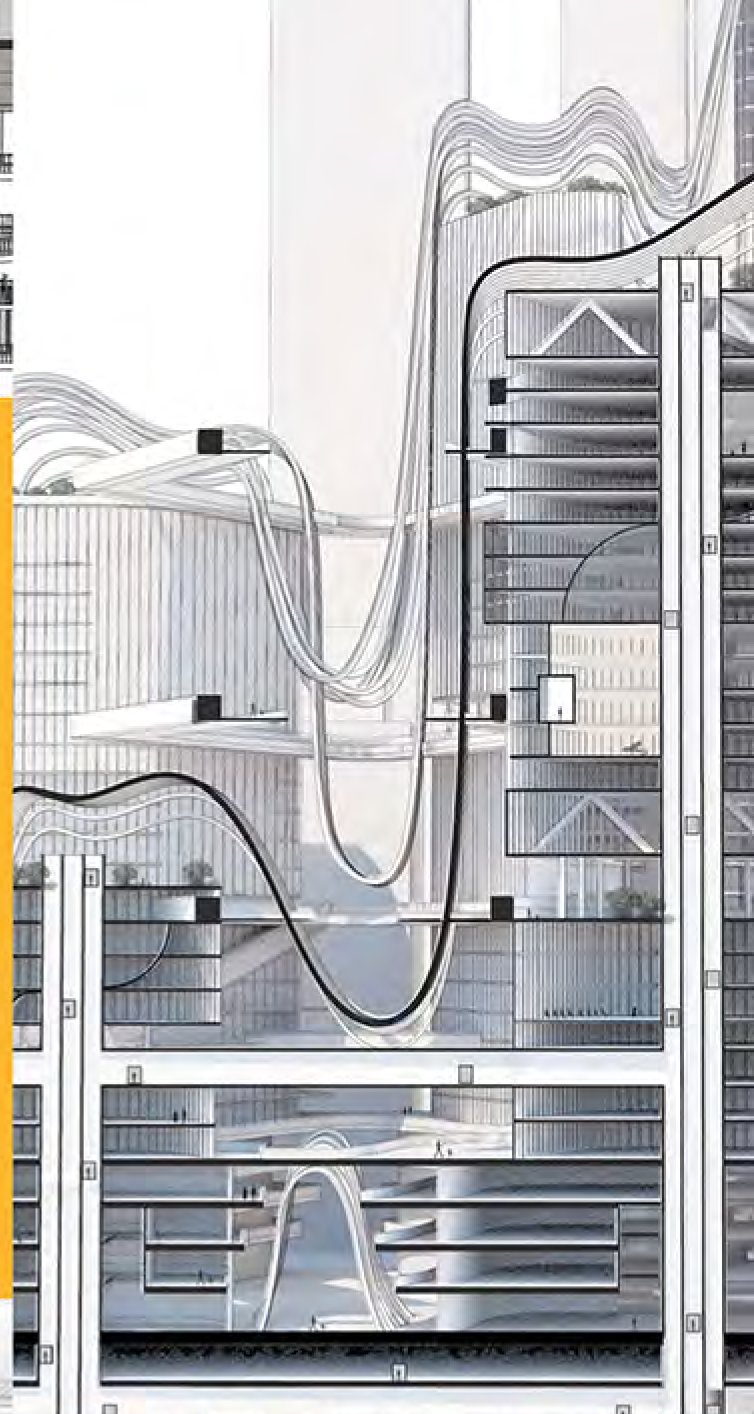
CTBUH Research Report

Ropeless Elevator Systems

The Potential for Multidirectional Transportation in Tall Buildings

Martina Belmonte, Dario Trabucco & Karl-Otto Schöllkopf



Council on Tall Buildings and Urban Habitat

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Preface

While elevator technology has made circulation throughout tall buildings possible (as well as safe and efficient), its essential concept has not changed much since its invention 160 years ago. Despite advancements in speed and performance, today's elevators largely remain a cabin pulled by a tensile rope in a vertical shaft, which limits the length of an elevator run when the cable becomes too heavy to support its own weight. Ropeless and multidirectional elevators, which manage to decouple themselves from this paradigm by way of magnetic levitation, have the capability to enable the evolution of the skyscraper typology, as well as their surrounding urban context, in a multitude of ways, which are explored in this comprehensive research report.

As populations occupy cities at greater rates, and thus more heavily rely upon dense living on a smaller footprint, clusters of buildings, each offering diverse services and amenities, represent an enhanced quality of life available at height. Ropeless and multidirectional elevators, when installed in and along skybridges, have the ability to link these clusters in a more efficient way, allowing building occupants to select a destination in the third or fourth tower in a planned complex with the touch of a button. The possibilities for these elevators present further advantages if linked to surrounding public transportation, increasing urban cross-pollination and improving accessibility for families and those with mobility restrictions. Additionally, by loading several cabins into a single shaft, configured as a loop or series of horizontally-linked loops in tall buildings, opportunities to repurpose area that is typically expended on multiple elevator shafts into rentable space presents economic benefits as well.

This report first presents a detailed history of elevator technology, followed by an exploration of practical and theoretical research and modeling, and culminates in a series of design considerations. A survey of the most optimal, and thus most receptive, markets for this technology, is presented in chapter four as a supplement.

It is the objective of this volume to impart upon architects, designers, urban planners, vertical transportation professionals, and other tall building industry peers a comprehensive scope of the design possibilities for tall buildings and urban planning enabled by ropeless and multidirectional elevators, which, once freed from the limitations of a strictly vertical elevator system, could catalyze a new era of the contemporary high-rise, and thus the modern city.

1.0 Historical Overview of Elevators and High-Rise Buildings

The elevator has deeply influenced and revolutionized one of the most profound building typologies in the history of architecture: the skyscraper. The elevator's advancements have been of immeasurable value to the increased heights of tall buildings, as they made it possible to safely transport building occupants to the highest floor possible and back again – without which, increases in height were effectively unusable. Moreover, the ability to travel to different floors within a tall building altered not only the class structure of real estate, but also the nature of the programming tall buildings could provide, yielding building types such as mixed-use, with different services bookended by residential or commercial space. Elevators have also had significant implications for families, the elderly and those with disabilities, creating more accessibility in growing urban environments where denser developments are stacked vertically onto smaller lot sizes.

