

Ropeless Lift Feasibility Study

Your author believes they are infeasible at this point.

by Hongliang Liang

Key words: ChatGPT, MMLS (Multi-Mobile Lift System), Ropeless Lift, Counterweight-less Lift, Maglev, Linear Motor.

1. Introduction

In order to test ChatGPT, I asked it a question on April 4, 2023: Is a ropeless/counterweight-less elevator possible or not? The answer was:

“Yes, ropeless or counterweight-less elevators are possible, and they are already being developed and tested by companies such as TKE AG, Hitachi and others. These elevators use magnetic levitation [maglev] technology, similar to that used in high-speed trains, to lift and lower the elevator car. The elevator car is propelled by linear motors installed in the shaft walls, and the car moves horizontally to reach the desired floor. These elevators offer numerous advantages such as faster travel times, reduced energy consumption, and the ability to have multiple elevator cars moving in the same shaft at the same time. However, they are not yet widespread and will require significant infrastructure changes to existing buildings to install.”

1.1 Introducing TRIZ

TRIZ (from the Russian теория решения изобретательских задач) was developed by Soviet inventor and science-fiction author Genrich Altshuller (1926-1998) and his colleagues in 1946. In English, the name is typically rendered as “the theory of inventive problem solving,” and occasionally goes by the English acronym TIPS.

The basic principle of TRIZ is that a technical problem is defined by its contradictions. That is, if there are no contradictions, there are no problems.^[1]

1.2 Introducing Quality Function Deployment

Quality function deployment (QFD) is a method developed in Japan beginning in 1966 to help transform the voice of the customer into engineering characteristics for a product. Yoji Akao, the original developer, described QFD as a “method to transform qualitative user demands into quantitative parameters, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts and ultimately to specific elements of the manufacturing process.”^[2]

As function or quality will spend engineering resources, the designer should consider which functions are essential and which functions are negligible. The quality should be determined by reliability; it should be good enough to maintain a high reliability over a certain period.

For an example regarding quality: The shutter of a Japanese film camera had a 40K lifecycle, while the shutter of a German film camera had a 100K lifecycle. A roll of 35-mm film can be made into 40 shots, so a 40K lifecycle would cost 1,000 rolls of film; if an ordinary photographer took 100 rolls a year, the shutter of the camera would be able to last 10 years. So a 40K lifecycle is a reasonable specification, while 100K would be too long for ordinary photographers.

Another example regarding function: I bought a 28-in. color TV in 1997; the function Picture in Picture (PIP) was popular then. The 28-in. color TV with PIP had a price equal to one 28-in. color TV without PIP plus one 9-in. color TV. Actually, the PIP function is almost useless, but it was very expensive at that time. This meant: “The 9-in. icing on a 28-in. cake is more expensive than a 9-in. cake.” These kinds of costly functions should never be taken into account when we design and develop the products.

2. Background

I joined MovvéO Ltd. in June 2014 – the company was called Lerch Bates Europe at that time – and I was the design manager until May 2019. During that time, I was responsible for all detailed vertical-transportation (VT) designs by MovvéO.

My former boss Adrian Godwin had an electrical background. His conceptual VT designs had always been brilliant: His designs for lift control systems – traffic analysis application Adsimulo and mobile phone app AdInspect are still at the leading edge in the VT consultancy industry. Godwin created many innovative ideas in VT system design. His mechanical designs included “Skytrak” (multiple cars in one curved hoistway), a concept that won the International Association of Elevator Engineers (IAEE) inaugural prize for “High-Tech” Innovation in 2010. This and other ideas, especially the ropeless “Vertrak” with multiple cars in one vertical hoistway (similar to TKE Elevator’s MULTI but with a different mechanism) were very difficult (or impossible) to realize, as he underestimated the technical complexity and overestimated the market demand.

