"Skytrak" – An Elevator System for the 21st Century

Adrian M Godwin BSc DMS MCIM CEng MIET

Lerch Bates, United Kingdom

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Abstract

The dream of having more than two passenger elevators travelling in one lift shaft has been around for 50 years or more. This is because of the innate efficiency gains, especially for very tall buildings, that would follow such a quantum leap in passenger handling capacity.
"Skytrak" is a proposal for a radically new form of vertical transportation, in that it dispenses with suspension ropes and counterweights and, in the process, offers architects a completely new degree of freedom for transporting people around and between buildings.

Skytrak enables a new vision of what the live, work, play "green" communities of tomorrow might look like and, in addition, makes the 1,000m plus tall building much more of an efficient and practical proposition.
Skytrak's new space efficient approach to moving people uses linear motors and "retarders" to give vertical transportation its new found independence yet inherent safety. This paper explains the technical feasibility and opportunities that Skytrak would bring to vertical transportation.

1. BACKGROUND

The key task for the elevator consultant when planning elevator services for any building is to ensure that the design adopted represents the solution with the absolute minimum "space take" possible whilst respecting the agreed design criteria for the traffic handling performance of the system. Thus, typically, the design and specification of elevator systems for tall buildings is a complex process. This complexity is demonstrated by the fact that many elevator system designs already adopted in high rise buildings are considered sub-optimal.

Tall buildings often incorporate shuttle elevators that take people to one or more sky lobbies, from which local elevators take people on to their final destination providing additional complexity. Some of the more recent techniques adopted in addressing the design of elevator services in tall, often multi-use, buildings in order to minimize “space take” have included the following:

1. Use of “through” shuttle cars i.e. with front and rear openings, to allow close to simultaneous boarding and alighting of passengers and to enable use of different decks/entrances during different times of the day.
2. Use of double deck or TWIN ® lifts enabling two cars to operate in one shaft often combined with so-called “destination hall call” control systems.
3. “Time sharing” of the same elevators for different traffic types at different times of the day to achieve 24 hour utilisation.
4. Use of shuttle and local elevators both being double deck or TWIN ® type cars. This approach can also be adopted for service elevator design.
5. Use of so-called “expert systems” with elevator control system simulation capabilities able to identify optimum solutions quickly despite a huge range of variables being possible.

Simulation of elevator systems was first performed in the late 1970’s by Barney and Dos Santos (Barney and Dos Santos, 1977) in their pioneering work led by Mike Godwin. Around 1998 a PC-based simulation program was developed for general use by Peters (Peters, 1998). This program, called ELEVATE, enabled users to model individual groups of lifts within most types of buildings with associated elevator control systems and types of traffic.

In 2006 the author assembled a team which commenced work on a totally new simulation, visualisation, BIM output and expert system program. The new program nick-named "Adsimulo" would allow the building designer to look at multiple groups of elevators in operation in parallel, to analyse designs involving sky lobbies, double deck elevators with new so-called "destination" hall call control and, importantly, give output data and solutions that took account of building space taken as well as generate a complete 3-D Building Information Model of the proposed elevator services and enable visualization of passenger usage right through the building (see Figure 1).

