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Alternative Forms of Tall Building Evacuation

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Abstract

The terrorist attacks on, and consequential collapse of, the World Trade Centre towers on September 11th 2001 has resulted in, arguably, the largest single retrospective analysis of the design of tall buildings since the birth of the typology in the latter stages of the nineteenth century. All aspects of tall building design – safety systems, structure, façade materials, positioning, layout etc – have been called into question, and significant research has – and continues to be – undertaken in the quest to validate and improve the viability of the high rise. In terms of tall building evacuation, post 9/11 research and recommendations have tended to concentrate on the improvement of existing tall building systems – predominantly lifts and stairs. Whilst this work is vital towards making tall buildings safer, it is not enough. We need to tackle the problem at a more fundamental *design* level, not as an *alternative*, but in *addition* to the improved safety aspects of lifts and stairs. This paper briefly charts some of the 'alternative' evacuation propositions in the wake of 9/11 before focussing on the proposition of the horizontal link at height between tall buildings – the skybridge – and outlining the very real benefits they could bring to tall buildings.

1.0 Introduction

The safety aspect of tall buildings – both future proposals and existing high-rise stock around the world – has become of paramount importance, not only to tall building owners and developers (and thus, through extension, all professionals involved in the creation of tall buildings) but, as the collapse of Yamasaki's twin New York towers clearly portrayed, to both the inhabitants of tall buildings and the urban population at large.

Most of the international safety research in the wake of 9/11 has focussed on improving the following aspects of tall buildings:

- *structural systems*, especially with regard to progressive collapse,
- *fire proofing*, to structure, fabric and evacuation routes,
- *evacuation systems*, concentrating specifically on vertical evacuation systems such as elevators and stairs.

Whilst this work is vital towards making tall buildings safer, it is not enough. The risk to our cities is increasing – through terrorism, war, extreme environmental effects or accident as urban densities increase – and we need to tackle the problem at a more fundamental *design* level, not as an *alternative*, but in *addition* to the improved safety mechanisms suggested above.

2.0 Post 9/11 'Alternative' Evacuation Approaches.

Although most of the post-9/11 international evacuation research effort has been conducted in the field of elevators-for-evacuation and the improvement of existing systems such as fire stairs, it is worth noting that a number of individuals and small organisations have been conducting research into 'alternative' methods of tall building evacuation since 9/11. Much of this research shares a common root of stepping back from existing evacuation methods and approaching the problem from a conceptual design level.

Unfortunately, due to the conceptual design nature of many of the propositions, they have been met with almost universal scepticism from the larger professional safety community. In the case of the work of Jose Romano (Use of Facades in Emergency Exiting, in CTBUH, 2003) or Anshuman Khanna (The Inflatable Ejection Module, in CTBUH, 2003), which are both typical of these type of early ideas which emerged soon after 9/11 [see Figure 1], it is perhaps not difficult to understand why, when you compare these conceptual diagrams to the detailed technical analysis of elevators-for-evacuation, for example.

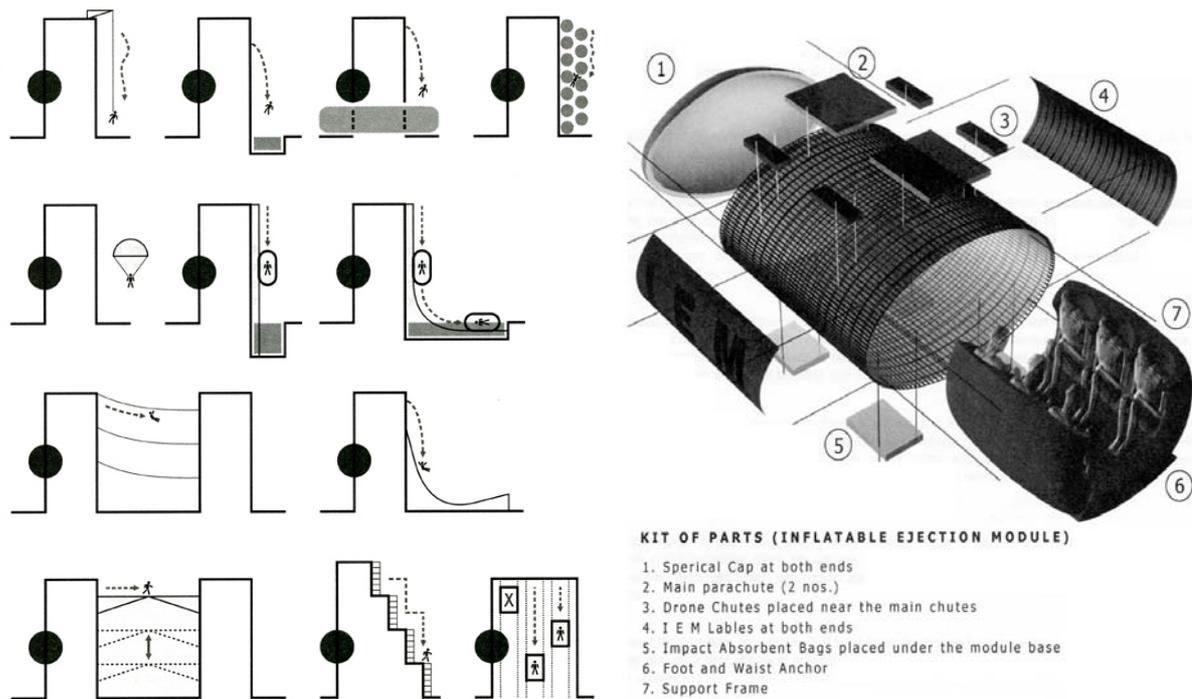


Figure 1: Post 9/11 'Alternative' evacuation concepts; (a) Use of facades in emergency exiting (source: Romano, in CTBUH, 2003, p.748), (b) Inflatable Ejection Module, (source: Khanna, in CTBUH, 2003, p. 743).