The form and emergence of entire densified cities can thus be attributed to the widespread adoption of elevator technology, and the height and form of tall buildings is only as limited as the elevators that can serve them. As architects look to continue building skyward, this text introduces and addresses some of the opportunities elevators have to continue transforming cities through innovation.

Through an examination of the historical development and symbiosis between the skyscraper and the elevator, this chapter seeks to explain the limitations both skyscrapers and elevators currently face, and to begin to explore, through case studies and design considerations provided in the rest of this text, how the form and context of cities could be altered by continued innovation in elevator technology.

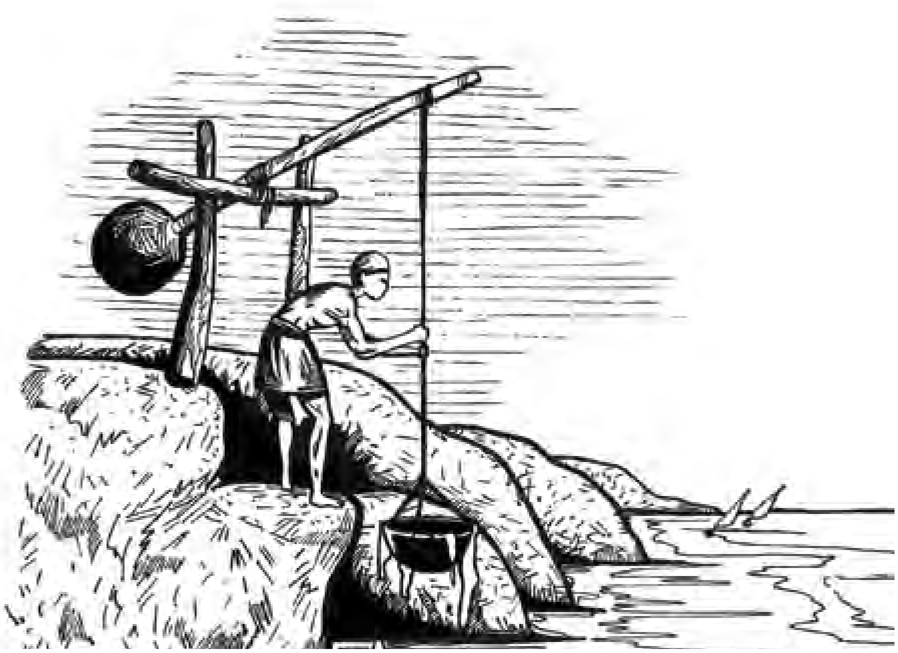

Figure 1.1.1. A representation of the Egyptian *Shadoof*, which used a cantilever system to collect water or lift heavy objects, circa 20th century BCE. Source: Travelers in the Middle East Archive, redrawn by Gianluca Contran

1.1: Pre-Industrial Lifting Technology

20th Century BCE – 4th Century CE

The origins of lifting technology can be traced to rudimentary tools used by early humans to vertically displace heavy loads, often with systems of counterweights and simple hinges. The Egyptian *Shadoof*, used circa 20th century BCE, is perhaps the earliest documented predecessor of a lift system. Consisting of a pole connected to a container on a rope at one end and a counterweight at the other, the *Shadoof* gained leverage by supporting the pole with a branch that allowed the operator to raise and lower it without requiring as much exertion (see Figure 1.1.1).

This simple technology was the basis for more complex articulated systems that were used to lift materials, goods and more rarely, workers. The Greek temples were constructed using levers, which connected to winches and pulleys to lift heavy stone blocks and support workers during operations at high altitudes (see Figure 1.1.2). In addition, evidence of mobile platforms has been found in Greek theaters for lifting actors during performances.

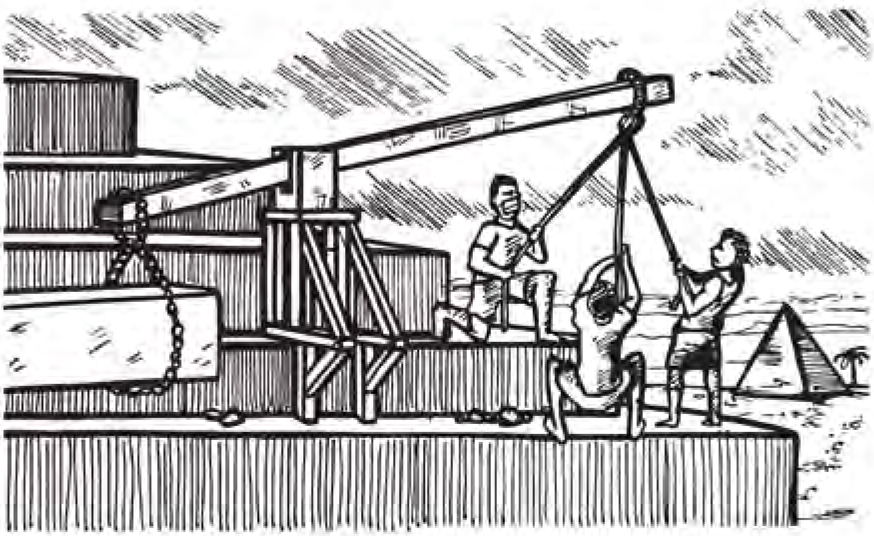

Figure 1.1.2. **Similar to Greek temples, the great tombs of Egypt required rudimentary, yet effective, lifting technologies.** Source: Jean Gavois, redrawn by Gianluca Contran