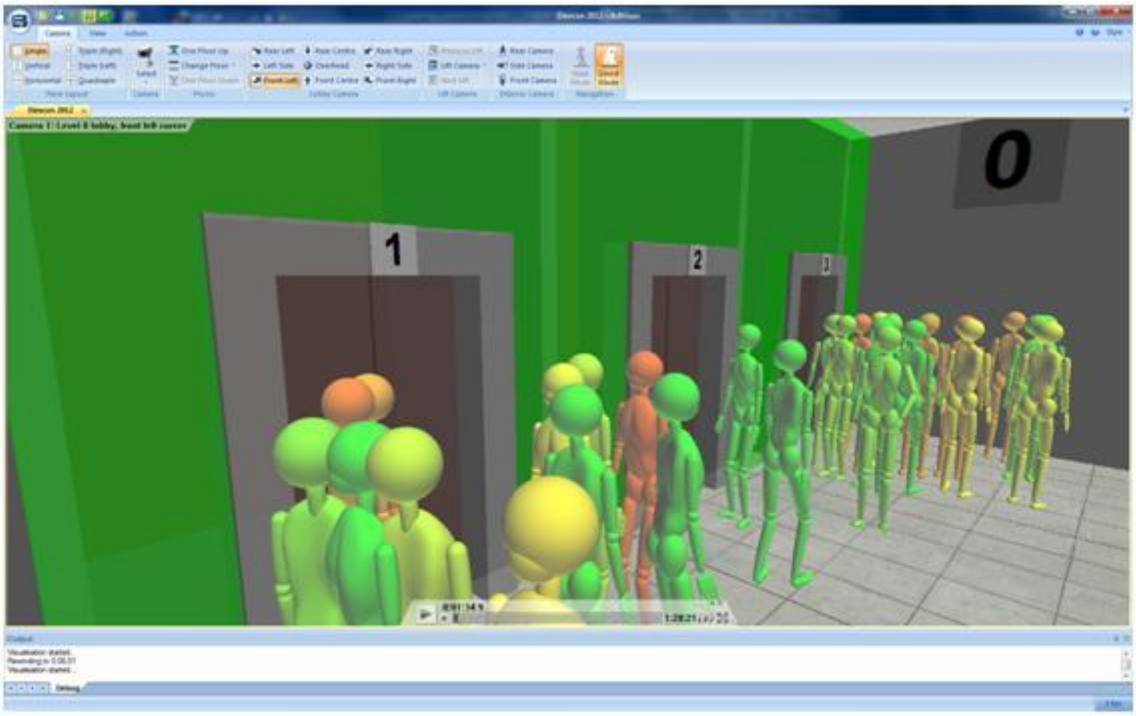


Figure 1: Lift Lobby Visualization with Passengers Colored according to Waiting Time

The Adsimulo “expert system” is an extension to the Adsimulo simulation program. It is designed to help the user find the optimum elevator solution for a building i.e. the solution that takes the least space out of the building but meets all the other design criteria set by the user. The hierarchy of the data held in the “expert system” consists of three layers:

- Building Information; includes number of floors, tenancy type on each floor, floor to floor heights, floor populations etc.
- Tenancy Information; each tenancy represents a functionally different part of the building e.g. residential tenancy, office tenancy etc. Tenancies are considered as independent facilities and passenger traffic between any two given tenancy types are not simulated. Because the type of lifts and their performance parameters can vary for each type of tenancy the data held with it also contains information about the range of acceptable car capacities, the type of control system to be adopted, target car passenger loading, the lift kinematic characteristics and door operating times, passenger transfer times, maximum transit times, lobby layout details and the traffic handling design criteria against which solutions must meet.
- Zone Information; the zones represent the groups of floors within a tenancy that are served by a single group of elevators. Each tenancy contains at least one zone. The building and tenancy information is provided by the user based upon building specification and the agreed design criteria to be adopted. Anybody with adequate knowledge of the tenancy requirements, likely lobby arrangements and target design criteria can enter this data via an input screen (see Figure 2).

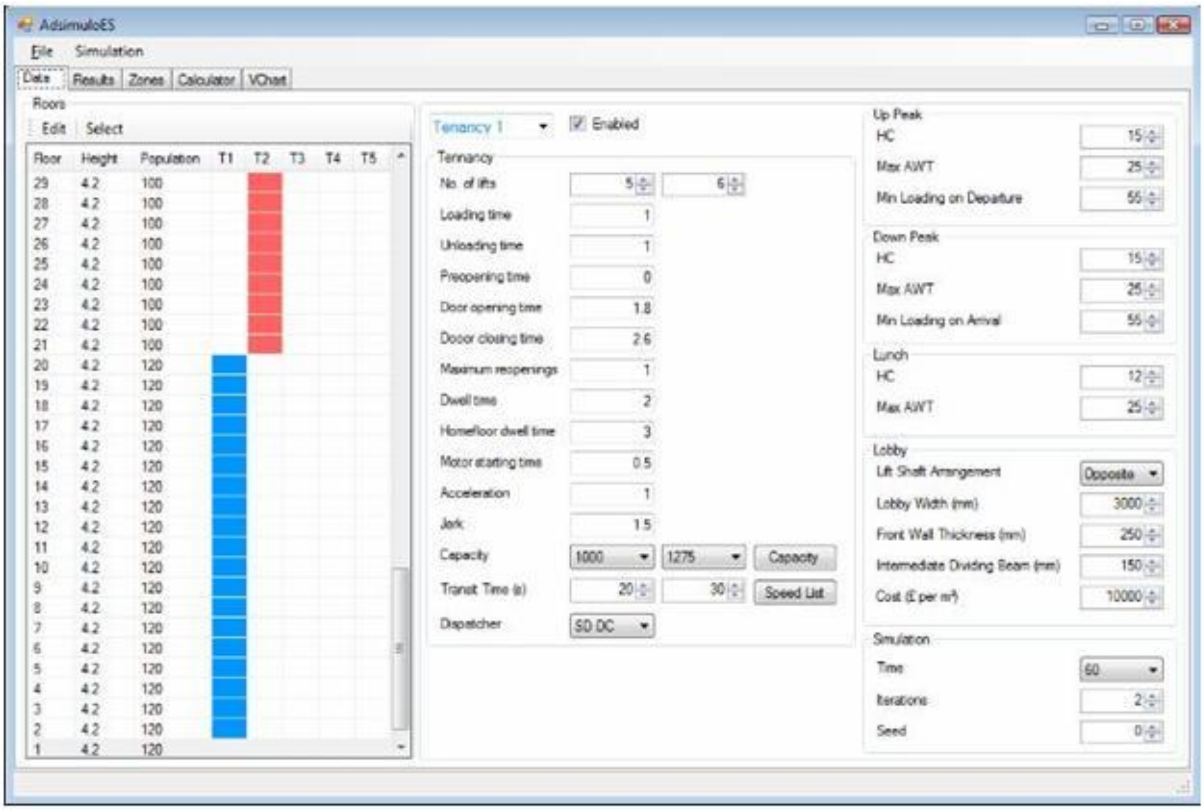
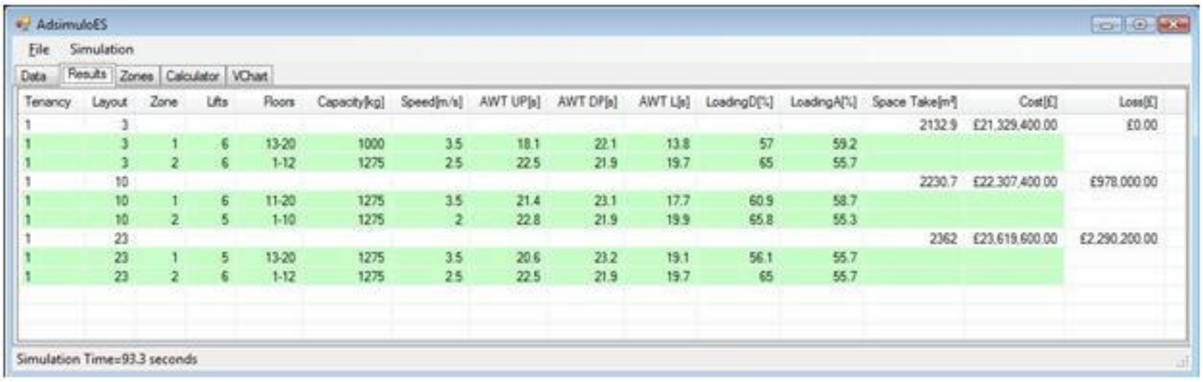