However perhaps the concept of 'alternative' evacuation options have been too readily dismissed, with several of the propositions holding real potential? Perhaps some of Romano's wilder propositions – such as jumping out of tall buildings into pools of water or a system of giant, inflatable exterior-facade balls – are perhaps a little far-fetched, but others – such as exterior chute devices or an abseil-type system – are maybe not so out of touch with reality.

This has been proven in small pockets of activity around the world where ideas have been taken from the conceptual plane and translated into reality. In South Korea, for example, hotel rooms at height are equipped with a box containing an abseil belt and descent line connected to the window wall, and a hammer to break glass in the event of emergency, for external abseil evacuation ¹ [see Figure 2a].

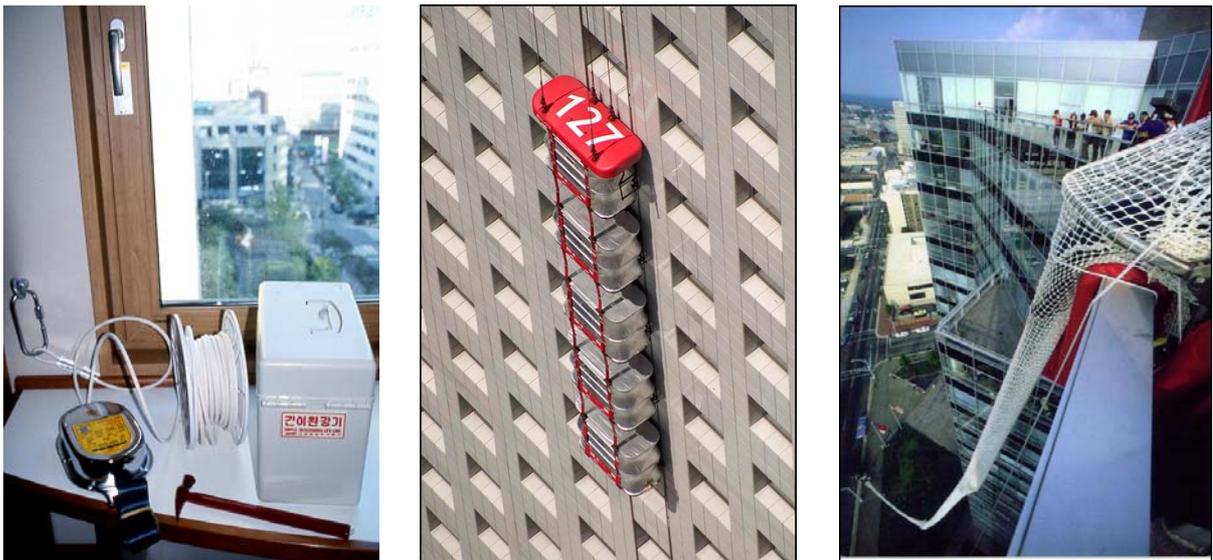


Figure 2 'Alternative' evacuation systems implemented (a) Typical hotel, South Korea – abseil belt and descent line (source: Author), (b) Platform Rescue System, by Escape Rescue Systems Ltd, (c) Escape Chute, by Escape Rescue Systems Ltd, (source for b & c: Shimshoni, 2005)

¹ It is necessary to point out that these 'alternative' evacuation methods are very much intended as secondary emergency systems in the unlikely event of the primary evacuation system (i.e. fire stairs) being compromised.

Perhaps the most convincing of these realised 'alternative' evacuation systems are those produced by Jonathan Shimshoni and his company *Escape Rescue Systems Ltd* in Israel (see Shimshoni, in CTBUH, 2005). A number of proprietary systems have been tested and are in operation in isolated instances around the world. The Platform Rescue System² is an enclosed set of platforms which move along guides on the exterior face of the building and can be either a permanent type (usually housed from view on the roof), or a mobile type brought by emergency responders arriving at the building [see Figure 2b]. The collapsible array of five platforms can evacuate 150 people from a number of floors at once through exit windows. When the array meets the ground, the lower platforms are concertinaed together as evacuees exit each level. This system also has the added benefit of providing an alternative route for emergency responders and their equipment to access the building.

Escape Rescue Systems' Escape Chute System [see Figure 2c] is a cylindrical or trough shaped device made of fire-resistant netting. There are two types of system; inclined and vertical. In the former system, the angle of inclination of the chute helps to slow down the speed of the evacuee, with a series of 'steps' inside the chute further slowing acceleration. In the vertical system, the cross-sectional area of the netted chute is small – evacuees slow themselves down by applying outward pressure with the feet, with the hands held above the head.

