gearbox, and the gearbox's output rotates a sheave that serves as a passageway for the rope that connects the car to the counterweights. Gearless elevators, on the other hand, do not have a gear train since the drive sheave is instead directly connected to the motor. This eliminates the requirement for a gear train as well as the energy losses that come along with it. Therefore, one of the primary benefits of gearless motors is that they are approximately 25 percent more efficient than geared motors. Because of their higher torque and lower revolutions per minute (RPM), gearless engines are able to run more quickly and have a longer lifespan than their conventional counterparts. The cost of gearless elevators, including the cost of materials, installation, and maintenance, is often higher than that of geared elevators. This is the most significant disadvantage of gearless elevators. AC gearless motor machines are used in more elevators today despite that they are more expensive. This is because they have higher overall efficiency and may be utilized for a greater amount of time [5,7,8].

## 2.3 Machine-Room-Less (MRL) technology

Elevator equipment used to be so big that it needed its own room, usually placed above the hoistway on the roof of a building and at least 8 feet tall. The machine room was costly because it was needed to support heavy machinery. Introduced in the mid-1990s, MRL technology was one of the enormous advances in elevator design since elevators became electric a century before. Elevators without a machine room employ a gearless traction machine positioned in the hoistway. Utilizing a counterweight aids the machine in spinning the elevator sheave, which propels the cab through the hoistway. As a result, manufacturers reconfigured the motors and any other equipment that would normally be placed in a machine room to fit inside the hoistway, which eradicated the need to construct a machine room (**Figure 1**). The reduced starting current needed for the MRL also contributes to its energy efficiency. The MRL uses only 30 to 40 percent of the energy used by comparable traction and hydraulic motors. The MRL is a high-performance, space-saving, and energy-efficient elevator as a result [6,9]. It becomes even more energy-efficient if it is combined with regenerative drives (see next section). Today, MRL elevators are increasingly common.

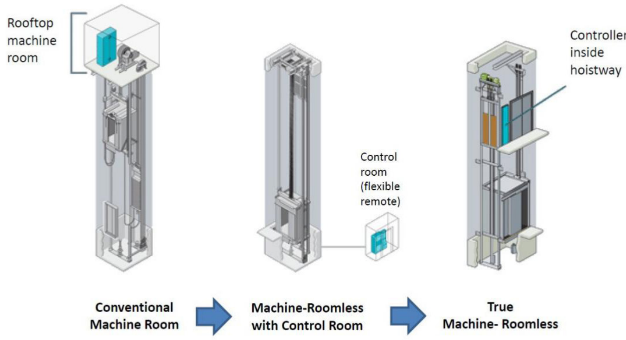


**Figure 1.** Gearless machine-roomless revolution.

Source: Adapted from otisworldwide.com.

## 2.4 Regenerative drives

Another significant development in energy-efficient elevator technology is the use of regenerative drives, which allow energy to be recycled rather than wasted as heat. They function by accumulating and transforming the energy expended during braking to keep the elevator's speed constant. In order to balance the weight of the elevator vehicle and the passengers, traction elevators employ a counterweight. The counterweight is optimally sized, roughly equivalent to a car loaded at 40%-50% of capacity. The elevator will perhaps overtax the motor and brake system if the counterweight is too heavy or too light. Instead, a midway weight works well to balance energy consumption in both upward and downward motions. The elevator uses brakes to maintain its rated speed when the elevator car is loaded less than or more than 50% of its maximum capacity (cars moving up are light or heavy, respectively). When applying breaks, the AC motor functions as an energy generator by converting mechanical "heat" energy into electrical energy and channeling it back into the facility's electrical grid [7,10]. Further, because there is no longer a requirement to cool equipment that is subjected to the excessive heat generated by traditional motors, this results in an extra reduction in the amount of energy consumed (**Figure 2**). The length of travel, frequency, pattern of use, and device age affect energy savings. Longer distances and more trips generate more energy [11,12] (**Figure 3**).