Figure 2: Expert System Input Screen

The “expertise” then invoked is in essence a “searching process” which is based upon a tree traversal algorithm and the elimination of those branches of the tree that cannot meet the target criteria. In the single processing step each possible combination of elevator group configuration and zone configuration is analyzed. Any given zone is expanded by increasing the number of floors served provided always that the elevator group analyzed still meets or exceeds the target design criteria set for the tenancy. This elimination process significantly reduces the potential number and type of solutions since only a relatively small subset of zones has to be simulated. Additionally, again to minimize the number of simulations to be conducted, the lift rated speed is optimized based upon travel and acceptable maximum transit time.

When the “searching process” is completed and all simulations have been performed, the tree of search results is converted into a list of zones representing different scenarios. Each scenario is automatically evaluated using the “space take cost function” which is calculated using the lobby and elevator shaft layout data.

The potential solutions that meet all the design criteria but also have the lowest space take are listed in descending order starting with the least space take i.e. the “best” solution at the top of the table (see Figure 3). Since the nominal value of each square meter of space is a user input field the output list informs the user how much more space and building value will be lost against the “best” solution by adopting an alternative.


AdsimuloES
File Simulation
Data | Results | Zones | Calculator | VChart

Tenancy	Layout	Zone	Lifts	Floors	Capacity[kg]	Speed[m/s]	AWT UP[s]	AWT DP[s]	AWT L[s]	LoadingD[%]	LoadingA[%]	Space Take[m²]	Cost[£]	Loss[£]
1	3											2132.9	£21,329,400.00	£0.00
1	3	1	6	13-20	1000	3.5	18.1	22.1	13.8	57	59.2			
1	3	2	6	1-12	1275	2.5	22.5	21.9	19.7	65	55.7			
1	10											2230.7	£22,307,400.00	£978,000.00
1	10	1	6	11-20	1275	3.5	21.4	23.1	17.7	60.9	58.7			
1	10	2	5	1-10	1275	2	22.8	21.9	19.9	65.8	55.3			
1	23											2362	£23,619,600.00	£2,290,200.00
1	23	1	5	13-20	1275	3.5	20.6	23.2	19.1	56.1	55.7			
1	23	2	6	1-12	1275	2.5	22.5	21.9	19.7	65	55.7			

Simulation Time=93.3 seconds

Figure 3: Listing of “Best” Solutions by Space Take and Opportunity Cost

All of the above simply goes to confirm that we are very rapidly reaching the limits of efficiency and, indeed, speed of design in the application of elevator systems which have a maximum of two cars in one lift shaft. If we are going to make further substantial increases in efficiency of vertical transportation systems we need to be able to run more than two cars in one shaft and that, in turn, means cars must all move in one direction in one shaft and, in most cases, transfer into another shaft to reverse direction. It follows directly then that we must dispense with the traditional ropes and counter-weights.