Despite these real examples of successful trial in countries such as Israel, they are very far from any form of acceptance or implementation on anything other than a small scale. Recommendation 20 of the NIST report then, made in 2005, is particularly heartening:

"NIST recommends that the full range of current and next generation evacuation technologies should be evaluated for future use, including protected/hardened elevators, exterior escape devices, and stairwell descent devices, which may allow all occupants an equal opportunity for evacuation and facilitate emergency response access".

Recommendation 20, (NIST, 2005).

3.0 The Skybridge for Evacuation

One method of improving the safety of tall buildings is by introducing horizontal evacuation at height through use of a *skybridge*³ linking towers. The concept of being able to evacuate occupants at a level other than ground, should the building be at risk, seems sensible, especially if any emergency in a tall building effectively cuts off connection to the ground plane.

The historical precedent of the skybridge – in both the built and theoretical realm – has already been disseminated by the author⁴ (see Wood, 2003). The intention in this paper is to concentrate on the potential evacuation benefits of the skybridge, using the Petronas Towers as the main case study:

3.1 Petronas Towers: An Evacuation Case Study

The 452-metre, 88-storey Petronas Towers in Kuala Lumpur, Malaysia⁵ – designed by Cesar Pelli Associates – contains perhaps the best known example internationally of a high-rise skybridge [see Figure 3]. The skybridge itself is two-storey in nature and connects the two towers at the 41st and 42nd floors. These levels make up a major 'skylobby' elevator change-over zone, where building occupants traversing the upper half of the tower change from low-zone to high-zone elevators. All visitors and staff requiring floors above the 42nd floor have to change elevators at this skylobby level. Due to the double-deck nature of the Petronas elevators (building users requiring odd-numbered floors throughout the tower access at the ground level, those requiring even-numbered floor access at a first floor mezzanine level), this skylobby also needs to occur across two levels – 41 and 42.

² First installation of the Platform Rescue System was in the 21-storey Ramat Gan tower in Israel in July 2004. The system is in an advanced process of certifying by TUV Munich (see Shimshoni, in CTBUH, 2005).

³ It is necessary here to define the terms of the skybridge. Generally speaking the author defines a skybridge as "a primarily-enclosed space linking two (or more) buildings at height". The important factors to note here are the terms (i) enclosed, (ii) linking between buildings, and (iii) at height. Thus, by definition, any 'open' bridges, bridges which do not connect between buildings (e.g. pedestrian over-road bridges which proliferate in most cities of the world) or low-level enclosed bridges (which are also present in many cities of the world) are not, for the purposes of this study, generally regarded as skybridges.

⁴ This includes over 20 built examples of skybridges internationally, including the 1922 Wrigley Building, Chicago; the 1960 National Congress Complex, Brasilia; the 1971 Kajimi Corp HQ, Osaka; the 1983 UN Plaza Hotel, New York; the 1993 Umeda Sky Building, Japan; the 1994 St. Lukes Tower, Tokyo; the 1995 Gemini Centre, Milan; the 1998 Petronas Towers, Kuala Lumpur; the 2001 Twin Towers, Vienna; the 2003 Highlight Towers, Munich; and the 2003 Marriott Apartments, Dubai. For more on these and other projects, see Wood, 2003.

⁵ The Petronas Towers held the title of the 'World's Tallest Building(s)' from their completion in 1996 until 2004 when they were overtaken by the 508-metre, 101-storey Taipei Financial Centre (Taipei 101) in Taiwan (currently still the world's tallest building, though works on site have started for the 600-plus metre Burj Dubai tower in Dubai, scheduled for completion in 2008/09).