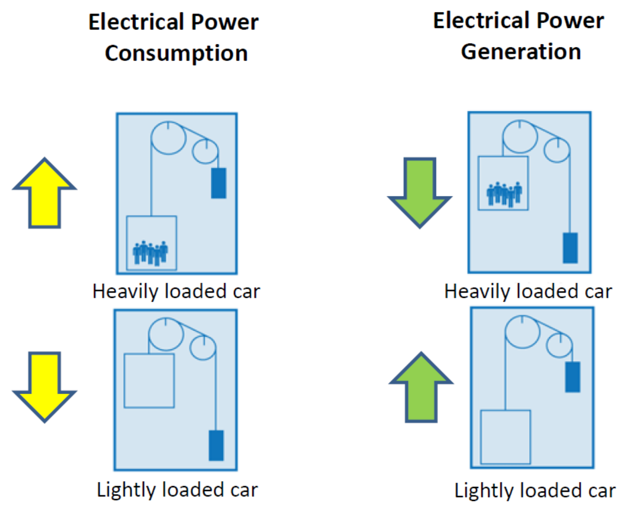


**Figure 2.** The regenerative drive system.

Source: Adapted from otisworldwide.com.

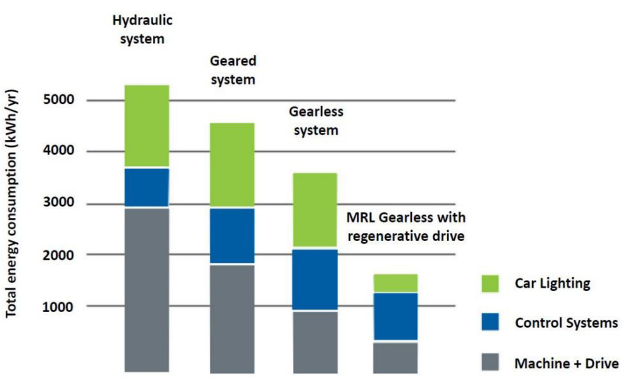


**Figure 3.** A comparison of energy consumption among different elevator systems.

Source: Adapted from otisworldwide.com.

## 2.5 Elevator rope

Because it links the elevator engine with the cab, sheaves, and counterweight, the elevator rope is a crucial part of traction elevators. Steel ropes hold cabins. However, in very tall buildings, the rope gets too long and too heavy to the point that it cannot support its own weight. As height increases, starting currents and energy usage rise, increasing energy consumption. In other words, the combined weight of the steel ropes required to operate elevators to supertall heights is the largest obstacle. Each elevator requires four to eight ropes, and at a certain height, it becomes impractical to utilize them for single runs on supertall structures, forcing builders to incorporate one or more transfer levels, or "sky lobbies". In response to this challenge, elevator manufacturers have been strengthening cables. The Schindler's aramid fiber rope is more robust and lighter than the steel one. Otis' tiny Gen2 elevators use ultra-thin wires encased in polyurethane instead of steel ropes (**Figure 4**). Mitsubishi produced a more potent, denser string with concentric steel wire. These more robust, lighter cords move elevator cabs more efficiently, conserving energy [11,13,14].

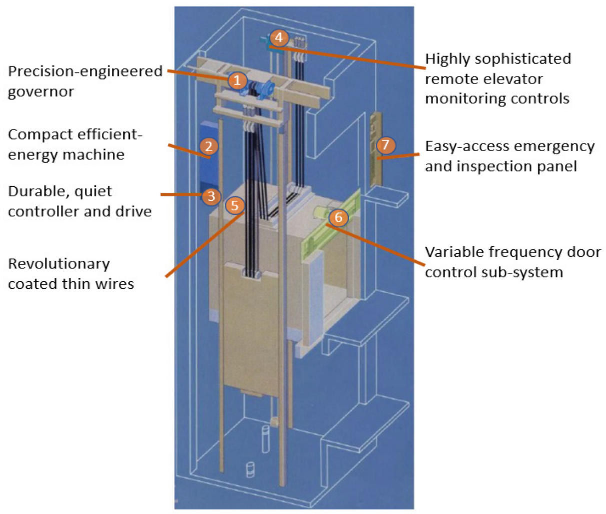


**Figure 4.** Diagram of OTIS GeN2 lift.

Source: Adapted from otisworldwide.com.