2. REMOVING THE COUNTER-WEIGHT

It is only when one considers dispensing with the counter-weight that one realizes how heavily reliant upon this simple device the basic design of most traction elevators are. Some of the many advantages of the "beautiful" counter-weight include:

1. Minimising the energy input required to hoist a given load.
2. Minimising deceleration forces especially when "emergency" stops are made.
3. Displacing the local structural loads of the cabin, usually to high level.
4. Simplifying emergency release operations.
5. Smoothing of the passenger ride quality by virtue of the large masses adopted

To reinforce the many advantages of using a counter-weight let us imagine for a moment some of the many implications of removing it:

1. Probable increase in local shaft structural loads of approximately 6-7 times
2. Probable increase in drive motor power by approximately 6-7 times
3. Increase in energy losses of approximately 6-7 times
4. Transmission of power and data to/from the car without using trailing cables
5. Increase in the braking force required from the fail-safe brake
6. Manual release of the fail-safe brake for passenger release not practical
7. Serious problem of dealing with emergency stopping in either direction
8. Control of headway between cabins and capability to take cabins off the track when inoperative

3.0 APPLICATION OF LINEAR MOTORS

Once one moves beyond having just two cars in one shaft you are almost certainly talking about the application of linear motors along the entire length of travel of the cars that would be moving up or down each shaft in order to provide independent speed control of each car. That said, today, most of the key components necessary have been identified and are available at commercially viable costs. Examples are:

- Linear Motors – Retarders - Generators
- Rare Earth Permanent Magnets, Super Capacitors (rare earth materials can be in short supply)
- Power Inverters and Fast Response High Efficiency Sensor-less Drives
- Control Software and Data-logging
- Security and Monitoring Systems
- Transportation Control Software (SIL4 Processors)
- Wireless Signalling and Communications
- Lightweight Materials for Cabin Structure

One of the keys to commercial realization is the form of the linear motor itself that must have a high "power to weight ratio" and be simple and relatively inexpensive to mass produce per meter length. All the above areas of technology are well advanced and at a stage of development suitable for the proposed application. There remain however four key challenges to be overcome by any multi car system. These are as follows;

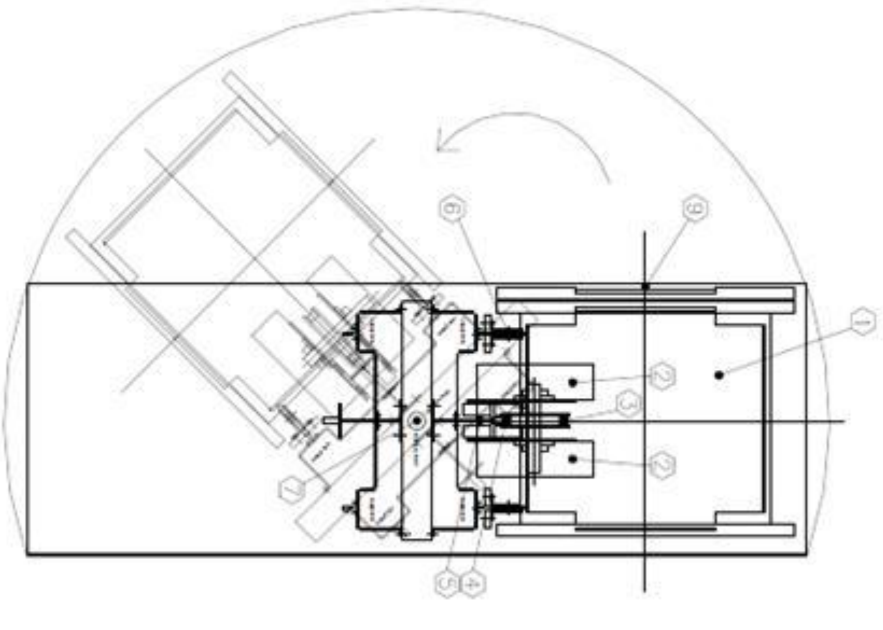
1. Avoidance of passenger trappings due to power failure
2. High speed stop in the "up" direction
3. Efficient "switching" of cars between shafts
4. Minimising power input and losses

The attraction of "Skytrak" is that it adequately addresses all of the above challenges enabling multiple cars to circulate in adjacent "up" and "down" lift shafts thereby providing a quantum leap in passenger handling capacity. It could also do this without the mechanical complexity of moving cabins on and off the track upon which they are normally travelling.

4.0 "SKYTRAK" DESIGN

The starting point for the design is to utilize conventional elevator shaft dimensions, construction and design with minimal modifications. The fire certified elevator entrances and landing doors are also retained. The passenger interface and the car interiors will appear indistinguishable to conventional elevators for the user. The structure of the cars themselves however would be made of lightweight composite materials. The design utilizes pairs of adjacent elevator shafts for it's operation. Between each pair of shafts is a central track structure or spine that carries the cars travelling in both shafts (see Figure 4).

Figure 4: Plan Layout on Adjacent Up/Down Lift Shafts and Novel "Switch"



The cars are cantilevered away from the central track. Each car has front and rear entrances which are used alternately depending on whether the car is travelling in the “up” or “down” shaft. The plan space taken by each lift car is equivalent to a conventional 1600kg/21 person car with a side counter-weight.