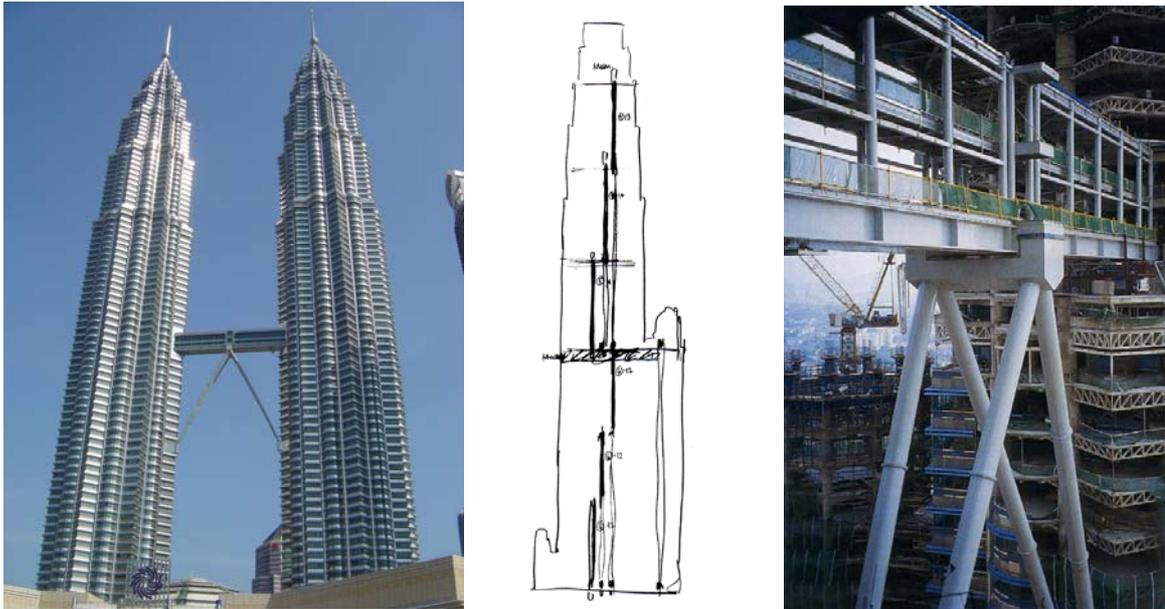


Figure 3: Petronas Towers Skybridge; (a) View of towers showing skybridge connecting at 41st & 42nd floor (source: author), (b) Lift zoning sketch diagram, showing 'skylobby' elevator change-over at 41st & 42nd floor levels (source: Pelli & Crosbie, 2001, p.114), (c) Double deck nature of skybridge (source: Pelli & Crosbie, 2001, p.54)

Whilst this skylobby zone contains large open spaces to facilitate circulation of the hundreds of people who pass through each day, it also contains many of the communal facilities shared between the two towers – the Conference Centre, the Upper Surau (prayer room) and the Executive Dining Room. Thus the skybridge's primary function, in non-emergency mode, is to facilitate circulation between the two towers for use of the shared facilities contained in each tower at that level. Operationally, Tower 1 houses the employees of the Petronas corporation, whereas Tower 2 is a multi-let office tower.

In terms of the evacuation provision in the Petronas Towers, each tower has two stairwells running vertically down the entire tower, located in the central mid-core. A third stairwell is located in the 'bustle'⁶ and serves floors 43 and below. Since Malaysian Building Codes are based largely on the British Regulations due to the country being a British colony for many years, two dedicated firefighter's lifts were required, which are also located in the mid-core, adjacent to the fire stairs. These fire-fighting lifts are used for emergency responder access and evacuation of the mobility impaired. The evacuation strategy for Petronas Towers is detailed below:

In the event of an emergency that is able to be contained on a single floor, a 'Stage 1 Evacuation' is mobilised (Ariff, 2003). In this scenario the occupants from that floor, the floor above and the floor below will vacate their floor and use the nearest fire stair to descend 3 floors (then deemed 'Temporary Refuge Floors'), where they await further instructions from the fire authorities. The floors above and below the three affected floors will be put on alert in case there is a need for further phased evacuation. No other normal building occupants will be informed of the incident. If the emergency is contained, the occupants can return to their floor areas via the passenger lifts.

Where a Stage 1 emergency is not able to be contained, a 'Stage 2 Evacuation' will be called where the whole tower is evacuated. Figure 4 illustrates this total building evacuation, in terms of 4 recognised zones:

- *Low Zone* (Level Ground to 37⁷); occupants evacuate down fire stairs to Ground level Concourse and immediately exit the building.
- *Middle Zone* (Level 40 to 60); occupants evacuate down fire stairs to level 41, cross over the lower floor of the skybridge and use shuttle elevators in the 'safe' tower to access Ground level Concourse, where they exit the building.
- *High Zone* (Level 61 to 77); occupants evacuate down fire stairs to level 42, cross over the higher floor of the skybridge and use shuttle elevators in the 'safe' tower to access Mezzanine level Concourse, where they exit the building.
- *Top Zone* (level 78 to 86); as with *High Zone*

⁶ The 'bustle' is the projecting circle of office space appended to the typical floorplan from levels ground up to 43.

⁷ Levels 38-39 are occupied by the mid-zone mechanical floor, with thus no ordinary populace.