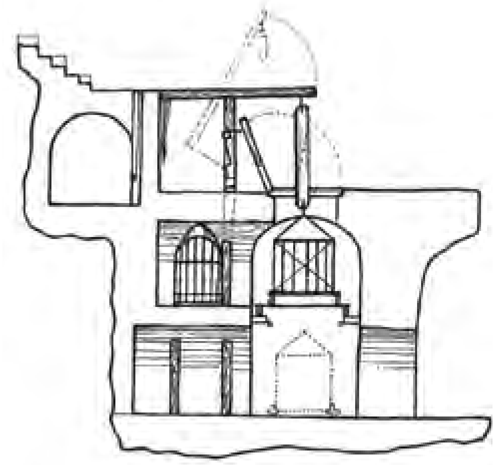

Figure 1.1.3. The elevator mechanism designed for the Colosseum (Rome, 70–80 CE), which transported gladiators and animals to the arena level. Source: Jean Gavois, redrawn by Gianluca Contran

Buildings constructed during the Roman Empire (4th century CE) exemplified complex and elegant architectural solutions such as aqueducts and bridges, indicating that workers and materials were effectively hoisted during construction. Large Roman buildings, such as the Roman Colosseum, demonstrated a mastery of controlled lifting technology; during Gladiator fights, below-grade rooms containing warriors and lions were elevated to the arena with a series of levers, pulleys and winches (Gavois 1983) (see Figure 1.1.3).

5th Century CE – 15th Century

By the Middle Ages, rope-driven systems were employed for lifting materials and workers at building sites. They were connected to winches, platforms, or a basic container to lift materials and goods and, according to some depictions, workers – although this was potentially risky because ropes were not as tensile as later metal and cable connections. However, there were still examples of dedicated systems for transporting people; among them the systems designed to reach the Meteora (or "in mid-air") Monasteries, which were scattered among the Hellenic mountains in Greece. (see Figure 1.1.4) Because of their remote location, a customized system was required to reach them, consisting of a net or basket suspended from a rope and operated by community members (see Figure 1.1.5).

Improvements in vertical transportation enabled increases in building height and supported more elaborate architecture exemplified in the Gothic Cathedrals found throughout Europe during the Middle Ages. With intricate spires, domes, and detailed carved figures, these heritage sites demonstrate adept application of complex lifting systems to execute remarkable designs. Baskets and platforms, intended to hold materials or workers, were suspended by cables and ropes that were drawn through a pulley or winch to control upward and downward motion. These devices were in turn powered at ground level by a wheel, which was rotated by a human or animal.

An early lifting concept that more closely resembles the modern elevator existed in the Middle Ages, consisting of a rope suspended at a desired height and connected to a container as well as a counterweight that was carefully calibrated to trigger a lifting or lowering of the load. The lifting effect was usually initiated by the traction of a human or animal.

2.0 Contemporary Innovations in Vertical Transportation

The main objective of this chapter is to present an essential foundation of technologies and solutions in the vertical transportation sector, spanning approximately 30 years back from this book's publication date in 2019, with a concluding section that highlights the relationship between intermodal transportation and multidirectional elevators. This includes conventional elevator systems and strategies, as well as innovative transportation systems that were designed and patented, some of which have been used in a practical context, while others were never fully realized.

Due to the wide variety of new technological solutions, ideas, patents and applications, this chapter will provide an overview of this topic by highlighting some of the most relevant innovations, as opposed to summarizing the technical specifications of each. Some of these ideas are only at the patent stage and have never been tested in a practical context. However, this only emphasizes why there is a need to continue driving research in the vertical transportation and multidirectional transportation industry to develop existing ideas into working models.

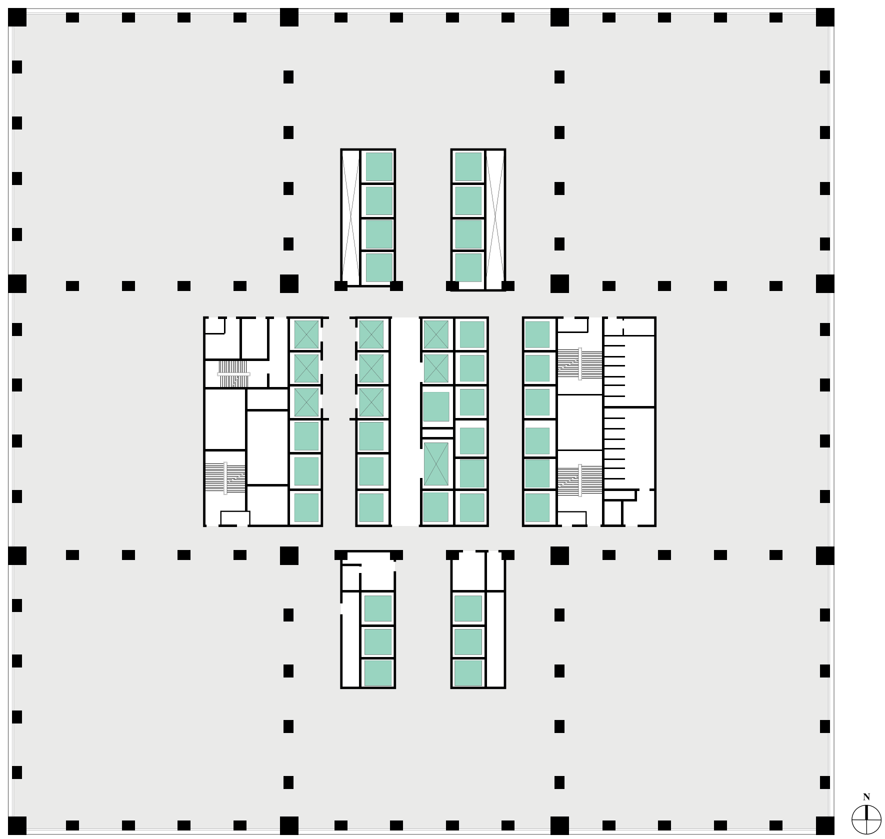

Figure 2.1.1. This floor plan of Willis Tower (Chicago, 1974) illustrates that the core still occupies considerable space, even with structural advancements. © Skidmore, Owings & Merrill LLP, redrawn by Michele Bettineschi

2.1: Vertical Transportation Limitations

As previously discussed, successful and safe vertical transportation has underpinned the continued success of the high-rise (Barr and Luo 2017). Improvements in speed and efficiency have greatly advanced elevators; however, the issue of dedicating significant amounts of rentable area to the building of elevator shafts continues to present a challenge to designers and developers (Willis 1995) (see Figure 2.1.1).