The plan layout also depicts the design of the novel “switch” that enables cars to be “switched” from the “up” to the “down” shaft and vice versa. This means that each car is never actually taken off its track removing complex mechanical handling devices which often cause noise, delay and unreliability. Once the car is safely in position on the portion of track forming the switch, the track section is rotated through 180 degrees until it aligns with the track in the adjacent shaft. The car can then drive off safely and another can be loading on to the track on the reverse thereby speeding the throughput of cars between adjacent shafts. The complete operation to move between “up” and “down” tracks is estimated at substantially less than 30s so that the typical headway between cars is maintained. In addition to the switches at each end of the travel there are servicing/parking bays beyond the switch enabling cars to be either parked off-line when there is little or no demand or to be serviced or cleaned etc.

The central spine track (see Figure 5) consists of a series of steel sections upon which are mounted twin linear motor stators, the guide rails and the power inverters together with power and data distribution. Also visible are the twin failsafe brakes which travel with each car and the large diameter roller guide shoes on the car running on T section guide rails. An “actuator” is also shown on each car assembly which provides for acceptable deceleration of the car in the event of high speed “up stopping”.

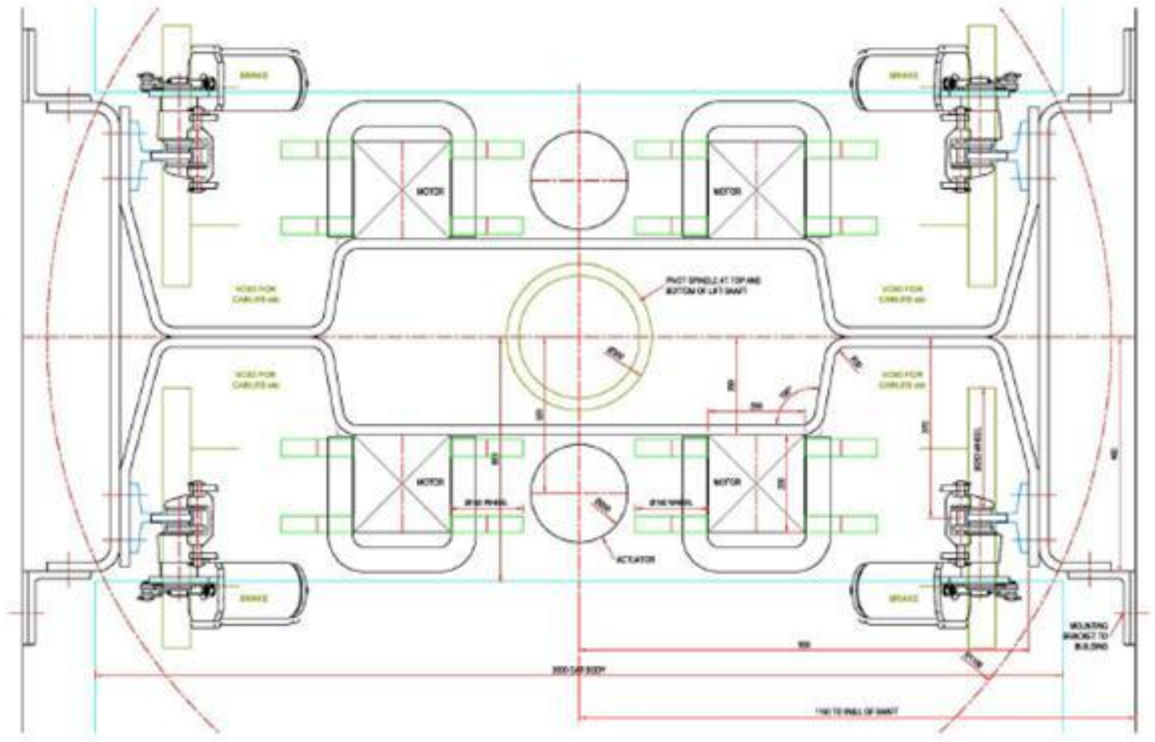


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Figure 5: Plan Layout on Central Track Structure with Pivot

It is envisaged that each section of track would be around typical floor height of approximately 4m. Each section can be factory assembled and tested prior to shipping and then hoisted and bolted into place as they are stacked one upon the next. This would almost certainly ensure faster erection times than with conventional guide rail installation. It is also possible that single cars could be placed into service to serve a lower portion of the building e.g. for construction use prior to the entire travel and system being finally completed. Finally a special base section of the track is used to transmit structural loads to the building foundations and provides connection points for power and data.

Additional measures, not shown here, are used to mitigate against electrical losses overall and peak power input when cars accelerate upwards fully loaded.

5.0 QUANTUM INCREASE IN PASSENGER HANDLING

The nominal 5-minute handling capacity of one "Skytrak" system as proposed herein is very simple to calculate. Given a notional 30s average interval between car departures at the main lobby the number of persons that can be transported in a 5 minute period is 0.8 (80% car loading assumed) x 21 (21 person/1600kg capacity car) x 10 (car departures in 5 minutes or 300 seconds) = 168 persons. Further, it no longer matters what the vertical travel height is since the greater the travel the more advantageous the solution. Speeds can be kept relatively sedate making the obtaining of good ride quality easier subject only to acceptable passenger journey times. The existing limitations upon vertical travel for conventional electric traction lifts of about 600m are dispensed with at a stroke. "Skytrak" offers dramatic benefits during lunchtime or 2-way traffic as well since it can provide as much down traffic handling capacity as for up traffic.

