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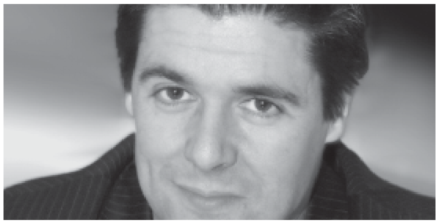
Rethinking Evacuation: Rethinking Cities



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Based at the Illinois Institute of Technology, Antony is also a studio Associate Professor in the College of Architecture at IIT, where he convenes various tall building design studios. A UK architect by training, his field of specialism is the design, and in particular the sustainable design, of tall buildings. Prior to becoming an academic, Antony worked as an architect in practice in Hong Kong, Bangkok, Kuala Lumpur, Jakarta and London.

He is the author of numerous book and papers in the field of tall buildings, sustainability and related areas, including the 2008 title "Tall & Green: Typology for a Sustainable Urban Future." His PhD explored the multi-disciplinary aspects of skybridge connections between tall buildings. He is associate editor of both the CTBUH Journal and the John Wiley & Sons Journal: "The Structural Design of Tall and Special Buildings" and co-chair of the CTBUH Tall Buildings and Sustainability working group.

"Though this idea might seem a fantastical proposition, skybridges are increasingly being realized – albeit in a piecemeal way – in cities around the world."

The terrorist attacks and consequential collapse of the World Trade Center towers on September 11, 2001 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 19th 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.

Rethinking Evacuation

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

Most of the international safety research in the wake of 9/11 has focused on improving three key 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.

While this work is vital towards making tall buildings safer, it is not enough. The risk to our cities is increasing: terrorism, war, extreme environmental effects or accidents all threaten our cities in a new way. We must tackle the issues of safety at a more fundamental *design* level, not as an alternative to other safety measures, but in addition to the improved safety mechanisms suggested above.

One method of improving the safety of tall buildings is by introducing horizontal evacuation at height through the use of "skybridges"[1] linking towers. The concept of occupant evacuation at a level other than the ground plane is logical, especially when considering an emergency event which effectively cuts off connection to the ground plane. Furthermore, the events of 9/11 have had a significant psychological impact on tall building occupants which threatens the current accepted regulations concerning the evacuation design of tall buildings internationally (particularly strategies of phased "defend in place" evacuation strategies, as opposed to total building evacuation). Despite the very real benefits to improved tall building evacuation offered by skybridge links at height, very little research has been conducted to date on the potential of the skybridge concept.

Petronas Towers, Case Study

"Rather than concentrating on the vertical aspect, which creates a spatial dead-end, the 3-D city depends on sky passages that connect buildings together at certain levels. In the early twentieth century, each building had its own underground level; now these are connected and became part of the city. The same thing could happen in the air."

(Hiroshi Hara, 1999)

The 452-meter (1,483-foot), 88-story Petronas Towers in Kuala Lumpur, Malaysia (designed by Cesar Pelli Associates) contains perhaps the best known example internationally of a high-rise skybridge (see Figure 1). The skybridge itself is two stories in height and connects the two towers at the 41st and 42nd floor. These levels are also the location of a major "skylobby" elevator change-over zone,

[1] The author defines a skybridge as "a primarily-enclosed space linking two (or more) buildings at height." Thus, by definition, any "open" bridges, bridges which do not connect between buildings (pedestrian over-road bridges which exist in most cities of the world) or low-level enclosed bridges (which are also present in many cities of the world) are not generally regarded as skybridges.

Figure 1. Petronas Towers' Skybridge © Antony Wood

where building occupants traversing the upper half of the tower change from low-zone to high-zone elevators.[2]

While the 41^{st}/42^{nd} level zone contains large open spaces to facilitate the circulation of hundreds of people who pass through each day, the floors directly above and below contain many of the communal facilities shared between the two towers: the Conference Center, the Upper Surau (prayer room) and the Executive Dining Room. Thus, the skybridge's primary function, under normal circumstances, is to facilitate circulation between the two towers for use of the shared facilities contained in each tower at these levels.

The "whole building" evacuation strategy for Petronas Towers (see Figure 2) divides each building into three separate zones. Within the Low Zone (Ground Level to 37^{th} floor) occupants evacuate down fire stairs to the ground level concourse and immediately exit the building. Middle Zone (40^{th} to 60^{th} floor), occupants evacuate down/up fire stairs to 41^{st} Floor, cross over the lower floor of the two-story skybridge and use shuttle elevators in the "safe" tower to access the ground level concourse, where they exit the building. High Zone (61^{st} to 86^{th} floors) occupants evacuate down fire stairs to Level 42, cross over the higher floor of the two-story skybridge and use shuttle elevators in the "safe" tower to access the Mezzanine Level Concourse, where they exit the building.