Godwin was not able to use computer-aided design, while I am a professional mechanical engineer with an MSc degree in engineering design and engineering design management; I am also a good electrical engineer: The result of self-learning in China. It is possible for a mechanical engineer to gain electrical knowledge at home or at work, as such knowledge is based on logical thinking in mathematics and physics, as well as the understanding of advanced theories, but not vice-versa, as mechanical design skills and knowledge would be mainly based on special training in the college/university setting and

practical experiences. I don't believe self-learning from home could train a good mechanical engineer or designer.

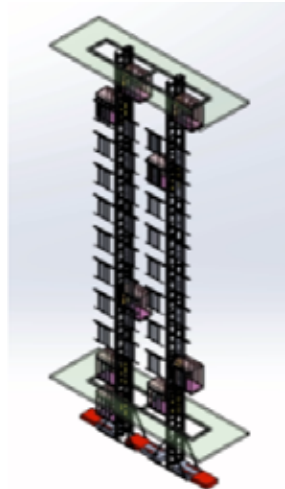
There are some differences between Godwin and me, as I believe the key to engineering design is to well-deploy the function and qualities following QFD, so I always use well-established technology to modify existing standard products, instead of creating a new product. I also focus on mid-range products rather than top-range, because the mid-range products are always in the greatest demand and have the biggest margin in the market. As consultants, we should use our experience and well-known/well-established technology to help our clients achieve success.

Although I have never done any research or design in ropeless lifts, Adrian and his father, Michael Godwin, often requested (not required) me to create drawings for their research of ropeless lifts. I always agreed to the request and did the drawings without saying anything or showing any reluctance. To be honest, I hate those designs so much: Firstly, I didn't think the mechanism would work; and secondly, they had never taken any advice from me.

But Adrian had to rely on me to create the drawings. I just followed his instruction to work as draftsman without saying anything. He had always been very satisfied with my drawings. I even made a 3D animation demo of the Vertrack ropeless lift for him (Figure 4).

3. Adrian Godwin's Ropeless Lift Design

3.1 Value Generation



Sky lobby at +1000m (250 floors @ 4m) above-ground with population of 2,000. Target 16.8% 5-min "up peak" HC.

Conventional double deck lift solution is 8 double deck lifts 1600kg @ 12.0m/s. There would be a car available every 30s but... we cannot make the 1000m travel with conventional lift technology.

Vertrak 5 min. Handling Capacity (HC) = $0.8 \times 21 \times 10^3 = 168$ persons per pair of shafts

With two Vertrak systems (4 shafts) the required HC is met.

There would be a car available every 15s.

A simulation uses nine cars for each pair of adjacent lift shafts.

"Space take" of one shaft is ~ 10 sq m. Vertrak solution would save 250 floors @ 40 sq m or 10,000 sq m @, say, US\$5,000 per sq m, the equivalent of US\$50m of building value. [3]

Figure 4: Vertrack demo^[4]

3.2 Advantages of Multi Mobile Lift System (MMLS)^[4]

- ◆ MMLS provides 80% increase in 5-min HC to a destination 600 m above ground.
- ◆ Just one MMLS can give us an adequate "quality" of service of around 25 s.
- ◆ MMLS can give us the same handling capacity for destinations 60, 600 or 1,200 m above ground.
- ◆ MMLS has no requirement for high speed and, in fact, speed will only influence journey time.
- ◆ For hotels and/or residential facilities, the conventional solution loses handling capacity.



"VERTRAK is a "nick name" for a revolutionary and truly disruptive new product for the 150 year old elevator industry. VERTRAK will enable multiple cars to circulate up and down within two adjacent lift shafts dramatically reducing the space taken by elevators in tall buildings increasing both their development value and sustainability." [3]

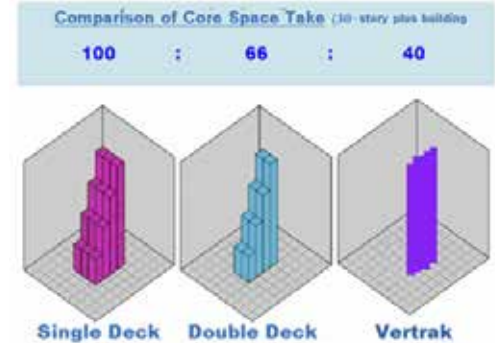


Figure 2: Space take comparison^[4]