Preliminary studies indicate that "Skytrak" technology, once delivered, will be capable of providing significant reductions in floor space take even within buildings of just 30 floors. The premium payable for the technology will be offset many times over by the reduced number of elevators, elevator shafts, machine rooms and structure related to conventional elevator installations and the additional space generated as a result. The approximate quantum decrease in space take compared with both single deck elevators is 60% and against double deck elevators is 26% (see Figure 6).

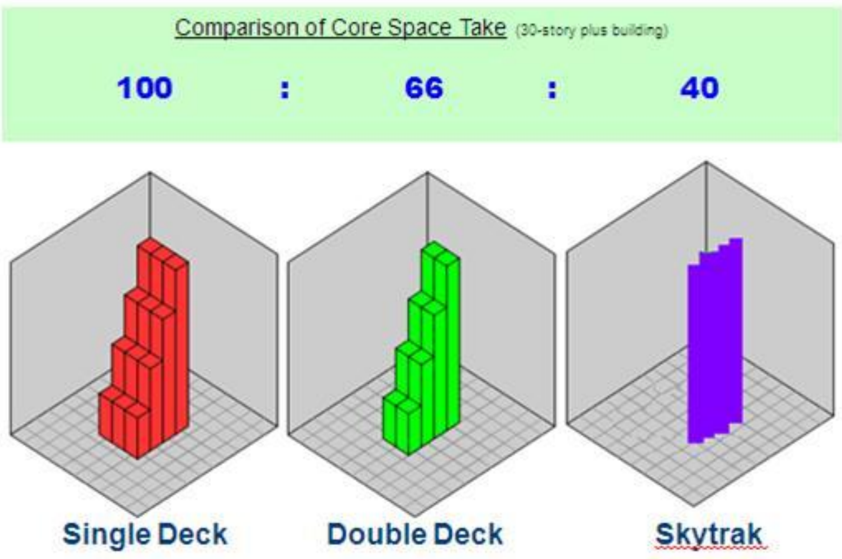

Figure 6: Comparison of Space Take for Types of Vertical Transportation

6.0 IMPACT ON TALL BUILDING DESIGN

As already discussed the an important advantage of Skytrak is the ability to service any upper floor in a 1km plus tall building direct from the ground floor. The most immediate impact of "Skytrak" would be in replacing high capacity double deck shuttle elevators serving upper sky lobbies.

Let's draw a simple analogy. Suppose we had an upper office sky lobby 1000m (250 floors @ 4m) above ground requiring access by up to 2,000 persons. Let's assume we require

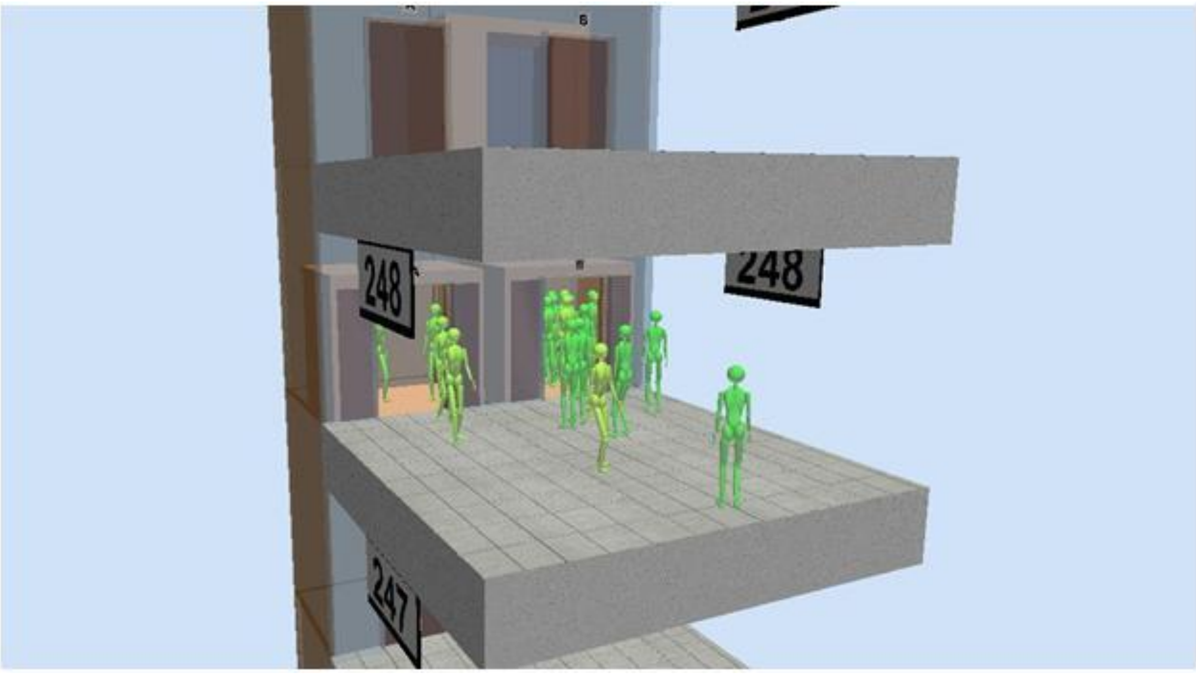

Figure 7: Simulation of Skytrak at Skylobby Floor 248 with Car Transferring Between Shafts at Floor 249 above.