The KONE "UltraRope" is the most significant breakthrough. It has a carbon fiber core and a unique high-friction coating, allowing cars to travel up to 1,000 m (3,280 ft). This is twice the current 500 m (1,640 ft) limit. A 1000-m UltraRope weighs 10% of steel ropes. The 90% reduction in rope mass saves considerable energy. The 1-kilometer, 3,281-foot-tall Jeddah Tower in Saudi Arabia (construction on hold) plans to install the super-light KONE UltraRope elevators, reducing the number of required sky lobbies. Using UltraRope, an elevator can travel the 653 meters from the Jeddah Tower's base to the observation deck in just one trip. In South Quay Plaza, one of the highest residential buildings in Europe and the first to be outfitted with KONE UltraRope, eight of these elevators were built [13]. In the future, technology such as UltraRope will enable elevators to ascend higher and reduce the need for sky lobbies. During the next iteration, KONE plans to devise methods for moving people that high and quickly while ensuring their safety and well-being particularly related to variations in pressure and temperature at high altitudes.

## 2.6 Double-deck elevators

A double-deck elevator consists of two stacked cabs where one serves floors with even numbers, and the other serves floors with odd numbers. As skyscrapers get higher, reducing the number of shafts needed becomes more important because they eat up valuable interior space on every floor (**Figure 5**). Double-deck elevators are most useful for applications in very tall buildings, particularly for shuttle services [14,15]. However, the double-deck elevators suffer from some operational challenges. Equal floor rise could present a limitation; i.e., for local service, double-deck elevators must load and unload two decks simultaneously. Even though traffic is reduced during off-peak hours, both decks will be operating [15,16].

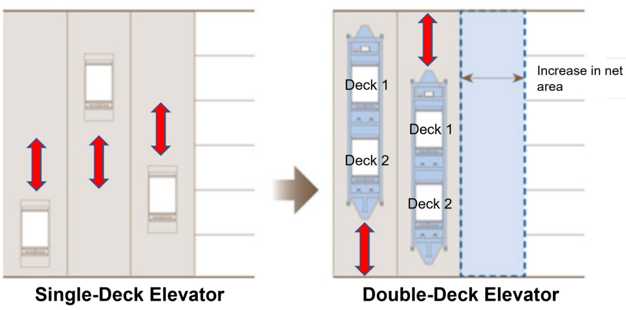


**Figure 5.** Double-deck elevators save on the number of shafts needed to serve a building.

Source: Adapted from hyundaielevator.com.

## 2.7 The TWIN systems

Sharing similar characteristics with double deck systems, TWIN is an elevator system in which two standard cabs are installed within the same shaft but operate independently. A device that monitors the distance between two elevators prevents them from collisions (**Figure 6**). A computerized system optimizes travel for both cabins by assigning passengers to cabs most efficiently, reducing wait time and empty journeys, and saving energy [16-18]. Simply, the system enables more elevators with fewer shafts – it is estimated to require one-third fewer shafts than conventional elevators, saving core space. In addition to freeing up valuable space, the TWIN system reduces the required building materials for shafts, decreasing embodied energy. Because there is just one control machine for both elevators in the same shaft, significant space and energy are saved as a result of this design decision [17,19].

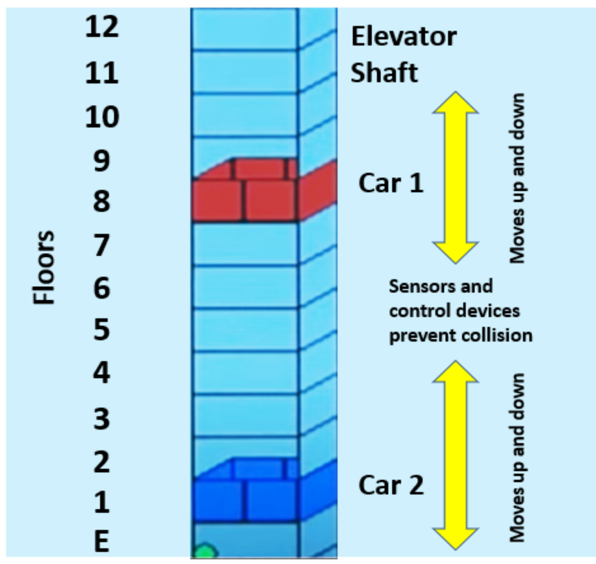


**Figure 6.** In the TWIN system, each shaft holds two cars that operate independently. A computerized system and sensors coordinate their movements and ensure no collisions.

Source: Adapted from youtube.com/watch?v=DMfqwhj_S3U.