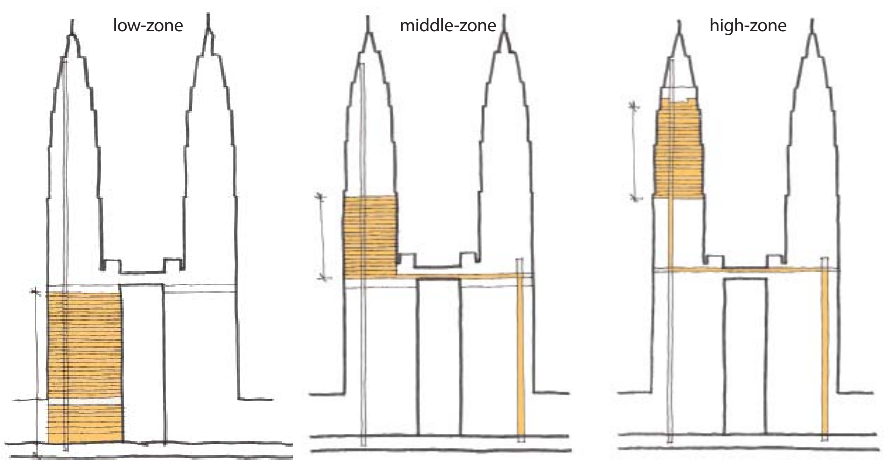

Figure 2. Use of the skybridge for different zones of the Petronas Towers for total evacuation of a single tower © Antony Wood in conjunction with Daniel Parry-Davis

In a full, single building evacuation scenario, the skybridge thus becomes an integral part of the fire evacuation procedure, with the skybridge providing an alternative fire escape route for all occupants in the upper half of the tower (approximately 50% of the total building occupants). Additionally, once these occupants reach the "safe" tower, they can exit using the normal elevators, which greatly speeds up the evacuation process. To achieve this integration of the skybridge in the evacuation procedure, the skybridge itself had to be fire-rated, including increased fire-resistance of the thresholds between skybridge and towers, and pressurization of the space (and adjoining skylobbies) to prevent smoke-ingress.

One of the primary positive effects of utilizing 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 floor (Pelli & Crosbie, 2001). At an estimated fire-stair area of 18 square meters (194 square feet) per floor, through 42 floors in two towers, this is a floor area saving of approximately 1,512 square meters (16,275 square feet). With Kuala Lumpur office saleable floor area rate of approximately US$1,613 per square meter (US$150 per square foot), this is a savings of over US$2.4 million. This, in purely space-saving terms, contributed significantly to financing the cost of the skybridge.[3]

Addressing the NIST Recommendations

"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."

(Recommendation 20, NIST, 2005)

[2] All visitors and staff heading to floors above the 42^{nd} floor must 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 while those requiring even-numbered floor access at a first floor mezzanine level), this skylobby also needs to occur across two levels – 41 and 42.

[3] It should be noted that the author has drawn on a number of sources for this approximation. The fire-stair has been assumed at 3 by 6 meters. Financial data on typical Kuala Lumpur's 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). The 2005's office sales for typical towers in the KL "Golden Triangle" area in this report ranged from RM 347–482 per square foot. A higher saleable floor area rate of RM 550 per square foot for the more prestigious Petronas Towers, and an exchange rate of US$1 = RM 3.67, has been assumed (Note: 1 square meter = 10.764 square feet).