16.8% 5-minute one-way "up peak" handling capacity (just to keep the numbers simple). From section 5.0 above we know that one pair of shafts can handle 168 persons per 5 minutes therefore we would need two pairs of shafts or four shafts in total with a "Skytrak" system. There would nominally be a car available every 15s. Such an arrangement has been simulated and utilizes nine cars shared between each pair of adjacent lift shafts (see Figures 7 and 8).

If we used conventional double deck lifts to provide the same handling capacity we would need eight double deck lifts @1600kg at a minimum contract speed of 12.0m/s. There would be a car available every 30s. Of course we know that we cannot make the 1000m travel with conventional lift technology but would have to do it in two stages.

With the space take of one elevator shaft being approximately 10 square meters the “Skytrak” solution would have the potential to save 250 floors @ 40 square meters or 10,000 square meters @, say, US$5,000 per square meter, the equivalent of adding back US$50m of building value.

Initial studies indicate that in “SuperTall” buildings the adoption of “Skytrak” could easily add more than US$100m of value to such buildings and radically change the development financial viability by dramatically reducing the “footprint” required by the elevator core.

Figure 8: Simulation of Skytrak depicting Multiple Cars in Each Shaft and Transfer of Cars Below Main Lobby

7.0 THE FUTURE

Once "Skytrak" has been proven in the context of its application to vertical transportation it is anticipated that it can be readily adapted to moving away from the vertical and finally giving architect's the new degree of freedom they have been seeking for the last 100 years!