Figure 1: Vertrack in building^[4]

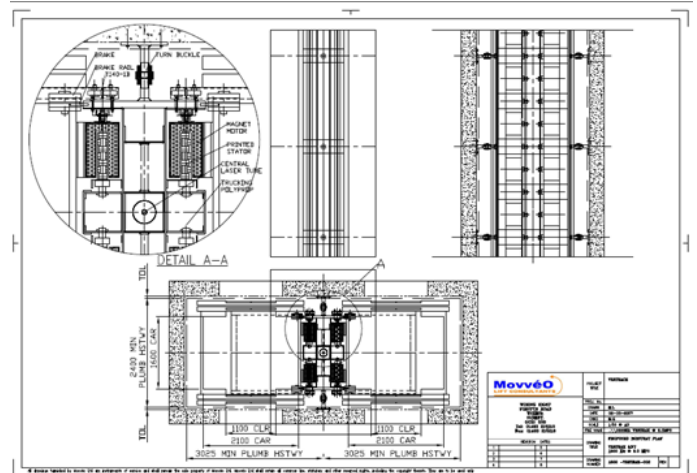


Figure 3: Vertrack general arrangement^[4]

50 floors	Apartments and Villas – average 120 sq m NIA. 20 apartments per floor with an average of 3 bedrooms = 60 persons per floor. Total population for zone = 3,000
50 floors	Offices – average 2,500 sq m NIA. One person per 10 sq m NIA. 20% reduction for absentees gives 200 persons per floor. Total population for zone = 10,000
50 floors	Hotels & Leisure – 40 floors of hotel @ 40 sq m NIA/room. 60 rooms per floor @ 2 persons = 120 persons per floor. Total population for zone = 4,800 plus 1,200 for leisure and health facilities on 10 floors.
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Table 1: Stacking use of a 1,000-m tall building^[3]

- ◆ MMLS has equally high handling capacity in both directions with no degradation in 5-min HC.
- ◆ MMLS also offers the prospect of being able to interconnect between multiple sky lobbies.

3.3 Adrian Godwin's Conclusions^[3]

- ◆ MMLS makes a 1,000-m tall building viable.

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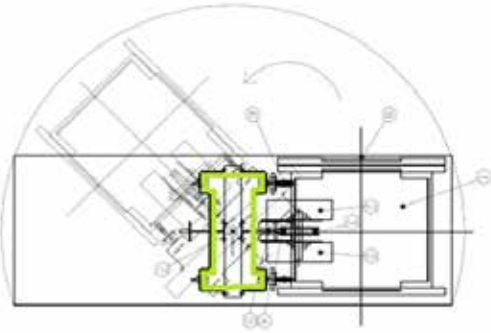


Figure 5: Vertrack working principle^[4]

minimize the number of stops, as a result, the waiting time would be longer, but the travel time will be much shorter.”

ChatGPT’s answer:

“The MULTI system was designed to operate without ropes, using linear motors and magnetic levitation technology to move elevator cars vertically and horizontally. This innovative design allowed for multiple elevator cars to operate in a single shaft, increasing the capacity and efficiency of the system. According to TKE, the MULTI system had a maximum capacity of 1000 kg (or approximately 13 people) per elevator car, and a maximum speed of 5 m/s. However, it’s worth noting that the actual capacity and speed of the system could vary depending on