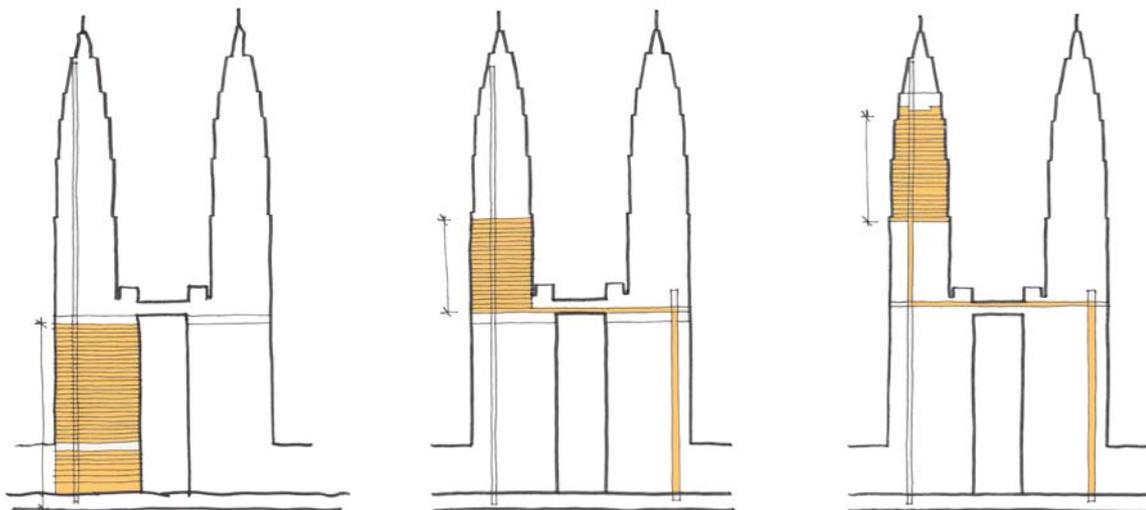


Figure 4: Use of the skybridge for different zones of the building for total evacuation of a single tower (a) low zone, (b) middle zone, (c) high zone (source: author, from interpretation of Ariff, 2003)

In full single building evacuation mode then, the skybridge becomes an integral part of the fire evacuation procedure⁸. The skybridge provides an alternative fire escape route for the approximately 50% of occupants in the upper half of the tower. Further, since these occupants are evacuating through a tower not at risk, they can use the elevators in the 'safe' tower, which greatly speeds up the evacuation process. To achieve this integration of the skybridge in the evacuation procedures, the skybridge itself had to be fire-rated. This meant pressurisation of the space (and adjoining sky-lobbies) to prevent smoke-ingress etc.

After the events of 9/11, the building managers of the Petronas towers reviewed their emergency response plans. In light of the imminent terrorist threat to tall buildings, a decision was made to expand on the current evacuation procedures as outlined above to enable the simultaneous evacuation of both towers at once. In this case the skybridge is effectively rendered unusable⁹ and the strategy below is adopted:

- *Low Zone* (Level Ground to 37); occupants evacuate down fire stairs to Ground level Concourse as in the single building Stage 2 evacuation.
- *Middle Zone* (Level 40 to 60); occupants descend down the fire stairs to level 41, where they use designated shuttle elevators in the same tower to access Ground level Concourse.
- *High Zone* (Level 61 to 77); occupants descend down the fire stairs to level 42, where they use designated shuttle elevators in the same tower to access Mezzanine level Concourse.
- *Top Zone* (level 78 to 86); as with *High Zone*

The obvious implication of the total evacuation of both towers simultaneously as outlined above is that elevators are used in the event of a fire, in the building at risk.

⁸ Though the skybridge contributes significantly to the evacuation efficiency of the towers, it was not originally conceived for that reason. Interestingly, however, an early design meeting for the Petronas Towers took place in New York on the day of the 1993 bombing of the World Trade Centre. According to the project architect for the towers, Lawrence Ng, this event helped focus the Petronas design team on the need for efficient life safety systems, and the fire evacuation potential of the skybridge (see Ng, 2003).

⁹ This, at least, was the theory. The simultaneous 'both building' evacuation drill that was conducted in the wake of 9/11 resulted in much confusion. The lack of information / education of the building occupants on evacuation procedures generally – and the procedures for the simultaneous evacuation of both towers specifically – led to many evacuees moving in opposite directions across the skybridge as they attempted to evacuate their respective tower. However, once the procedures were clarified, a further drill took just 32 minutes for a simultaneous evacuation of both towers (Ariff, 2003). It should be noted, however, that organised fire evacuation drills, especially where occupants are pre-warned and thus prepared, are not necessarily indicative of evacuation performance in real fire situations, where the lack of occupant preparedness and the impact of the fire itself (smoke etc) can have a significant bearing. In the wake of 9/11 the Canary Wharf group also initiated an evacuation drill of one of their towers, where 5469 occupants evacuated in just 20 minutes using elevators only (House of Commons, 2002). One cannot help but doubt that the same efficiency would be achieved in the confusion of a real emergency scenario. In the WTC 9/11 evacuation, the average surviving occupant spent approximately 48 seconds per floor to evacuate, approximately twice that observed in non-emergency evacuation drills (NIST, 2005, p.190).

One of the main positive side-effects of utilising the skybridge for evacuation in the Petronas Towers (other than significantly improving evacuation efficiency for the full evacuation of a single tower) is that it allowed the omission of an additional fire stair that would have been needed in each tower from the skylobby to the ground floor¹⁰. At an estimated fire-stair area of 18m² per floor, through 42 floors in two towers, this is a floor area saving of approximately 1512 m². At an approximated Kuala Lumpur office saleable floor area rate of US\$1613 per m², this is a saving of over US\$2.4 million. This, in purely space-saving terms, went a long way to financing the cost of the skybridge¹¹.

3.2 The Potential for skybridges in Hong Kong

Hong Kong has great potential for the incorporation of skybridges, due to a combination of the following three factors [see Figure 5]:

- (i) A high urban density, resulting in the presence of dense clusters of towers in very close proximity,
- (ii) A liberal, commercially-focussed environment which has enabled resolution of the significant ownership / public-private challenges posed by skybridges so that extensive networks of them are already in existence at a lower level within the Central – and other – districts,
- (iii) An evacuation code which requires 'Refuge Floors' as part of tower evacuation.