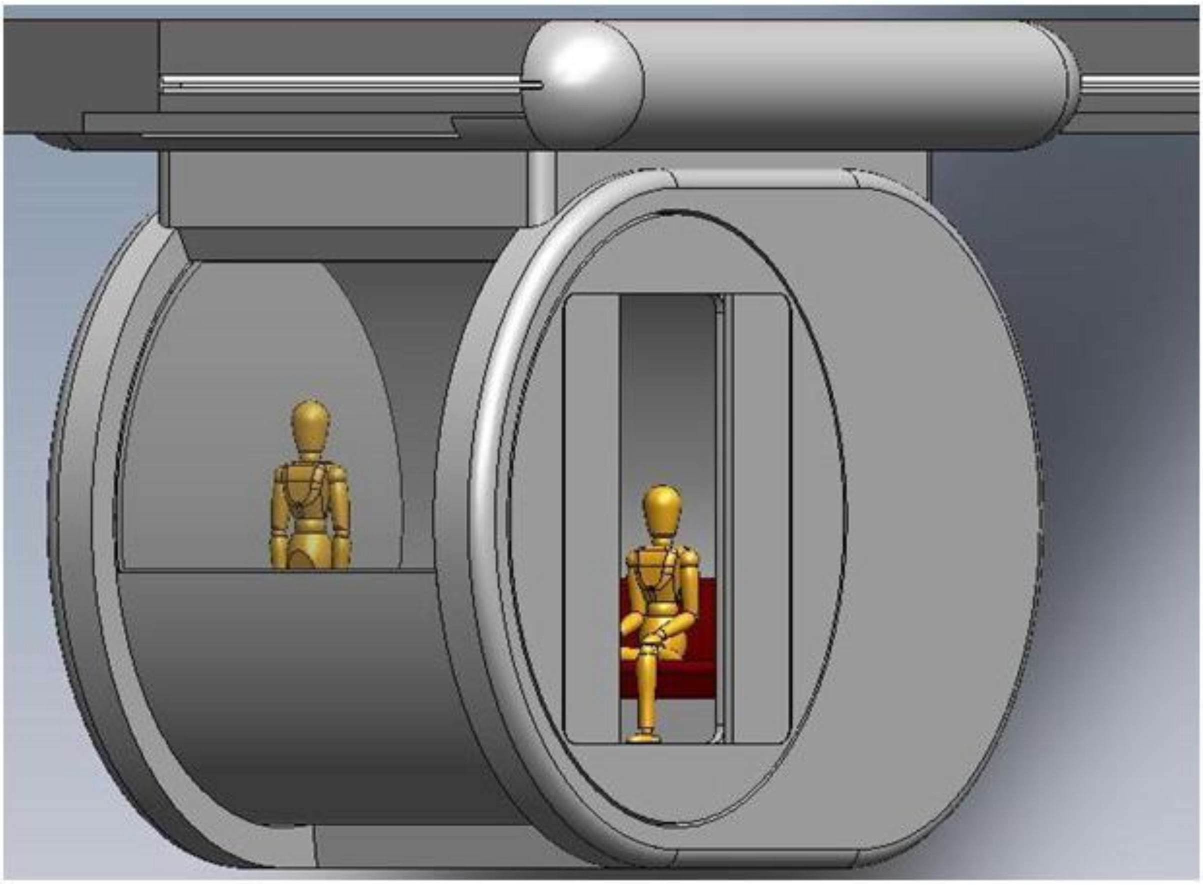

Figure 9: Visualization of Skytrak Rotating Cabin

The "Skytrak" cabin assembly (see Figure 9) is able to rotate as it travels thereby enabling curved trajectories to be negotiated safely and comfortably. The cabin assembly is designed to have an "all up weight" (including 1600kg of load capacity) not exceeding 3200kg. This means that composite materials have been used extensively and that all the "on board" components e.g. seating, cabin structure, battery pack, capacitor pack, overspeed monitoring device, inertia switch, tilt switch, TEC air conditioning, slewing and slip rings, wi-fi data connection, door operator, brakes and the cabin rotational drive have all been selected and designed for minimum weight.

Completely new types of building geometries would be feasible with the “Skytrak” technology (see Figure 10).

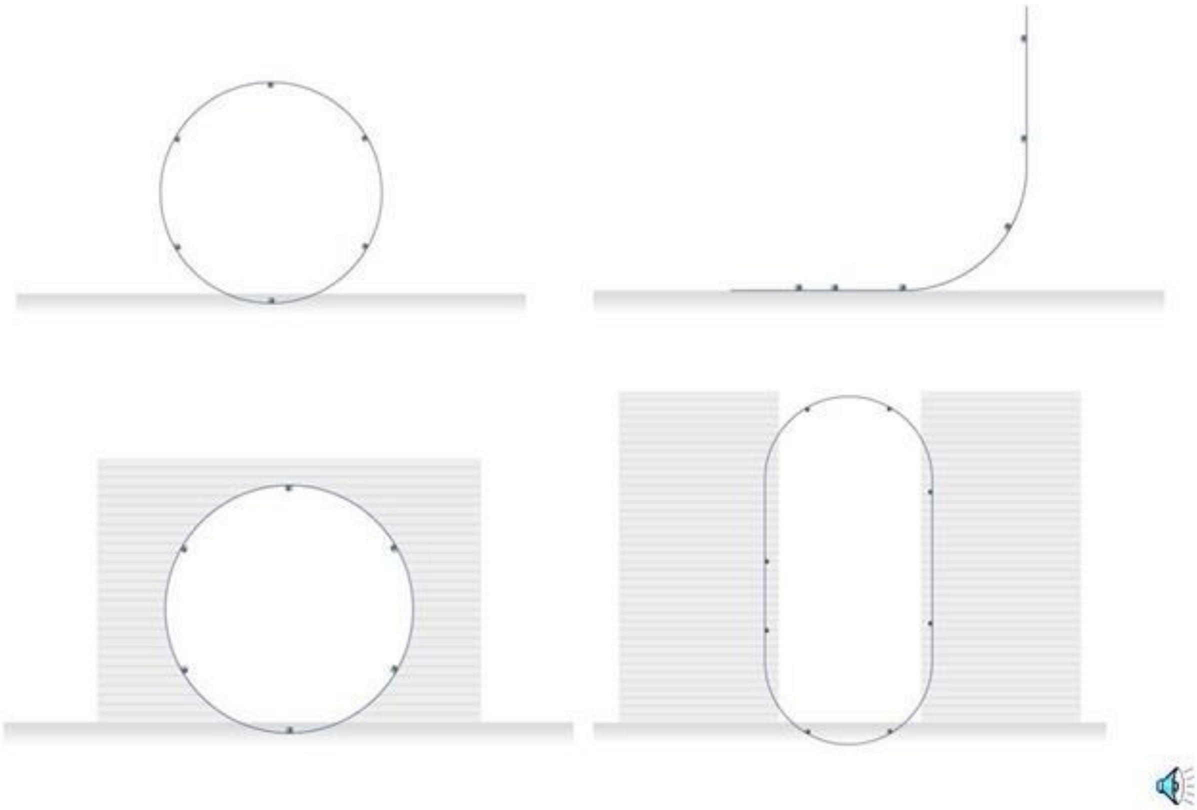

Figure 10: New Building Geometries Enabled by “Skytrak”

Finally, a recent South American Discovery Channel series featured “Skytrak” as a major influence upon the design and efficiency of buildings for the 21st century. A futuristic building enabled by “Skytrak” was featured in the documentary (see Figure 11). In summary, “Skytrak” holds out the promise not only of greater efficiency in building design but also of allowing architects a new opportunity to design and deliver completely new types of buildings.

Figure 11: Buildings of the Future as Featured on Discovery Channel