1. Segmentation	2. Extraction	3. Local Quality	4. Asymmetry
5. Consolidation	6. Universality	7. Nesting	8. Counterweight
9. Prior Counteraction	10. Prior Action	11. Cushion in Advance	12. Equipotentiality
13. Do It in Reverse	14. Spheroidicity	15. Dynamicity	16. Partial or Excessive Action
17. Transition into a New Dimension	18. Mechanical Vibration	19. Periodic Action	20. Continuity of Useful Action
21. Rushing Through	22. Convert Harm into Benefit	23. Feedback	24. Mediator
25. Self-Service	26. Copying	27. Dispose	28. Replacement of Mechanical System
29. Pneumatic or Hydraulic Constructions	30. Flexible Membranes or Thin Films	31. Porous Material	32. Changing the Color
33. Homogeneity	34. Rejecting and Regenerating Parts	35. Transformation of Properties	36. Phase Transition
37. Thermal Expansion	38. Accelerated Oxidation	39. Inert Environment	40. Composite Materials

Table 2: The 40 TRIZ principles of invention

- ◆ MMLS offers building efficiencies of 75%-plus.
- ◆ MMLS enables sustainable megatall buildings.
- ◆ Traffic simulation capabilities for MMLS are required.
- ◆ Strategies for fire, goods and waste are required.

Godwin assumed the maximum speed of his ropeless lift is 4.0 m/s and the building height is minimum 1,000 m. So, the waiting time can meet the criteria. Adrian intentionally or unintentionally ignored the travel time to the destinations, even if the speed of the car could be 4 m/s and the travel time from the bottom floor to the top floor of the 1,000-m building would be longer than 250 s (4 min and 10 s).

When the speed is 2.5 m/s, the travel time from the bottom floor to the top floor of the 1,000-m building would be longer than 400 s (6 min and 40 s).

The situation is similar to a customer inquiry in the past: “The conventional control has shorter waiting time than destination control. Why did you recommend destination control to us?” My answer was:

“Because the conventional control moves the queue from the lift main lobby into the lift cars so the waiting time will be shorter, but the travel time to destination will become unbearably long as the car may stop at every floor. Destination control needs longer time to group the passengers, so as to

factors such as the number of elevator cars in operation and the specific installation environment.”

I think a 1000-kg capacity is possible, because the MULTI system has a wider car than Vertrack’s deep car, but a maximum speed of 5 m/s would be impossible.

4. Five Principles To Evaluate Invention or Design

Your author believes experienced people know what cannot be done rather than what can be done. Meanwhile, technical measures are always the last resort to solve a technical problem. Before that, QFD should be taken into account. Therefore, following the principles of TRIZ and QFD, the author has summarized five principles to evaluate design or invention:

4.1. The Design/Invention Must Not Have Unsolved Fundamental Contradictions Left.

E.g., low speed versus high-rise in the invention of ropeless lift. Linear motor self-weight versus high-rise 1,000-m-plus.

For the speed of the office lifts, a rule of thumb is that speed=travel m/20 s so that the passenger lifts should be able to travel from the bottom floor to the top floor with a few intermediate stops within 60 s.

For any lift, the minimum travel time from the bottom floor to the top floor should be within 60 s. If so, for the passenger lifts in a 1,000-m building (residential tower or hotel at the top stack), the speed shall be at least $1,000 \text{ m}/60 \text{ s} = 16.67 \text{ m/s}$.

4.2. The Design/Invention Must Not Disobey Any TRIZ

Principles of Invention.

Following Altshuller's insight, the theory of TRIZ developed on a foundation of extensive research covering hundreds of thousands of inventions across many different fields to produce a theory that defines generalizable patterns in the nature of inventive solutions and the distinguishing characteristics of the problems that these inventions have overcome.^[1]

If any design is not following the TRIZ principle, it is very likely infeasible.

E.g., a high-rise elevator has no counterweight, but using a counterweight is one of the 40 TRIZ principles for hoisting equipment (Table 2).

A counterweight has the following functions:

- ◆ Compensates for the weight of an object by combining it with another object that provides a lifting force.
- ◆ Compensates for the weight of an object with aerodynamic or hydrodynamic forces influenced by the outside environment.