In most tall buildings, many of the most critical parts of the design – including foundational elements of structural, logistical and security systems – are located within the lower levels (see Figure 2.1.2). In addition to housing the main entry and exit points for the building, and thus having to mitigate and anticipate crowding at peak times, the foundational levels of a tall building are more prone to repeated stress, and require fastidious planning with a very small margin for error.

The height achievable by tall buildings is irrefutably limited to the technical and technological capabilities of vertical transportation systems. Still, there have been considerable improvements in the sector, whether through the advancement of elevator performance itself, or through the application of different dispatch and organizational strategies. These new advancements and arrangements have allowed for the achievement of greater heights by enabling increased numbers of building occupants to reach their destinations quickly and safely.

However, despite advancements, challenges remain, particularly surrounding the obstacle of serving all floors of the tower efficiently, but with most of the interchange, entering and exiting occurring on the ground floor, often dozens of stories away. The issue of large amounts of rentable area being dedicated to elevator shafts, more of which are required the higher a building rises, is another issue that designers have tried to solve through reducing the space of elevator cabins, loading multiple cabins into the same shaft, and experimenting with alternative configurations, including a continuous loop. The issues mentioned are intrinsic to the current format of most vertical transportation systems: a vertical shaft housing a single cabin and its requisite mechanical elements.

2.2: Design Challenges for the Contemporary High-Rise

Research in the elevator sector has enabled significant advances in building heights, notably the world's tallest building, the Burj Khalifa, which rises 828 meters. Buildings with the goal of achieving a kilometer in height, such as the Jeddah Tower, have also become engineering realities, in no small part owing to increases in elevator performance.

The execution of these complex projects is dependent upon the collaboration of experts from diverse fields and a high-degree of customization is inherent in the success of any boundary-pushing project; as such, designing the circulation system of a tall building without relating it to the architectural or structural context of a tower is inconceivable.

The common objective of all innovations in vertical transportation is to safely transport the largest number of people in the shortest possible time, without overestimating the space required to do so, as each square meter of space added to elevator shafts is one fewer of area that could be used for something else. Factors that can alter this estimation include the size of the tower, its primary functions, and the building's traffic volume and patterns. For instance, a mixed-use building with residential and commercial functions may have completely different circulation needs than an office building with a different company on each floor.

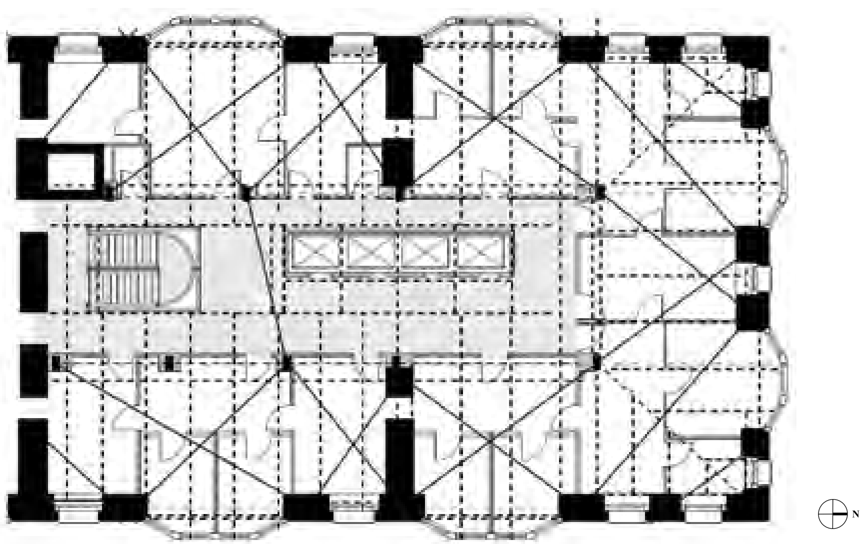

Figure 2.1.2. This ground floor plan of the Monadnock Building (Chicago, 1893) highlights a turning point in tall building history when thick masonry walls were replaced with steel frame skeletons, giving rise to taller buildings and the need for elevators. Source: Thomas Leslie, redrawn by Mattia Mercanzin

2.3: Design Solutions: Vertical Transportation

A study conducted by the Council on Tall Buildings and Urban Habitat in collaboration with Guinness World Records listed the fastest high-rise elevators in the world (CTBUH Journal 2017) (see Figures 2.3.1 and 2.3.2), demonstrating significant improvements to elevator speed over the past 160 years.

To achieve results of this caliber, vertical transportation experts have adapted principles from other disciplines, incorporating advancements from electronics, physics and even aerospace engineering. For example, elevators traveling at extreme speeds over long

3.0 Theoretical Models of Ropeless and Multidirectional Elevators

This chapter consists of a series of case studies that explore in-depth and theoretical applications of ropeless and multidirectional elevators, in order to illustrate some of their capabilities. By examining these technologies through a more tangible and visual lens, the objective of this section is to explore some of the possibilities this technology could create in an urban context. These case studies were developed by university-level students who were guided by practicing researchers and architects in the field.

Approach to Case Studies

In support of this research initiative, the CTBUH issued a "Master's Thesis Challenge", which invited architecture and engineering students to center their master's thesis project on dynamic tall building designs enabled by ropeless and multidirectional elevators. A selection of the submissions, which demonstrate an exceptionally broad range of applications for these elevator systems, have been collected in this chapter (see Figure 3.0.1).