Figure 5; The high potential for the incorporation of skybridges at height in Hong Kong; (a) dense high-rise clusters with towers in close proximity (view of mid-levels from IFC2), (b) a liberal, commercially-focussed environment which has already seen many linked towers, (c) the presence of common-level 'refuge floors' in many of the towers (source: all by author).

Regulations governing the evacuation design of tall buildings in Hong Kong¹² dictate provision of specific 'refuge floors' in buildings over 25 floors in height. These refuge floors must be located every 20 floors in industrial-use tall buildings (a fairly common functional type in Hong Kong, though rare internationally) and every 25 floors in non-industrial use buildings. These refuge floors fulfil the following functions:

- a place of refuge within the building so that, in the event of a localised emergency in the building, the population at risk can be housed at the refuge floor for safety,
- a relief area for evacuating occupants to rest,
- a sub-base for fire-fighting purposes,

¹⁰ Although Pelli clearly states this on Page 10 of his book on the Petronas Towers (Pelli & Crosbie, 2001), significant doubt has been cast on the assertion from KLCC Management – the 'client' for, and operators of, the Petronas Towers.

¹¹ It should be noted that the author has drawn on a number of sources for this approximation. The fire-stair has been assumed at 3m x 6m as an external dimension. Financial data on typical Kuala Lumpur Saleable office floor rates was obtained from an extrapolation of information contained within the Knight Frank research report: "Real Estate Highlights. Kuala Lumpur. Second Half 2005" (Knight Frank, 2005). 2005 office sales for typical towers in the KL 'Golden Triangle' area in this report ranged from 347 - 482 Malaysian Ringgit per square foot. A higher saleable floor area rate of 550 Malaysian Ringgit per square foot for the more prestigious Petronas Towers, and an exchange rate of US\$1 = 3.67 Malaysian Ringgit, has been assumed (Note: 1 square metre = 10.764 square feet).

¹² "The Code of Practice for the Provision of Means of Escape in Case of Fire" (1996), published by the Government of Hong Kong Special Administrative Region.

- a command point for rescue personnel to assist orderly evacuation of the building,
- a place for mobility-impaired occupants to wait for assistance in being evacuated,
- a break to sub-divide / compartmentalise evacuation stairs vertically to reduce the possibility of smoke logged stairs (especially through the stack effect)¹³
- a staging point for using lifts for evacuation if this is possible depending on the severity and location of the fire and the number of occupants requiring evacuation,
- a fire 'barrier' / non-combustible zone to cut off fire from spreading across different levels.

The nature of the refuge floor is such that it must be a completely vacant floor (i.e. devoid of all inflammable materials) with strengthened structural / fire resistance and additional fire-proofing measures to safely accommodate the evacuees in the event of an emergency, e.g. fire-resisting floors, robust ventilation systems, drencher systems etc. Although often the refuge floor is left open to the elements to reduce the costs of façade provision / take advantage of natural ventilation [see Figure 5c], drencher systems provision is often required at the periphery of the space to prevent fire / smoke ingress.

The incorporation of these refuge floors in a high-rise building has a significant impact upon the design, cost and operation of the building. Not only is there a major cost implication through the additional performance mechanical systems and materials required for the refuge floor, a significant lettable / saleable floor area is lost. In a 75-storey building (not uncommon in Hong Kong), this could be as great as two whole floors. For an average residential tower of floor plate size 1500m² and saleable floor rate of US\$6900 per m², this could be a saving of US\$10.4 million per tower. For an average office tower of floor plate size 2000m² and saleable floor rate of US\$9400 per m², this saving could be as high as US\$37.6 million per tower¹⁴.

Refuge floors also have an impact on other aspects of the tower. Interruption of the vertical extrapolation of function within the tower may have an impact on service risers (e.g. service supplies and drainage ducts may need to be diverted at the refuge floor). Also, the often open nature of the refuge floors (i.e. no enclosing façade envelope) has a significant (undesirable?) impact on the aesthetics of the building [see Figure 5c].

In safety terms, the events of 9/11 have seriously called into question the concept of 'defend in place' strategies in tall buildings, i.e. keeping occupants within the building in the case of an extreme event. The combined effects of all these factors – changing tall building occupant psychology in the wake of 9/11, increased costs / loss of revenue, interruption of vertical continuity and impact on aesthetics – makes refuge floors questionable as a solution for the improved safety of tall buildings.

A solution to overcome many of these problems however, whilst improving the safety aspect of the tall buildings involved, lies in linking these vacant refuge floors with skybridges. The potential for this in Hong Kong – in both future developments and with existing tall buildings retrospectively – cannot be overstated. As Figure 5c illustrates, the urban density of Hong Kong has resulted in dense clusters of tall buildings which are often only separated by a few metres in distance. Further, since regulations require refuge floors every 25 floors, from 25th floor level up, these refuge floors often exist at the same horizon level within the tower clusters. As can be imagined from viewing Figure 5c, linking these refuge floors with skybridges would be a relatively simple affair, requiring short spanning structures linking floors at the same level. Since these floors are currently vacant, there would also be no direct tenant issues to overcome with the change.