ChatGPT:

"The maximum acceleration of the Shanghai maglev train is about 1.5 m/s^2 (4.9 ft/s^2) and it can reach a top speed of 430 km/h (267 mph) in 4 min."

$A=F/M$, for ropeless lift $a=[F-g*(P+Q)]/M$, as $M=P+Q$, so without CTW, $F=a*(P+Q)+g*(P+Q)=(g+a)*(P+Q)=(9.8+1)*(P+Q)$,

Where F =driving force, A =acceleration, P =passenger weight in kg, Q =car weight in kg, g =gravitation acceleration.

Acceleration should be at least 1 m/s^2 for a high-rise lift, so the driving force per kilograms mass of a ropeless lift will be $10.8/1.5=7.2$ times that of a maglev train. This is why, for lifting equipment, a counterweight will be needed. For a maglev train, this is $F=a*(P+Q)+ Fr$ (Fr =resistance force). From here, it can be seen, a maglev train is able to work horizontally, but it is not so easy for it to work vertically.

In addition to the above mentioned, the maglev train will only have two stations and one stop per journey (the Shanghai Airport maglev train) or a few stops (the maglev train project between Tokyo and Osaka in Japan has nine stations and eight stops per journey), while the lifts in a 1,000-m building will serve 250 floors, which means 249 potential stops. Frequent acceleration and deceleration will cause other, even bigger, issues. As a result, the idea of the maglev train will not work with a ropeless lift. So, using the concept of a maglev train to build a ropeless lift is inappropriate.

4.3. "The Icing Shall Never Be More Expensive Than the Cake."

E.g., a ropeless lift will be more expensive than the low-rise building where the lift may be installed. A maglev train is a part of the infrastructure of a city or a country, so it may be possible for a mega city or a country to build a maglev train, but for a low-rise building to install a ropeless lift is unrealistic.

ChatGPT:

"The cost of building a maglev train system varies depending on various factors such as the distance to be covered, terrain, design, materials used and other factors. The construction of the first commercial maglev train in China, the Shanghai maglev train, cost approximately US\$1.2 billion for 30 km (US\$40,000 per meter one way). The proposed maglev train project between Tokyo and Osaka in Japan is expected to cost around US\$100 billion for 285.6 km. The cost of building a maglev train system is usually higher than that of a traditional high-speed rail due to the technology involved. However, the increased speed and efficiency of maglev trains may result in a significant reduction of operating costs over time. But the maglev train is for public transportation as the infrastructure in a city or in a country. The investment would be able to be paid back in the future."

4.4. A Single Breakdown in a Subsystem Shall Never Cause a Systematic Failure.

E.g., one of the ropeless lift's multi cars breaks down in a one-way single shaft. An additional issue relevant to rescue must be taken into account, which is inaccessible to the lift car when the lift is broken down in the sky.



BBC NEWS Tuesday, 18 October 2005: Council boss trapped in Spinnaker Tower. A man was trapped in the lift of Portsmouth's Spinnaker Tower for more than an hour - on the day the troubled structure finally opened to the public.

Figure 6: Rescue in the sky (Picture from BBC).

4.5. Never Challenging the Limitation; Any Mechanical Product Has a Physical Limitation.

When a device is approaching the limitation, the outcome is not proportionate to the input. If so, the concept will need to be changed. For example, if 1,000-m is the limitation of the building height, I would rather accept 800 m as the maximum, as the cost of two 800-m buildings with double the usable area may be less than a single 1,000-m building.

The ropeless lift will be similar, with a 1:1 (roping) cantilever machine-room-less (MRL) lift car without counterweight.

ChatGPT:

"In general, the maximum speed of a 1000 kg cantilever-style elevator is typically around 2.5 to 3 m/s. However, this can vary depending on several factors, including the height of the elevator shaft, the capacity of the motor and the safety features incorporated into the elevator system. It is always important to follow the manufacturer's guidelines and local safety regulations when operating an elevator to ensure safe and reliable performance."