Student Research Prompt

The objective of this chapter is to present readers with not only ideas for integrating ropeless and multidirectional elevators into buildings, but to demonstrate how the incorporation of this technology might affect the formation of cities, from safety and aesthetic contexts to more unique and site-specific ones.

Given that there are no real-world design references available for ropeless and multidirectional elevators as of the publication of this book, these case studies are meant to offer possibilities unbridled by current constraints. It is the intent of this portion of the research to offer a contemporary vision of cities of the future that will inspire current designers, functioning much like utopian visions of the future from the early 20th century (see page 21). Although these case studies are theoretical, they draw on the design principles outlined in this book, and demonstrate some of the capability for urban interconnectivity that would be enabled with the widespread implementation of ropeless and multidirectional elevators.

Participants

The design challenge prompted university students to exercise their creative freedom in proposing new and interesting solutions, free from financial limitations or an overwhelming familiarity with other restrictions in the industry. During the planning process, students were guided by tutors and faculty members from their universities, but were also permitted to seek help from external sources that could provide support on their research topic. The projects were then evaluated by a panel of experts in the tall building industry. A total of 20 projects made by both student groups and individual students made it to the final round of revisions, seven of which are exhibited in this book. Two additional projects are also included that were undertaken by a team of researchers at the Iuav University of Venice.

This chapter will present an overview and analysis of the projects submitted from three universities. The first was the Iuav University of Venice, supervised by Dario Trabucco (professor of building technology); Giovanni Marras and Serena Maffioletti (architectural design); and Paolo Foraboschi (structural design).

The second was the Melbourne School of Design at the University of Melbourne. These students used the research prompt for their Studio Class held by Giorgio Marfella, Scott Drake and Fiona McLean, with the external support of a team from Arup. Finally, students at the University of Nottingham presented projects they conducted with the guidance of their professor, David Nicholson-Cole.

Parameters

The challenge brief did not place particular limits or restrictions on the students and the only criteria for submittal was to devise an innovative new tall building design, drawing from the possibilities enabled by a ropeless and multidirectional elevator system. The building's functions, location, dimensions and design features were entirely dictated by the students.

This degree of freedom allowed each project to be unique, and each student decided to focus on different aspects related to the application of a new transport system. In addition, because there were no minimum or maximum size requirements for the projects, the designs ranged substantially in size and complexity. In some cases, for example, the new elevator system was

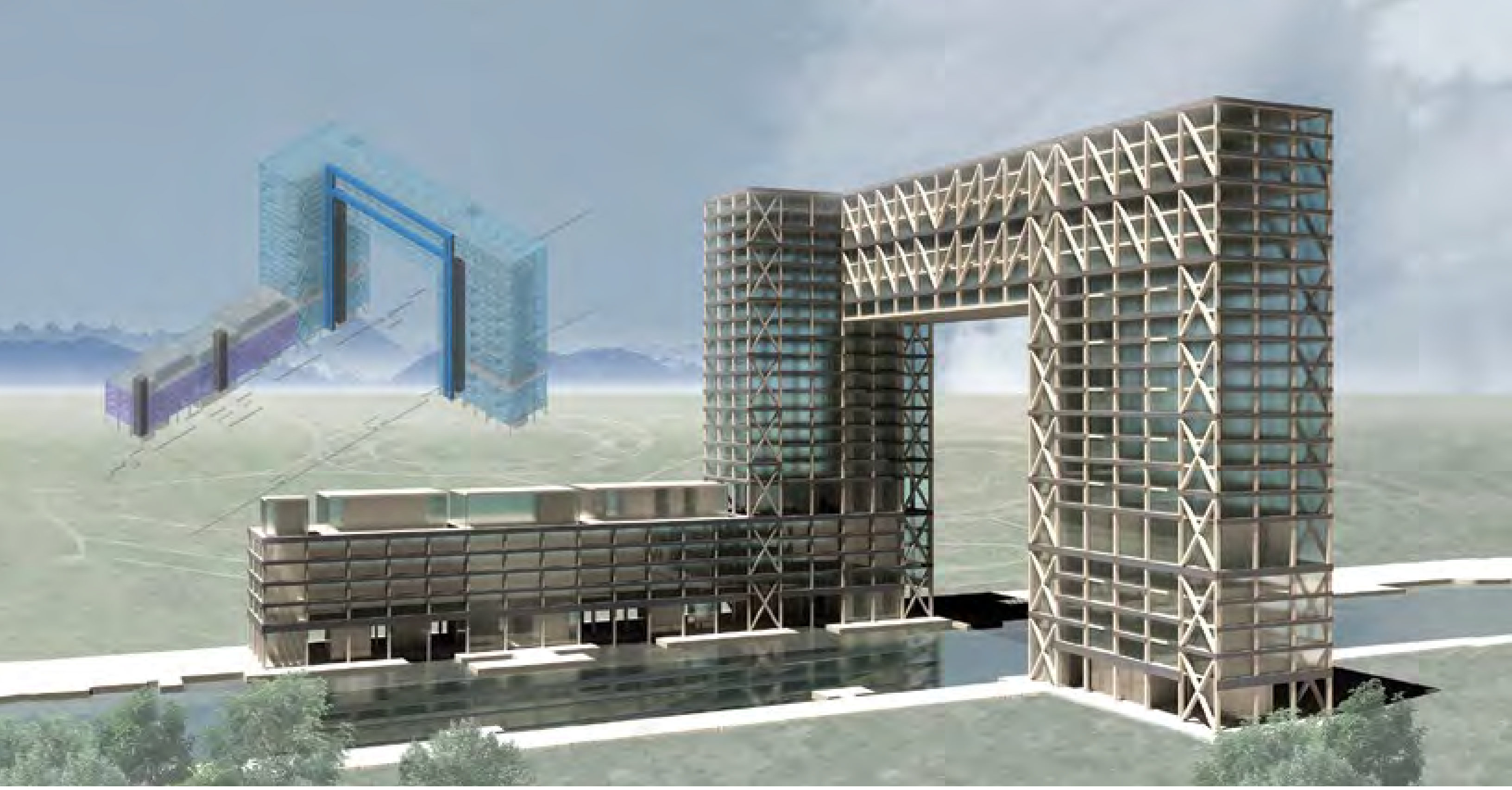

Figure 3.0.1. University-level students designed thesis projects centered around the possibilities enabled by ropeless and multidirectional elevators.
© Federico Biasotto, Angelo Paladin & Ettore Focaccia

created in relation to an urban public transportation system, as well as an individual building.