These skybridges would then not only offer the improved evacuation benefits enjoyed by the occupants of buildings such as the Petronas Towers (i.e. give the opportunity for evacuees to cross over to a 'safe' tower and evacuate swiftly via that tower's elevators in the event of an emergency), they could serve to enrich the operation of the buildings in normal usage. Enabled circulation between these towers in non-emergency mode could encourage the provision of commercial / community facilities in currently vacant space at the refuge floors (the refuge / holding aspect of which would be

¹³ It should be noted that these refuge floors thus have the added benefit of allowing easy transfer of fire stairs, which is beneficial especially in mixed-use towers.

¹⁴ This financial data was provided by Steve Watts, Head of the Tall Buildings group at Davis Langdon Seah, with input from Malcolm Johnston of the Davis Langdon Hong Kong office. The figures are based on actual sales of office and residential space in Hong Kong in the first quarter of 2006. An exchange rate of US\$1 = HK\$7.8 has been assumed, with typical saleable floor rates of HK\$5000 per square foot for residential space, and HK\$6817 per square foot for office space. A typical residential tower has been assumed to have a smaller floor plate (1500 m² GFA) than a typical office tower (2000 m² GFA). Note: It is usual that common areas in Hong Kong tower blocks – lift shafts, stairs shafts, service risers, corridors etc – are included in residential / office sales calculations. Each residential apartment / office tenant's published GFA includes for a 'share' of these areas.

significantly reduced due to the option for evacuees to move horizontally rather than wait). We could thus see a strata of commercially-viable retail / community facilities occupying these spaces – shops, restaurants, kindergartens – which would bring revenue to the building owners. In such a commercially-orientated climate as Hong Kong, this financial incentive is likely to make the skybridge-refuge floor solution as attractive as the safety benefits they would also bring.

The presence of a similar network of skybridges in Hong Kong at the first floor level, realised over the past 30 years (for more on this, see Wood, 2003 & Wood, Chow & McGrail, 2005) strengthens the potential further; urban density, improved evacuation efficiency, urban and tower enrichment, financial incentive and the prior experience of built case studies makes Hong Kong the prime centre internationally for exploiting the potential of the skybridge.

3.3 Skybridges and the NIST Report: Summarising the Safety Case for the Skybridge

It should be stated at the outset of this summary that this paper does not propose that skybridges are a solution to ensure the safe evacuation of tall building occupants in the event of fuel-laden aircraft flying into tall buildings, whether intentionally or accidentally. Obviously the WTC case study is not one in which skybridges would have made a significant difference since both towers collapsed¹⁵, and there are numerous issues of incorporation (e.g. strategic placing in height / vertical travel distance) that impact their contribution to the total safety scenario.

In the post 9/11 world which we inhabit however, skybridges could bring very real tangible benefits to tall building safety. The varying aspects of this contribution, in respect of the recommendations made in the NIST Report (NIST, 2005), are summarised below:

(i) *Alternative Evacuation Options.*

NIST Recommendation 20: NIST recommends that the full range of current and next generation evacuation technologies should be evaluated for future use which may allow all occupants an equal opportunity for evacuation.

The increasing height of both tall buildings individually and urban densities collectively with only one plane of physical connection (at the ground floor) seems nonsensical. From a safety point of view, this single plane of connection means bringing all evacuees down to the ground floor, which requires the longest accumulative time of individual evacuation journeys. Conceptually, even a single skybridge located at the centre of population density of the tower, would significantly reduce accumulative evacuation time through two factors: (i) in the absence of elevators being allowed for evacuation (as is predominantly the current case in most international safety regulations) and thus most evacuees needing to use only stairs for evacuation, approximately half of the buildings inhabitants would evacuate horizontally across the skybridge, thus reducing their vertical travel distance by half and speeding up other evacuees' journeys by reducing congestion in the stairs, (ii) since these skybridge-evacuating occupants would then be in a tower not at risk, they would be able to evacuate using the safe tower's escalators, thus greatly enhancing evacuation efficiency. This alternative escape option becomes even more relevant when growing social trends (such as declining human fitness, increasing obesity etc) are taken into account – offering non-stair based evacuation possibilities.

(ii) *The need for Mass Evacuation preparedness*

NIST Recommendation 17: NIST recommends that tall buildings be designed to accommodate timely full building evacuation of occupants when required in building-specific or large-scale emergencies.

Changing tall building occupant psychology in the wake of the collapse of the World Trade Centre towers has challenged the traditional *phased* evacuation design approach in tall buildings. It is now possible that tall building occupants will feel uncomfortable remaining inside a tall building in the occurrence of a perceived extreme event. The resulting scenario – the mass *simultaneous* evacuation of a tall building – is something that most tall buildings are unprepared for. Fire stairs and refuge holding areas in most tall buildings internationally have only been sized to accommodate small sub-populations of the building evacuating at once, and thus over-crowding, panic, personal injury and the compromise of evacuation routes could result.

Whilst future tall buildings could create provision for full building evacuation (though, arguably, the increased number and size of stair wells would have an impact on the financial viability of the tower), this is of little comfort to the thousands of tall buildings in existence internationally which have fire

¹⁵ A further issue with hypothetical skybridge connection in the WTC case study is, if only one of the towers had collapsed, could the skybridge connection have brought the second tower down with it?

stairs under-sized for this task¹⁶. Skybridges could allow tall buildings to achieve simultaneous full building evacuation, especially with existing buildings through retrospective incorporation, through methodologies as outlined in (i) above.