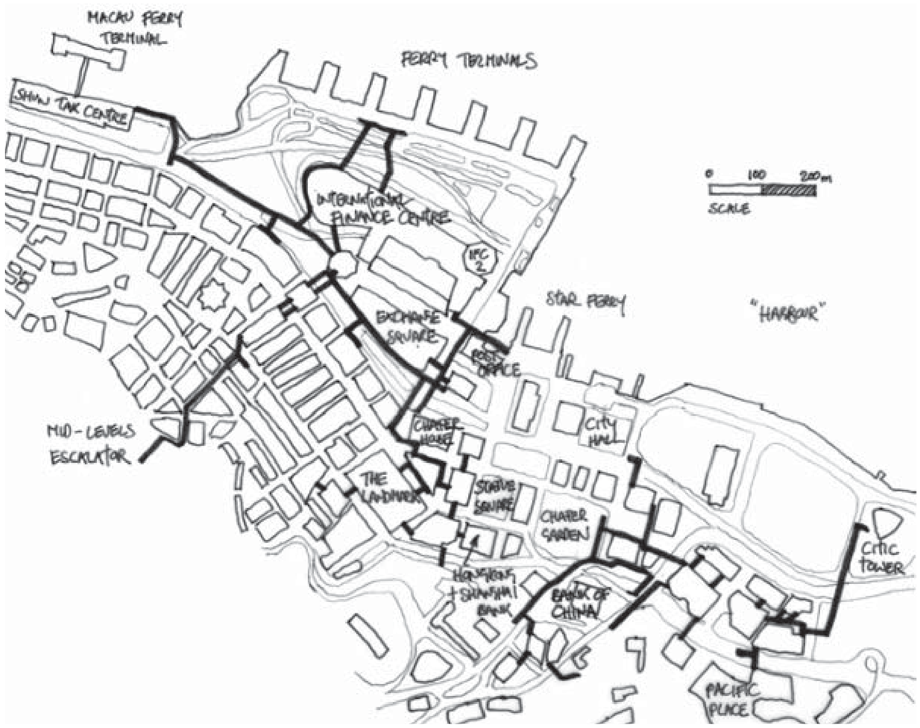

Figure 3. Extent of skybridge network in the central district of Hong Kong today © Antony Wood

The Petronas Tower example demonstrates the potential benefits of skybridge connections to evacuation efficiency. This alternative escape option becomes even more relevant when growing social trends (such as declining human fitness and increasing obesity) are taken into account, since the skybridge offers non-stair based evacuation possibilities. The strategy thus addresses Recommendation 20 made in the NIST Report as outlined previously.

In addition, skybridges offer other potentials, such as improving emergency responder access in tall buildings, since emergency responders would be able to use elevators in the safe, adjoining tower to access the tall building at risk through the skybridge. This addresses the NIST Report Recommendation 4: *"NIST recommends evaluating, and where needed improving… timely access by emergency responders."* Skybridges also offer benefits in providing possible redundancy of service routings, as suggested in NIST Report 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 Center towers was the severing of virtually all primary power and vertical services in the towers – sprinkler provision, pressurization systems, elevator power, etc. While it is debatable whether these systems would have made any difference in the outcome of events on 9/11, due to the location and intensity of the fires, in normal emergency situations these systems are vital. Essentially, the problem is that even if multiple separate vertical risers can achieve the required redundancy of life safety systems in tall buildings, an incident severing an entire floor's systems close to the ground plane could still eliminate the systems for the entire building. Skybridges offer the possibility of an alternative routing at height for additional supply of these vertical systems in the event of an emergency.

Finally, the skybridge offers the potential for improving evacuation options in existing tall buildings, through retrospective incorporation, which addresses NIST Report Recommendation 26: *"NIST recommends that state and local jurisdictions adopt and aggressively enforce available provisions in building codes to ensure that [improved life safety] requirements are met by existing buildings."* Despite the progressive nature of recommendations for the improved evacuation efficiency and safety systems of new tall buildings, there are still thousands of existing tall buildings which cannot incorporate these additional systems due to the constraints of existing form and floor layout (which eliminates the possibility of extra fire stairs). Skybridges could thus help achieve a higher level of life safety in existing buildings with the intervention affecting a small number of floors horizontally, rather than all floors vertically.

The Case for Hong Kong

Obviously, there are huge design and technical challenges to be overcome in the incorporation of skybridges in high-rise design. However, with the right drive and coordination, these challenges are perhaps not insurmountable. The most relevant city for the incorporation of skybridges is probably Hong Kong (Wood, Chow & McGrail, 2005), a metropolis which already has an extensive network of skybridges linking public and private towers in a network spanning several square miles (see Figure 3), albeit at the second floor level. The greatest potential for

...reality

"We are building a new reality at the World Trade Center, and this transaction will be the explanation point on that turnaround."

Christopher Ward, Executive Director of the Port Authority of New York and New Jersey, discussing the lease of one million square feet of office space to Conde Nast in One World Trade Center. From "Condé Nast Will Be Anchor of 1 World Trade Center," NY Times, May 18, 2011.

Hong Kong is created by the combination of dense clusters of towers created in very close proximity, and the requirement for vacant "refuge floors" as part of existing high-rise evacuation code (see Figure 4). One can imagine these common-level, vacant refuge floors being connected with skybridges (or perhaps "skyplatforms") spanning the often only two or three meter distances between the towers. Since these floors are currently vacant, there would be little direct tenant issues to overcome with the incorporation and, potentially, the vacant refuge floors could be used for leasable space/commercial function.

Beyond Evacuation: Rethinking Cities

"It is only logical to conceive of multi-level cities. The organization of, say, New York, which tolerates multi-level components, connected by only two horizontal levels (street and subway) and both of those at the base, is archaic…"

(Cook, 1989)

Despite the emphasis here on the potential benefits to high-rise evacuation, the skybridge can contribute to our cities in myriad other ways. As many architects and visionaries have shown over a period spanning more than a century – from the early 20th Century "King's Views of New York" (see Figure 5) to virtually all "urban vision" science-fiction cinematography (see Wood, 2003), 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 21st century has clearly seen a push towards greater height and urban density in our major urban centers, the ground-pavement level remains almost exclusively the sole physical plane of connection.