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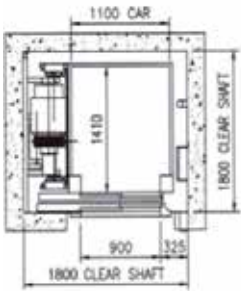


Figure 7: 1:1 Cantilever MRL lift plan view

The MRL lift with 1:1 cantilever roping, the design was expensive and poorly engineered; nor was it good for capacity above 1000 kg, as all the loads were taken by one wall on one side of the shaft. With this arrangement, the speed might be impossible to be greater than 2.0m/s, as I have never heard or seen such a lift has speed higher than that. For a 1:1 machine room-less the PM motor will be fairly big, if without CTW the PM motor will be doubled in size.

TKE Aufzugswerke GmbH, which no longer exists, used to have a slogan: "We accept no limit."

But Steve Jobs said:

"My model for business is The Beatles. They were four guys who kept each other's kind of negative tendencies in check. They balanced each other, and the total was greater than the sum of the parts. That's how I see business: Great things in business are never done by one person. They're done by a team of people."

Similarly, my model for product development is Japanese QFD: Any part or component has average or above-average quality, but they balance each other, and the total performance is greater than the sum of the parts or the components.

5. Possibility of Ropeless lifts

As mentioned earlier, never challenge the limitation. When it is approaching the limitation, a new concept needs to be invented.

5.1 PM Motor Characteristics

$$T = BLR^2\pi RA = 2BA(\pi R^2L) = 2BAV$$

where T=torque (total), B=magnetic field strength, L=conductor length in the magnetic field, R=equivalent radius of the motor, and V=motor volume (motor equivalent section of X length).

Due to magnetic saturation, magnetic field strength cannot be increased infinitely. To increase torque, only two ways are available: increasing the motor's diameter and/or increasing the motor's length. That is why PM motors are usually made flat (skinny but with large diameter) to obtain the highest possible torque. Another purpose of a large-diameter rotator is to obtain a larger ratio between the rotator and driving sheave, as the torque is proportional to the square of the radius.^[5]

I believe the ropeless lift will have to have the PM motor in the car rather than driven by linear motors. As a result, the ropeless lift may only be in two styles:

5.2. Rack and Pinion

5.3 Friction Wheels on the Car

This Univator Drive Concept has two fundamental contradictions:

- ◆ Any point on the rod has the same velocity, but when the car is in acceleration or deceleration, every motor has a deferent rotary speed with each other.



Figure 08: Rack and Pinion

ChatGPT: "Generally, rack and pinion hoists can have a maximum capacity of several tons and can lift materials to heights of several hundred meters. For example, some popular models of rack and pinion hoists used in construction can lift loads up to 5,000 kg and travel at speeds of up to 80 m/min (1.33m/s) to heights of up to 500 meters."

1.3m/s might be the maximum speed of a rack and pinion device, which is too slow for high-rise ropeless lift.

Figure 8: Rack and pinion

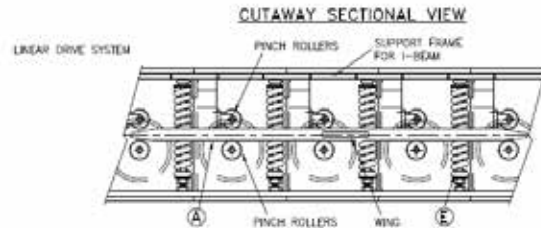


Figure 9: Industrial pinch roller drives^[4]



Figure 10: Adrian Godwin's "Univator" drive concept^[4]

- ◆ If the car travels on a curve, the curve shall have the same radius of curvature, as well as the rod.

In addition to the above two points, why is travel on a curve needed by the passengers? In which kind of buildings will it be required?

Univator is similar, with a curved friction wheel lift, but for the ropeless lift, the friction wheel should be mounted on the two sides of each lift car instead of the linear motors all the way up/down the one-way lift shafts.