## 2.8 LED lighting

Energy-efficient light-emitting diode (LED) cab lights within an elevator car and their adjustment to motion detectors are among the most critical factors in a building's efficient power consumption. LEDs are significantly more energy efficient than incandescent, halogen, and fluorescent light bulbs. LEDs emit less heat, which reduces the energy required to cool the cab. Numerous new structures currently incorporate LED lighting. Often, building owners are replacing conventional elevator lighting systems with LED illumination [12,20,21].

## 2.9 Computerized roller guides

Moving an elevator quickly and over great distances requires more than just strong motors and current. Fast-moving elevators, like bullet trains, need exceptionally smooth rails and rail joints to travel quickly. Any skyscraper will undoubtedly need a lot of rail joints because the vertical arrangement of elevator rails restricts their length to roughly 4.9 m (16 ft) due to alignment precision constraints. Elevators must also consider minute variations in the spacing between guide rails that result from temperature changes (contraction and expansion), wind forces, and other factors that cause skyscrapers to sway slightly during the day and night [22-24]. In response to these problems, ThyssenKrupp created automated roller guides. These guides exert forces in the opposite direction from the guide rails' normal direction of travel, reducing the effects of the bumps. While the elevator car ascends and falls, roller guides maintain contact between the rollers and the guide rails. They are also managed by a mechanism that pushes and pulls against the rails to avoid any misalignments or imperfections from generating tremors and rattle. These active roller guide systems serve this purpose as clever real-time shock absorbers. They mimic how a motorist may act if they knew of a sizable pothole in the road and swerved a little to avoid it. When a pothole is on the right side of the road, the driver will turn slightly to the left, and vice versa [22,25] (**Figure 7**).

## 2.10 Braking system

Mitsubishi developed a new braking system to ensure safety at higher speeds and longer distances. Safety mechanisms will immediately engage the brakes if "cables become transected", grabbing the guide rails. A revolutionary two-tier braking system that employs ceramic brake shoes can withstand shocks and extreme heat over 1,000 degrees Celsius (1,800 degrees Fahrenheit). Hence, a disc brake stops the primary pulley system in regular operation. In the event that the system detects a train going at an unsafe rate of speed, it will activate a mechanism at the train's undercarriage to grab the rails and bring the train to a stop within 15 meters (50 ft) [26-28].

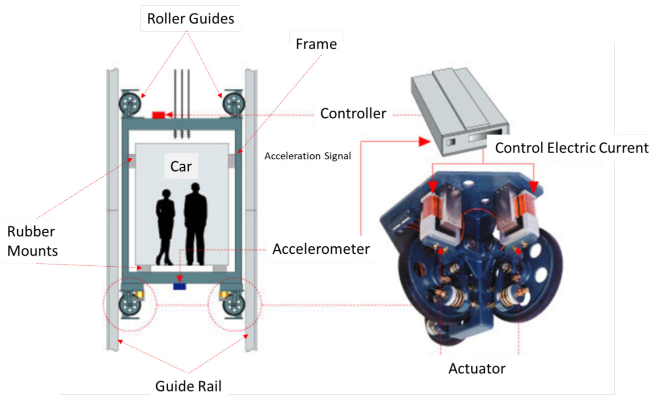


**Figure 7.** Illustration of the computerized roller guides system.

Source: Adapted from mitsubishielectric.com/.

## 2.11 Air pressure differential

When designing and constructing high-speed elevator systems that travel great distances, such as in supertall and megatall skyscrapers, the air pressure differential is a consideration. The first difficulty with air pressure is related to the elevators' rapid passage between floors, which causes air resistance in the elevator shaft. The air-pressure effect is comparable to that of a subway: as a train pulls into the station, it pushes a wall of air ahead of it. Similarly, when a standard 4,500-kilogram car with a 7,300-kilogram counterweight ascends or descends rapidly in an elevator shaft, it causes a tremendous amount of air displacement. With a high-pressure zone above the car and a low-pressure zone below it, the hoistway doors above the car are forced into the hallway, while the hoistway doors below the car are sucked into the hoistway. As a solution, ThyssenKrupp affixed wedge-shaped aluminum shrouds to the top and bottom of the cabs to make them more aerodynamic as they ascend and descend the shafts. The cab's resulting aerodynamic shape reduces air resistance, minimizes air displacement, diminishes door rattling, and lessens wind noise [22,23].