Overall Project Analysis

Because of the limited information on the standard sizing of multidirectional and ropeless elevator cabins and equipment, this dimension was also allowed to vary as much as students desired. However, some students tried to make accurate cabin and shaft sizing using formulas from available building and elevator data. This same freedom was applied to the direction of travel and mode of travel, resulting in elevators that could follow diagonal or three-dimensional routes among submissions. It is important to note that some of these innovations may not be achievable due to a lack of existing regulations, however, students were encouraged to think innovatively while this technology is still in its nascence.

Other projects focused on the flexibility enabled by horizontal movement, which influenced two overarching variations in the typology. The first group consisted of wider buildings than are typically found, which required the consideration of public transportation services and the connection between neighboring buildings as well as the building itself. A second group included proposed projects where the transport systems take advantage of this new technology in order to accommodate the specific program and needs of the building. Some of the projects interact with existing public transportation networks, linking them with buildings vertically and creating dynamic new urban connections.

Students proposed different approaches for the horizontal aspect of travel, keeping in mind that traveling in an elevator horizontally would still be a new experience for building occupants. For this reason, some students limited horizontal movement to relatively short stretches at a time and made sure to include entertainment and orientation information for passengers, allowing them to take in expansive views, read relevant news or socialize. Some skybridges were included as well.

In other projects, horizontal travel was exploited fully to explore new dispatch strategies, allowing a single system to manage both express and local service without requiring passengers to change cabins; instead, the cabin would change lines depending on its destination.

Other projects focused on improving accessibility to the elderly and people with reduced mobility. The implications for this perspective could extend to improving the quality of hospitals and elder care facilities. Some projects reimagined the role of the tall building core, distributing it throughout the building since it would no longer need to be limited to a vertical configuration.

Many of the projects addressed key tenants of communication between users and elevator service. In these, students created clear signage and envisioned streamlined onboarding

4.0 Data Analysis and Market Research

While the objective of the previous chapter was to examine some of the design implications of introducing a new transportation system type into tall building design, this chapter aims to identify the most ideal market for these systems, examined through a series of criteria.

The relationship between financial realities and the efficiency of an intra-building transportation system will also be explored, as the health of the financial market is a key driver in building sector innovation. The construction of a skyscraper represents a significant financial investment and will be designed in accordance with the availability of financial resources, which will determine its function, size, height, configuration, and location.

For ropeless and multidirectional elevators, market readiness will also determine the technology's traction – and ultimate success. Not only will available financial resources play a role in the adoption of this technology into daily life, demand for change and growth must be present to bring new systems out of obscurity – much how Elisha Otis brought elevators into the mainstream (see page 12). Evaluating the most feasible and logical applications of ropeless and multidirectional transportation were the primary foci of the surveys conducted.

The surveys are intended to evaluate building categories that might benefit from these systems and how they vary by geographical location. The first part of the chapter analyzes the current and future high-rise building and builds a narrative of what the most receptive market for new building typologies might be.

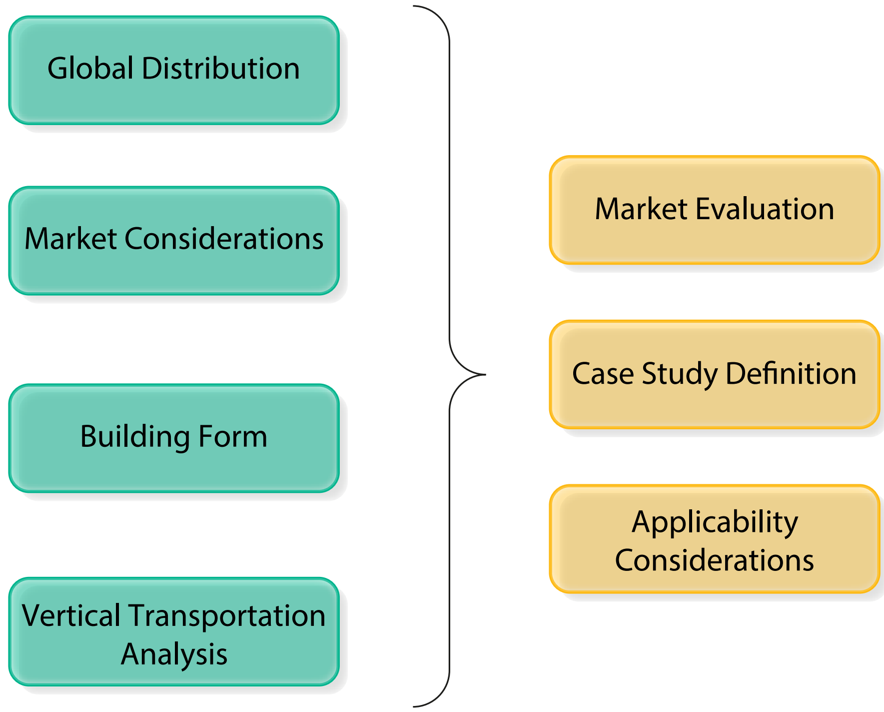

Figure 4.1.1. This chart represents how the global distribution, market considerations, building form, and vertical transportation analysis informed the evaluation of the best markets for ropeless and multidirectional elevators.

The second part of the chapter examines building designs that might be the best candidates for the application of new elevator systems. In this chapter, a diagram has been created that shows relevant factors that shaped the scope of the surveys. This could be a useful tool in determining the most common features and needs of the fastest-growing tall building typologies and programs, which could influence the type of internal transportation systems used, and their subsequent successes. These conclusions will be used to form a basis for the theoretical design considerations presented throughout this publication.