(iii) Improved Emergency Responder Access

NIST Recommendation 4: NIST recommends evaluating, and where needed improving timely access by emergency responders.

Although it would have made no difference to the outcome of events on 9/11 (due to the intensity of the fire and lack of facility - water etc - for fighting the fire), emergency responders were unable to reach the fire zone in the World Trade Centre towers. This was due to a number of factors; (i) the great height of the incident in the building (96th & 81st floors respectively), (ii) the expectation that they would reach the incident by climbing fire stairs, despite being heavily laden with equipment, and (iii) the downward flow of evacuees in the same stair wells, which impeded their upward flow. Although the provision of dedicated fire-fighting lifts with back-up power supplies, as has been used in the UK and other parts of Europe for many years now, would help expediate this situation, the provision of skybridges could also contribute significantly. Emergency responders would be able to use elevators in the safe, adjoining tower to access the tall building at risk perhaps half way up the tower, by using the skybridge.

(iv) Redundancy of Services

NIST Recommendation 12: NIST Recommends that the performance and possibly the redundancy of active fire protection systems (sprinklers, standpipe/hoses, fire alarms and smoke management systems) in buildings be enhanced.

An influencing factor in the collapse of the World Trade Centre towers was the severing of virtually all primary power and vertical services continuity in the towers – sprinkler provision, pressurisation systems, elevator power etc. Although, again, it is debatable whether these systems would have made a difference in the outcome of events on 9/11, due to the location and intensity of the fire, in normal emergency situations these systems are vital. The problem is that, even if multiple separate vertical risers can achieve the required redundancy in life safety systems in tall buildings, an incident severing an entire floor's systems close to the ground plane could still knock out the systems for the entire building. Skybridges could offer an alternative routing at height for additional supply of these vertical systems in the event of an emergency.

(v) Retrospective Incorporation

NIST Recommendation 26: NIST recommends that state and local jurisdictions adopt and aggressively enforce available provisions in building codes to ensure that egress and sprinkler requirements are met by existing buildings.

As we have seen, despite the progressive nature of recommendations for the improved evacuation efficiency and safety systems of future tall buildings, there are still thousands of existing tall buildings at risk. It would be very difficult, if not impossible, to add new fire stairs, widen existing staircases, or install new, separate service risers in these buildings. As has been outlined in the paragraphs above, skybridges could help achieve a higher level of life safety in existing buildings with minimum intervention (i.e. predominantly affecting just one floor), through retrospective incorporation.

(vi) Other Safety-related benefits.

As we have seen through the Petronas Case Study and consideration of the Hong Kong scenario, skybridges could have the following additional benefits as a result of their incorporation:

- A possible reduction in the number of fire-stairs needed, resulting in significant financial gain.
- The re-engagement of currently-vacant refuge floors for commercial use, offering further financial gain.

¹⁶ It should also be noted that there is a maximum safe size to the width of fire stair wells, thus the notion of increasing fire stair widths exponentially to allow greater evacuation flow could be problematic. Jake Pauls, in his excellent paper questioning many of the assumptions made in the wake of 9/11, sets this safe maximum at 1725mm width (1525 mm between handrails). Any greater width would put people in the middle of the stair beyond the safe reach of a handrail. For more on this, see Pauls, 2005. Jake Pauls is an interesting figure in both the field of tall building evacuation and links between buildings at height, having worked in the field for 38 years. A representative of the American Public Health Association and member of the Skyscraper Safety Campaign Professional Advisory Panel, he is a great advocator for the skybridge, first incorporating them in his architectural design thesis as a student at the University of British Columbia in 1969, entitled "A survey of fire problems in modern high-rise office buildings and proposal of design solutions" (see Pauls, 2005). The author is indebted to Mr. Pauls for his many useful insights and general encouragement given in the course of researching the skybridge.

4.0 Conclusion

Despite the very real benefits to improved tall building evacuation offered by skybridge links at height, as demonstrated by buildings such as the Petronas Towers in Kuala Lumpur, very little research has been conducted to date into the issues and potentials of skybridge incorporation¹⁷. It is now essential to fully research and debate their potential.

The skybridge, however, is not only a proposition for improving evacuation efficiency. As many architects and visionaries have shown over a period spanning more than a century, the re-creation of the urban realm in the sky through connections between buildings at height has a vast potential for the enrichment of our cities. To many it seems nonsensical that, though the twentieth century has clearly seen a push towards greater height and urban density in our major urban centres, the ground-pavement level remains almost exclusively the sole physical plane of connection. The full case for the skybridge is thus made on the following three grounds (For more on this, see Wood, 2003):

- for the improved safety of tall buildings, through greater evacuation efficiency,
- for the improved experience of our cities, through urban enrichment,
- for the improved quality of tall buildings, through increased physical connections reducing isolationist architectural design approaches.

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¹⁷ In an interview conducted by the author in 2006, Dr. Shyam Sunder, lead investigator into the World Trade Centre disaster intimated that, in all the numerous tall building safety / evacuation forums he had been involved in, the potential of skybridges had never been meaningfully discussed.