The second air-pressure problem is connected to the safety and comfort of the passengers, especially concerning the "ear-popping" effect when the elevator goes at a higher speed. This problem is more noticeable in the descending sequence, but it occurs because of the rapid and abrupt shift in air pressure that happens as the elevator ascends and falls. It's vital to remember that elevators in super and megatall buildings descend faster than a descending commercial flight. An airplane's landing procedure may take around 30 minutes, giving plenty of time to regulate the air pressure within the aircraft. In contrast, the amount of time elevators have to change the air pressure or depressurize might be as short as 30 seconds. This limits the time passengers in elevators have to adjust. In response, ThyssenKrupp developed a strategy that involves pressurizing vehicles (adding extra air pressure within the cars to make up for pressure drops) and then gradually releasing it to prevent passengers' ears from popping. Nonetheless, in all instances, because of the air-pressure issue, elevators continue to descend at a maximum rate of 10 m per second (33 ft/s) [22,23,29].

# 3. Energy-efficient software

Studies of elevator traffic have revealed that the elevator's cycle significantly impacts energy consumption. The operation of an elevator, the number of levels visited, peak load, low load, and empty trips may all be analyzed to develop energy consumption models. These models help to formulate practical management suggestions and control tactics. New software is empowering this endeavor [13,30].

## 3.1 Destination dispatching systems

Elevators answer calls when users press the up and down buttons. This technique works fine in buildings with limited "vertical ridership" and does not experience "rush hour" traffic. In heavy traffic, many buttons are pressed, causing elevator stops and longer travel times. Each stop in a high-speed elevator at six m/s may take 10-13 s. Elevator designers created the destination dispatching system (DDS) to address this problem. It was initially developed in the 1990s following the boom in more excellent microprocessor capability throughout the 1980s. A DDS is an optimization strategy for multi-elevator systems, which puts passengers for the same destinations into the same elevators. The technology analyzes passengers' data in real-time and efficiently groups destinations, reducing elevator stops. When entering a destination using keypads or touch screens on the Destination Operation Panel (DOP), which is often strategically located in the lobby, the system indicates and directs each passenger to the allotted elevator to board [14,31] (**Figure 8**).

## 3.2 People flow solutions

People Flow Solutions, much like the DDS, are intended to regulate demand on elevators and improve the flow of foot traffic, but primarily in more extreme circumstances. For example, KONE's Advanced People Flow Systems provide enhanced safety, convenience, and comfort. They integrate access and destination control, communication, and equipment monitoring to provide a seamless experience for users moving between facilities [18,32]. A solution that is both modular and linked, enabling tailored user experiences and touchless access that can be adapted to meet the specific requirements of a building.

## 3.3 Standby mode

Standby mode puts elevators in "hibernation" or "sleep" mode. At certain hours of the day, there isn't enough demand to warrant the use of all elevators—the majority of elevators operate between 20 and 30 percent of the time. Contrary to popular belief, elevators need power even when they are not in use. When cabs are idle, elevator systems must be kept powered, so they are prepared for the next passenger call. As such, the standby solution shuts down elevator machinery when not in use, conserving energy. When the car is vacant, the in-cab sensors and software put the elevator in a state known as "sleep mode", which turns off the lights, fans, music, and television screens. Depending on the control system, lighting style, floor displays, and operating consoles in each level and elevator cabin, the standby solution can save anywhere from 25% to 80% of the elevator's total energy consumption [19,33].

### 3.4 Predictive maintenance Apps

The creation of artificial intelligence- and machine learning-based algorithms have led to getting real-time updates on the status of an elevator. As such, new apps enable predictive maintenance. They empower building owners to use elevator data to diagnose, analyze, and notify them of maintenance needs and possibly automatically resolve service issues before they arise. With an IoT device connected to the elevator controller, the owner can gather precise information about the elevator's parts, identify flaws and weak signals before a failure, and offer repair assistance to specialists. Apps give building owners real-time insights from their phones or mobile devices to operate better and manage their buildings [20,34].