4.1: Survey Scope and Methodology

A data study (see Figure 4.1.1) targeted the characteristics of the most logical types of buildings for ropeless and multidirectional applications. Two surveys were conducted, which analyzed similar initial data and boundaries, but investigated the high-rise sector through different lenses. The first survey analyzed the geographical distribution of tall buildings, while the second identified unifying and differentiating design features. The buildings analyzed were used to draw some conclusions about the most common types of organizational strategies found in tall buildings, common vertical transportation layouts, and the main building functions and their proportions. Analyzing conclusions from the surveys helped create predictions for potential openings in the market for the incorporation of new circulation systems.

The basis of this research is the relationship between vertical distribution strategies and prototypical design. Therefore, a wide range of possible configurations and circulation strategies were examined. The data from both surveys was used to define the optimal building type and appropriate configuration of ropeless and multidirectional elevator systems.

Data Collection

Data was collected using The Skyscraper Center, an interactive database that is developed and maintained by the Council on Tall Buildings and Urban Habitat (CTBUH). With daily updates, The Skyscraper Center is a strong resource for evaluating design trends through a variety of controls, allowing for a nuanced analysis of circulation strategies. The data on the database is authenticated by the CTBUH and allows researchers to create a customized sample frame, according to specific parameters. For the purpose of this survey, there were five parameters chosen to filter the data, with the goal of identifying an ideal market for deploying ropeless elevator technology (see Figure 4.1.2). The logic for selecting the sample frame is explained below.

Minimum Height

The principal determining factor was defining the minimum reference height. The application of ropeless and multidirectional systems isn't necessarily the most efficient strategy for buildings of heights below 150 to 200 meters, unless they have a wide horizontal footprint. Given this parameter, the first survey included buildings only 200 meters or more in height, while the second survey included buildings of 150 meters and above.

Since the second survey investigated the topic from a design-oriented perspective, buildings of lower heights were included. This was also helpful in evaluating the market opportunity for buildings with larger horizontal footprints that could use multidirectional and ropeless elevators to expand outwards.

Location

The second factor identified the locations where high-rise construction was most prevalent. Rates of tall building construction have been steadily increasing, with geographic trends changing over time. For example, skyscraper concentrations in the Middle East and China have rapidly overtaken North America. This trend is clearly demonstrated in data that shows the number of completed buildings organized by year in different regions (Tall Buildings in Numbers, 2018) (see Figure 4.1.3). For the second survey, Singapore was included given the recent sharp increase in vertical development in the city.

Building Function

The third parameter relates to building programming, a key factor in the evaluation of circulation strategies and vertical organization in tall building

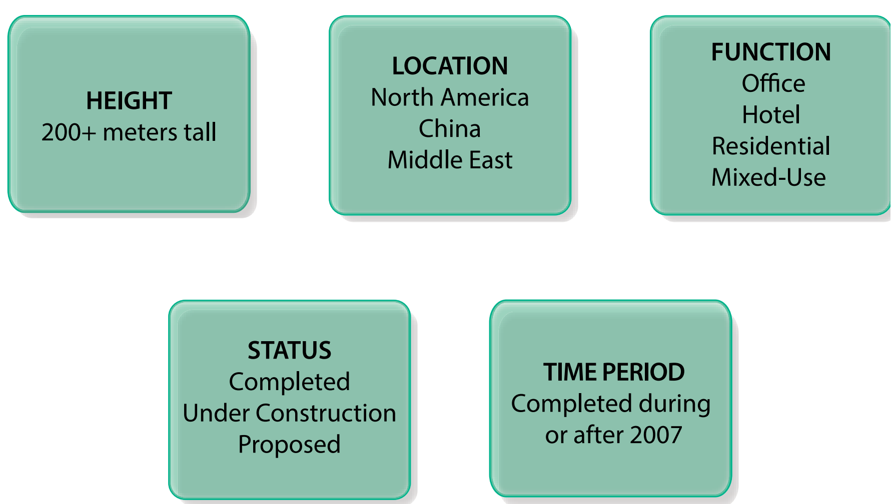

Figure 4.1.2. Five main parameters were established to filter data on The Skyscraper Center, including minimum height, location, building function, completion status and time period.

5.0 Design Considerations

As expressed in previous chapters, ropeless and multidirectional elevators could enable distinct urban design possibilities by freeing up building cores from their vertical format, increasing building height by reducing reliance on cables, and supporting efficient transit between buildings at height. Some buildings will adapt the new technology to function efficiently, but ultimately, new typologies will be made possible that present an evolution of the skyscraper's classic form. In both applying ropeless and multidirectional elevators to existing buildings and in creating new building types that respond to the changes in the elevator – as skyscrapers did in their nascence – design challenges should be anticipated and planned for. It is paramount that the tall building industry begin to establish some consensus on best practices for adapting their future designs to a ropeless and multidirectional elevator landscape (see Figure 5.0.1). Thus, this report seeks to explore key considerations for the adaptation of these types of transportation in any building typology.

Advancements in building transportation systems are made possible by the success and applicability of linear motor, multi-car solutions. These technological solutions will permit buildings to rise higher by freeing them from the restrictions of a vertical shaft, creating new typologies. Given that, this chapter will exclusively focus on the possibilities enabled by the application of ropeless and multidirectional elevator systems into tall building design.

Figure 5.0.1. When elevators were operated by permanent staff, directing people to the appropriate car was easy; now it is paramount to provide an intuitive user interface, particularly with the introduction of new elevator technology. © Gianluca Contran

The following design considerations were derived from simulations and theoretical models that were studied in Chapter 3. The intent is to present the full potential of these developing transportation systems and evaluate the effects that they will have on high-rise buildings and on the urban environment. Although this entire publication addresses designers, architects, and developers, this specific chapter invites them to begin thinking about the future implications of these new systems.