7. Conclusions

- 1) I personally believe, under current circumstances, ropeless lifts are infeasible. Only if and when new materials occur, such as super magnetic, superconductor, super battery or super capacitor, the ropeless lift may be possible. If a very small – but very powerful – motor is invented in the future

Finally, I would like to share a quote of Steve Jobs with my colleagues who are still involved with ropeless lift development:



Figure 11: Adrian Godwin's "Univator"^[4]



Figure 12: Curved friction wheel lift^[6]



Figure 13: Friction wheels on a lift hill^[6]

and can be directly mounted on the cabin, then it would be possible to realize the ropeless lift. Just like the MRL lift, a way to locate a gearless PM motor directly in the shaft to eliminate the machine room as the result of the invention of the PM motor.

- 2) The power transmission will be via electricity. An electrical counterweight should be used on the device when the cabin is moving down or braking. The motor will generate electricity to be saved in the super battery or capacitor.
- 3) A wheel-less car is not the vehicle. It will be a hovercraft or aircraft, so the ropeless lift or counterweight-less lift may be just a kind of aircraft but has a name such as "airlift," which is similar to airbus, where airbus is not a bus.
- 4) Any mechanical product has its own physical limitation, such as "Trees don't grow to the sky," which is a German proverb that is translated from "Bäume wachsen nicht in den Himmel." Current building technology may not be able to build skyscrapers higher than 1,000 m because the self-weight may collapse the building itself.
- 5) Never challenge the limitation because the outcome is not in proportion with the input when approaching the limitation.



Figure 14: Horizontal friction wheels^[6]

8. Author's Note

Customer need is the biggest driver of innovation, but customer need is also driven by price-performance ratio (PPR) or return on investment (ROI). I oppose the idea of "for innovation

to innovate." Without a customer need, any innovation will be science fiction. This is why Elon Musk's SpaceX is successful, while British billionaire Sir Richard Branson's rocket company Virgin Orbit has filed for bankruptcy in the U.S. after failing to secure new investment.



Figure 15: Adrian Godwin Skytrak, award winning innovation^[3]

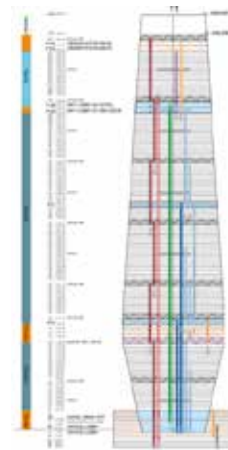


Figure 16: Adrian Godwin's concept design of an 800-m mixed-use tower^[4]

Steve Jobs:

"The ones who are crazy enough to think they can change the world are the ones that do", "Innovation distinguishes between a leader and a follower."

The innovations of ropeless lift from Adrian Godwin are used as case studies in this paper, although they were not as successful as his other VT designs. I highly admire his spirit and passion in innovation. He was my forever mentor and my hero, I am convinced that his contribution in VT system design in practice rather than in theory was second to none. Thus, this article is also dedicated to the memory of Adrian Godwin, chairman and sole owner of MovvéO Ltd, who passed away in 30th April 20119, with his passing, MovvéO Ltd ceased operations.

"Sometimes when you innovate, you make mistakes. It is best to admit them quickly and get on with improving your other innovations."

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Hongliang Liang graduated from Nanjing Architectural and Civil Engineering institute in China, majoring in hoisting transportation and construction machinery (1986-1990). He came to the U.K. in 2001 and obtained an MSc in engineering design and engineering design management at Huddersfield University in 2003. He has over 26 years' experience in VT, including 17 years in the lift and escalator industry. He launched his own business, Aliang Lift Design

Studio Ltd., in April 2020, providing survey/design for modernization and full replacement projects to lift suppliers and contractors along with VT consultancy, traffic analysis, VT system design, detailed design, tender negotiation for redevelopment and new development projects to engineers, VT consultants, architects and developers. He is a regular contributor to *China Elevator* and *ELEVATOR WORLD*.