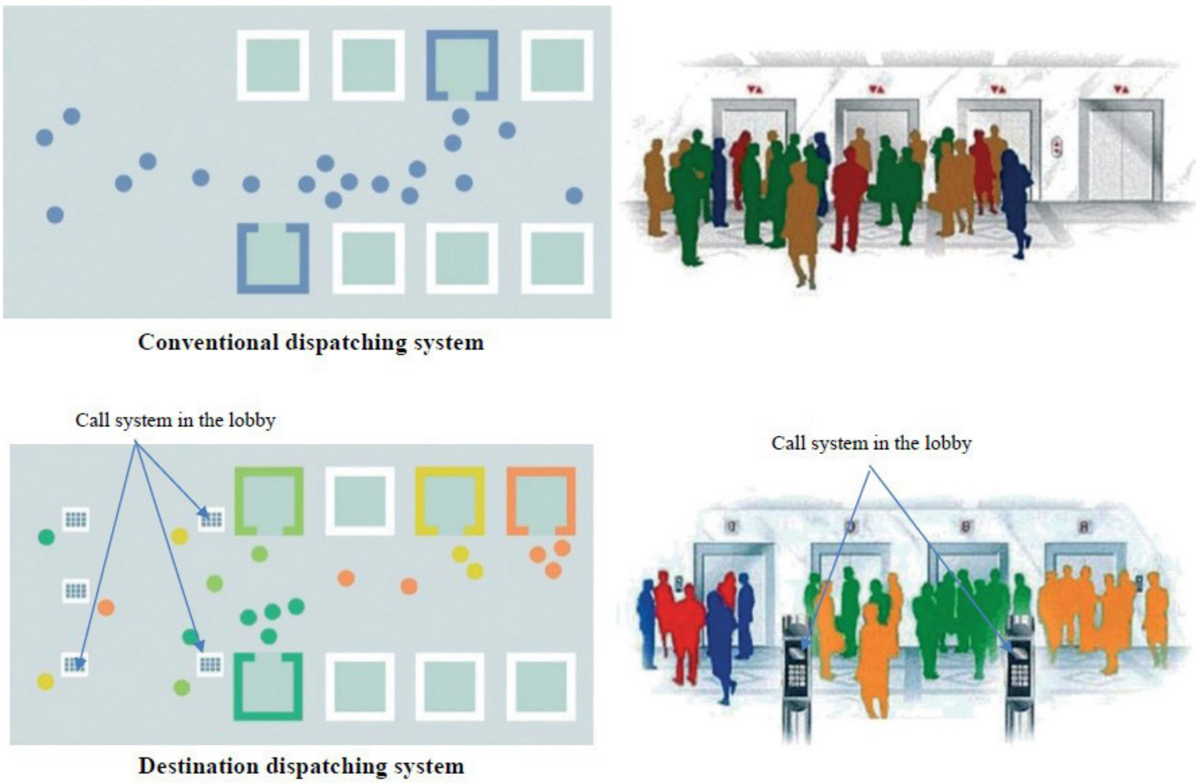


**Figure 8.** Conventional (top) versus destination dispatching system (bottom).

Source: Adapted from ThyssenKrupp.com.

## 4. Future developments

Since long before the concept of "smart" became popular, the elevator business has been actively seeking to improve elevator performance, including speed (**Table 1**), comfort, and those related to space and energy efficiency. The "positive-energy" elevator is the hoped-for culmination of the elevator industry's significant experience and ambition. Elevators that conserve energy and space, have motors that are not prohibitively expensive, are made of long-lasting materials, and have smart dispatching systems are still a primary focus of research. Solar elevators, in which solar panels are mounted on the hoistway to create power that may then be used to drive the elevator as well as contribute additional power to the city's power grid, are currently being developed by a few different firms.

**Table 1.** Skyscrapers with the fastest elevators (compiled by author).

| Rank | Building | Speed in Seconds m/ft | Year of Completion | Building's Height m/ft | Elevator Supplier |
|---|---|---|---|---|---|
| 1 | CTF Finance Center, Guangzhou, China | 20 (66) | 2016 | 530 (1,739) | Hitachi |
| 2 | Shanghai Tower, Shanghai, China | 18 (59) | 2015 | 632 (2,074) | Mitsubishi |
| 3 | Taipei 101, Taipei, Taiwan | 16.8 (55) | 2004 | 509 (1,670) | Toshiba |
| 4 | Yokohama Landmark Tower, Yokohama, Japan | 12.5 (41) | 1993 | 296 (971) | Mitsubishi |
| 5 | One World Trade Center, New York City, U.S.A. | 10.16 (33.33) | 2014 | 541 (1,776) | ThyssenKrupp |
| 6 | Burj Khalifa, Dubai, U.A.E. | 10 (33) | 2010 | 828 (2,717) | Otis |
| 7 | Sunshine 60 Building, Tokyo, Japan | 10 (33) | 1978 | 240 (787) | Mitsubishi |
| 8 | Shanghai World Financial Center, Shanghai, China | 10 (33) | 2008 | 492 (1,614) | ThyssenKrupp |
| 9 | China World Trade Center Tower III, Beijing, China | 10 (33) | 2010 | 330 (1,083) | Schindler |
| 10 | John Hancock Center, Chicago, U.S.A. | 9.1 (30) | 1969 | 344 (1,129) | Otis |