Due to the significant differences in the functioning and supporting equipment between rope-driven elevators and ropeless and/or multidirectional elevators, it is important to implement a system-wide analysis of building projects and how they may be affected by these technological innovations, including internal circulation and the organization of space.

5.1: Designing a New Circulation System

Free from ropes and counterweights and no longer limited to exclusively vertical motion, new elevator systems could drastically change how designers approach high-rises and urban planning.

Design considerations are divided into three different layout categories for clarity:

- **Core and lobby layout:** this section discusses floor plan configurations that could result from the use of a ropeless and multidirectional system. This includes a detailed description of several considerations to be taken into account during design.
- **Vertical layout:** this section presents different vertical organization and distribution systems derived from the application of ropeless and multidirectional systems, including an analysis of single and joined towers.
- **Horizontal connections:** the final section of this chapter explores the connections between buildings and other parts of the city. Currently, these connections are primarily pedestrian bridges between buildings that offer views and allow inhabitants the ability to travel between towers. With the

introduction of quicker travel between links due to horizontal elevators, there are many opportunities to increase the value of buildings and present opportunities to designers and developers to maximize new building typologies.

5.2: Core and Lobby Layout

Because the size of the service core and lobby configuration is tied to the quantity and size of elevator shafts, these design elements will be among the most profoundly impacted in tall building design by the introduction of ropeless and multidirectional elevators.

While current conventions indicate that at least 15–20% of the floor area of a skyscraper is dedicated to the core, ropeless and multidirectional loop configurations allow multiple elevator cars to travel within the same shaft, potentially reducing the size of the core (see Figure 5.2.1). While this result is financially advantageous as it may offer additional rentable area, it will ask structural designers to rethink conventional templates and approaches, considering that a substantial core has always been a major contributor to the structural integrity of tall buildings.

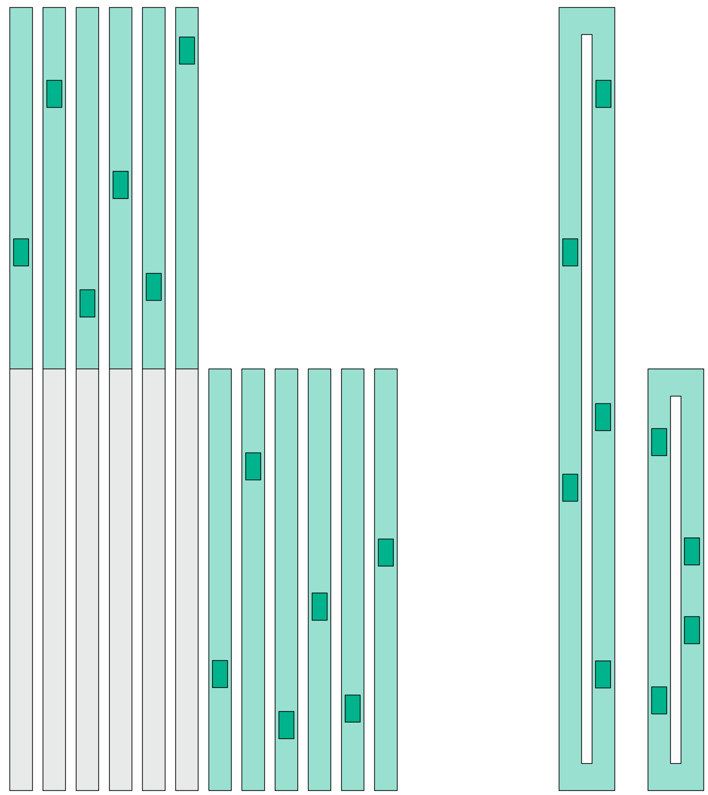

Figure 5.2.1 A comparison between a standard elevator system (left) and the space-optimizing capabilities of a ropeless and multidirectional system (right). © Michele Bettineschi

User Experience: Lobby

The core configuration is not the only aspect of building design that may change with the use of ropeless and multidirectional elevators; the user interface and order of operations may undergo a transformation, catalyzing a cascade of changes from the building's emergency evacuation plan and location of services, to signage plans.

Currently, the standard process for using an elevator is to enter the elevator bank, use a push-button panel to indicate if the user is going up or down, and wait for a cabin to arrive. When an elevator shaft emits a light or sound to indicate its arrival, the user can enter that cabin and select the desired floor. The cabin then moves through the shaft, which is generally exclusive to that individual cabin, until it reaches its destination (see Figure 5.2.2). When the users wait for the arrival of a cabin in the loading area, they can be confident that the first doors to open will bring them to their destination in the quickest manner.

With a ropeless and multidirectional elevator system, this process will undergo a change, and so expectations will have to be reestablished and reframed for passengers. Cabins will be able to travel along multiple routes, and the user can no longer expect the system to travel exclusively up or down. Cabins will even be able to travel simultaneously in the same shaft, but

Skyscrapers may be our most powerful tool in providing dense, energy-efficient living for a rapidly urbanizing population, but this typology faces certain limitations inherent to its traditional form, namely, the lack of interplay between tower, urban context, and community. Through a historical overview, case study analysis, and a series of design considerations, this report explores how ropeless and multidirectional elevator technologies can enable cities to be more interconnected, efficient, and accessible.

Running on a series of seamless loops, and powered by magnetic levitation, ropeless and multidirectional elevator cabins could follow a multiplicity of routes within a given building, not only reducing the quantity of shafts needed and increasing rentable area, but also allowing elevators more options in terms of where they stop across a building's dimensions. When paired with skybridges and "skyspaces," at-height services and communities could be easily linked with one another, bolstering the critical link between a piece of architecture and the urban sphere, while combating some of the insularity endemic to skyscrapers.

This Research Report is the product of two years of research by the CTBUH Research Office in Venice, CTBUH Staff, professionals in the field, and a research team of architecture and supporting academic advisors. It is part of a series of research reports that offer insight into specific areas of skyscraper research, offering a wealth of knowledge essential for industry professionals, academic researchers and all others interested in the relationship between skyscrapers and urban habitat.

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