Additionally, one of the major failings of tall buildings in architectural terms is that most are designed as stand-alone icons superimposed on – rather than integrated into – the urban fabric. Despite the often significant vertical height of these buildings, very few of them connect to the city (or each other) at any level other than the ground plane, and often the very objective of the project brief is to "stand out," rather than to "fit in."

If cities concentrate perhaps ten or a hundred times more people at a given location through building tall, there is also a need to replicate the supporting urban facilities that exist at the ground plane up in the sky, including the parks and the sidewalks, the schools and the hospitals, and other public/civic functions. The ground plane should be considered as a duplicable layer of the city which needs to be replicated – at least in part – at strategic horizons within and between buildings in the sky, not as a replacement of the ground plane but as an addition to it. Every tall building would then need to be considered as a vital element in an overall, three-dimensional urban framework, rather than as a stand-alone icon superimposed on a two-dimensional urban plan.

Figure 4. Hong Kong: the presence of common-level "refuge floors" in many of the separate towers allow easy incorporation of short skybridge linkages © Antony Wood

Figure 5. 1911: King's Views of New York (cover illustration "Future New York is pre-eminently the City of Skyscrapers" by Richard W. Rummell)

The Skybridge: In Practice

Though this idea might seem a fantastical proposition, skybridges are increasingly being realized – albeit in a piecemeal way – in cities around the world. Figure 6 illustrates some of the more significant examples in recent years.

There is perhaps also a reason that, of the seven final entries for the World Trade Center Tower competition, five of them proposed some form of direct linkages between towers (see Figure 7) (Wood & Oldfield, 2005). The actual variance in physical manifestations of the skybridges in the WTC replacement proposals is interesting. Proposals range from sinuous bridges to whole floor plates spanning the void, from skywalks at one level to skybridges at multitude levels. Far from impacting only evacuation efficiency, the provision of skybridges has revealed itself to have positive influences on many other aspects of tall building design; structural robustness, possible letting configurations and redundancy of service supplies to name but three.

Conclusion

As a conclusion to this paper, the following list is offered as a summary of how high-level skybridge connections could contribute to the re-thinking of both our tall buildings and our cities:

1. Offer improved evacuation efficiency (and multiple routing options) in tall buildings.
2. Offer improved emergency responder access to tall buildings (firefighters


2001, Twin Towers, Austria, Maksimiliano Fuksas


2003, Marriott Apartments, Dubai


2003, Kyobo Tower, Seoul, Mario Botta


2003, Highlight Tower, Munich, Murphy Jahn


2004, Chong No, Seoul, Rafael Vinoly


2005, El Faro Tower, Buenos Aires, Dujovne-Hirsh


2006, Ten Towers Munich, Kiessler & Partner


2006, Nina Tower, Hong Kong, CDI


2008, Fusionopolis, Singapore, Kisho Kurokawa


2009, Pinnacle @ Duxton, Singapore, ARCStudios


2009, Linked Hybrid, Beijing, Steven Holl


2010, Marina Bay Sands, Singapore, Moshe Safdie

Figure 6. Examples of skybridges in recent years

Figure 7. Many of the official and unofficial competition entries for the World Trade Center tower replacements proposed connections between towers at height, (A) Foster + Partners, (B) SOM, (C) Richard Meier et al, (D) Foreign Office Architects, (E) United Architects, (F) THINK Team (G) Coop Himmelblau (H) Richard Dattner – Source: Stephens S., 2004, Imagining Ground Zero: Official and Unofficial Proposals for the World Trade Center Competition

given access to an at risk tower at a high level through elevators in adjoining "safe" tower).

3. Offer redundancy and alternative routings for services provision.
4. Offer a gain in commercial floor space/ building revenue, through reduction of number of fire stairs and refuge floors.
5. Offer alternative normal circulation routes for pedestrians in increasingly congested cities.
6. Offer pedestrians protection from extreme climatic elements (hot, cold, humid, rain, wind, etc.).
7. Allow more efficient (and energy-efficient) circulation of occupants between neighboring towers.
8. Allow easier access to functions shared between towers, thus increasing the viability of those functions.
9. Allow the connection and expansion of commercial or retail space into a neighboring building.
10. Offer access to a better environment at height in increasingly dense cities (improved light, air, and views).
11. Offer the opportunity for a greater sense of community to develop in neighboring tall buildings (skybridges as "streets in the air" creating social-interaction spaces).
12. Offer the potential for creating gardens at height (skybridge as "skygarden").
13. Allow the linear migration of plants (and possibly animals) within cities encouraging biodiversity: the skybridge as landscaped corridor.
14. Offer the opportunity for an improved urban fabric which relates to both the culture and environment of the city, by requiring each building to be an essential part of an urban whole, rather than a stand-alone icon. ■

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