## 4.1 Net-zero solar energy elevator

Solar electricity is becoming increasingly popular, so an elevator that runs on solar energy could be a plausible solution to save energy. A net-zero elevator system produces at least as much energy as it consumes over a year. German elevator manufacturer ThyssenKrupp is working on a net-zero solar energy elevator prototype called the Synergy Elevator. It incorporates state-of-the-art energy-saving features, including a regenerative drive and LED cab lighting, a more efficient controller capable of a deep-sleep standby mode, and an auto-power-down feature that shuts off the cab lights and fan when the elevator is not in use. These features reduce the total standby power draw by about 75%. The prototype integrates a rooftop solar photovoltaic (PV) array to offset the elevator's energy consumption. The 3.75 kW solar PV system was designed to produce about 4,000 kWh per year in a climate similar to that of Boston—this prototype was tested in USA CSE's Boston Headquarters [35,36].

Similarly, Schindler Elevator Corp. introduced a solar-powered elevator prototype. The Schindler Solar Elevator uses rooftop solar panels and a Hybrid Energy Manager (HEM) to store solar energy in batteries to power up to 100% of the elevator. Schindler claims the solar elevator saves energy, avoids power peaks when elevators start each journey and can operate independently of the power grid during power outages. The new solar elevator employs a regular Schindler 3,300 gearless machine room-less elevator, which is up to 60% more energy efficient than hydraulic elevators. Overall, this elevator system incorporates several energy-saving features, including a stable start, LED car lights, a frequency converter with an energy-efficient standby power mode, and control devices that automatically switch car lights to standby mode [36].

## 4.2 Circulating multi-car elevator system

In the case of conventional elevators, one car moves up and down the same elevator shaft. However, in a circulating multi-car elevator system, multiple cars (each equipped with a rotating magnetic array propulsion wheel) travel in the space of two conventional elevator shafts in a circulatory movement (**Figure 9**). This system is like a Ferris wheel, except instead of having counterweights, each vehicle has its own motor. Hitachi was able to effectively verify this elevator system by using a replica that was only one-tenth of the actual size. Its prototype for circulating multi-care elevators uses the steel rope drive method. That is, in this system, two cars are connected to two steel circulating ropes making up one unit while the cars are placed in a diametrically opposite positions and driven by motors installed in the upper section of the building. The two cars are used as a mutual virtual counterweight and they achieve an energy saving of one-third compared to a system in which they are not counterweighted. Several sets of this circulating steel rope system with attached cars are combined and a motor controls the movement of each circulating rope set. Another feature of this elevator is the support rail system installed throughout the elevator shaft to guide the movement of the cars and prevent lateral sway motion. The revolving multi-car elevator is expected to not only enhance capacity but also decrease the required number of shafts and cut down on the amount of waiting time. Unfortunately, the current prototypes will need more safety improvement to meet international standards [37,38].

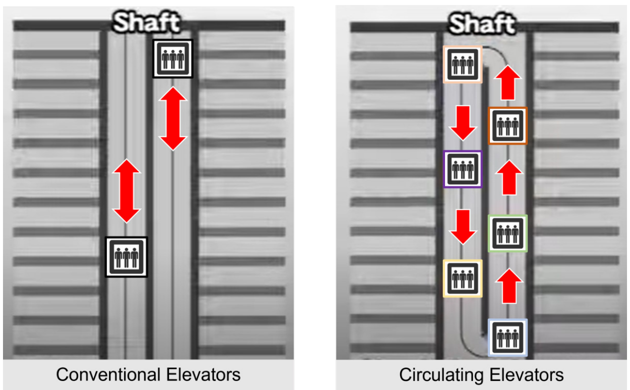


**Figure 9.** One car travels up and down the same elevator shaft in a traditional elevator system (left). In contrast, numerous cars in a circulating multi-car elevator system circulate between two conventional elevator shafts, each powered by a spinning magnetic array propulsion wheel (right).

Source: Adapted from youtube.com/watch?v=ESo-0KXeCFo.

### 4.3 Multi-directional elevators

Traditional elevators utilize cables to move a cabin strictly up and down. The MULTI, on the other hand, handles elevators more like a subway system. The cabins move sideways, frontways, and backways as well as up and down (**Figure 10**). Each system consists of numerous cabins individually powered by linear induction motors. Inspired by the TWIN concept, ThyssenKrupp created the first multi-car ropeless elevator system in 2017. Each car is propelled around a looping shaft by a motor system rather than ropes. As there are no ropes required to move the cars, this system is no longer height restricted. As such, MULTI offers a solution that allows increasing elevator height much above the KONE's 650-meter steel rope restriction. Because the MULTI uses many cars, it assures to reduce wait time. Finally, it promises to minimize energy use by integrating a "smart" device that reduces peak power demand by up to 60 percent, reducing the overall structure's carbon footprint [39,40].

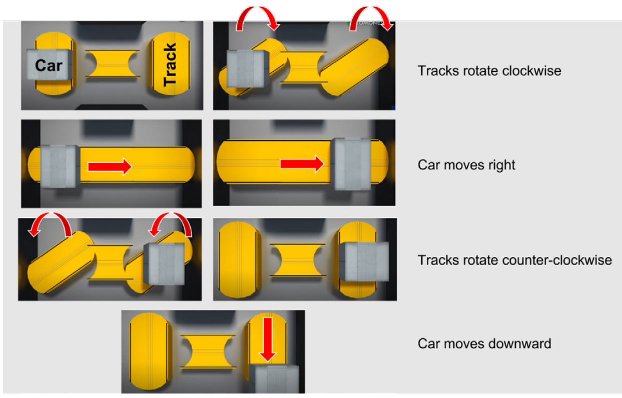


**Figure 10.** In a multi-directional elevator system, tracks rotate to allow cars change their directions.

Source: Adapted from youtube.com/watch?v=NBv1bkuj0Ac.

### 4.4 Robotization

Certainly, robotics technology will impact the construction of elevators and their shafts. Using robotics technology instead of humans will improve multiple prime areas, increase construction speed, reduce the energy used for construction and involved costs, enhance precision, and improve safety. Schindler has created a robot for the safe and exact installation of cabins using artificial intelligence and technology, paving the way for increased automation. This robot is fully autonomous and self-climbing, and it moves through the elevator shaft to precisely measure and place the anchor bolts required for the installation of the elevator rails [39].

### 4.5 Drones

Similarly, drones are becoming more prevalent in the industrial and construction sectors and will have significant roles in constructing elevators. The installation of a new elevator entails numerous tedious, complicated, and costly activities, including the geometric measurements of wells to the certification checklists of field processes and inspection activities. Due to their mobility and ability to take photographs, drones can assist construction personnel. Drones might cut installation time by 21% to 26% and costs by 11% [40,41].

## 5. Conclusions

This article discusses the current technological advancements that help to make elevators "smarter". The concept of energy-generating elevators is gaining traction as a result of recent technological advancements [42]. The success of the communal environment in the vertical city depends on careful planning of the vertical transportation system. The planning team must have a thorough understanding of the varied demands that a mixed-use skyscraper will face due to its diverse purposes. Planning well can increase the transparency of logistical operations to the general public, renters, and inhabitants. The smoothest and least noticeable logistics operations are the best. If "smart" designs are used to integrate cutting-edge elevator technologies, they could lead to "greener" skyscrapers. Early cooperation among elevator manufacturers, builders, architects, urban designers, interior designers, and computer scientists may result in efficient solutions that further save costs, boost performance, and encourage efficiencies [43,44].

## 6. Future research

With the advent of COVID-19, elevator makers, engineers, and architects need to research ways to mitigate the possible spread of the coronavirus by elevators. Undoubtedly, applying social distancing within elevators is difficult because that reduces their effective capacity significantly. Alternatively, engineers may need to reconfigure the design of the elevators' air circulation system so that it prevents contamination and the spread of the virus [45,46].

## Conflict of Interest

There is no conflict of interest.

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