Tall Buildings: Search for a New Typology

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Abstract

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Tall building design, despite 130 years of development, has not advanced to a satisfactory state, especially on environmental/sustainability grounds. Most Tall Buildings historically seem to have been designed as either vertical extrusions of an efficient floor plan (the ‘commercial’ approach), or as stand-alone pieces of high-rise urban ‘sculpture’ (the ‘sculptural-iconic’ approach). In both cases the main relationship with the urban setting is either a commercial or a purely visual one, with the tall building usually dominating.

This has led to the syndrome of tall buildings as ‘isolationist’ architecture – stand-alone, non-site specific models that are readily transportable around the cities of the world. This has served to create an alarming homogeneity across global urban centers – a creation of a ‘one size fits all’ skyscraper ‘mush’ which rejects, in some places, thousands of years of local vernacular traditions. This is especially true of cities in developing nations, where to import all things ‘western’ is often to be seen as progressive and modern. Thus the vast majority of tall buildings internationally follow the standard template of the rectilinear, air-conditioned, western ‘box’.

In addition, tall buildings have become synonymous with the greatest excesses of energy expenditure – in both embodied construction and operation. Though there are definitely advantages tall buildings can offer, both in creating more sustainable patterns of life through higher density and also through the potential for greater renewable energy generation at height, there is no doubt that in their current form, most tall buildings are energy-profligate. In short then, many of these tall buildings are contributing to the degradation of both the local (cultural) and the global (climate change) around the world.

It does not, however, need to be this way. Tall Buildings have the opportunity to reinvent themselves as the typology for a sustainable urban future – focused centers of live, work and recreation with innovative forms, technologies and environments to face the challenges of the future climate-changed world, whilst also contributing to the continuing local culture of a place. This new typology needs be inspired by the cultural, environmental and vernacular traditions of the location. This is important in maintaining the cultural integrity and continuity of any urban domain, but especially in developing countries which are at risk of adopting wholesale western urban models (and mistakes) at the expense of more appropriate local solutions.

In short, tall buildings and cities need to be inspired by the specifics of place – physically, culturally and environmentally. This submitted ‘PhD by Publications’ – consisting of a Narrative and six published papers – explain how the author’s research has contributed to this central thesis; the quest for a new typology for tall buildings which are appropriate to the local, the global and the major challenges of the age.

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UoN Links: Antony maintains regular involvement with the UoN, where he supervises a PhD student within the School of the Built Environment. He also contributes to the High Rise design studio module which he established before leaving UoN, and the newly formed Masters in Sustainable High Rise Architecture Course for which he is external examiner for 2009-10.

Papers Submitted: 6 No. papers published in highly regarded peer-reviewed Journals (*in chronological order*):

(1) WOOD, A. (2003). **Pavements in the Sky: Use of the Skybridge in Tall Buildings.** *Architectural Research Quarterly* (ARQ). Vol. 7. Nos. 3 & 4. 2003. pp. 325 -333. Cambridge University Press, UK. ISSN: 1359-1355.

(2) WOOD, A. (2004). **New Paradigms in High Rise Design.** *CTBUH Review – the Journal of the Council on Tall Buildings and Urban Habitat.* Issue No. 3. Fall 2004. pp. 16-24. Council on Tall Buildings and Urban Habitat, Chicago, USA.

(3) WOOD, A. & OLDFIELD, P. (2007). **Bridging the gap: An analysis of proposed evacuation links at height in the World Trade Centre design competition entries.** *Architectural Science Review.* Volume 50.2. June 2007. pp.173-180. University of Sydney, Australia. ISSN: 0003-8628.

(4) WOOD, A. (2007). **Sustainability: A New High Rise Vernacular?** *Journal of the Structural Design of Tall and Special Buildings.* Volume 16, Issue No. 4. December 2007. pp. 401-410. John Wiley & Sons Ltd., UK. ISSN: 1541-7794

(5) OLDFIELD, P., TRABUCCO, D. & WOOD, A. (2009). **Five Energy Generations of Tall Buildings: A Historical Analysis of Energy Consumption in High-Rise Buildings**. *Journal of Architecture.* Volume 14, No.5. October 2009. pp.591-613. Routledge, Abingdon, UK. ISBN: 9780415570077

(6) WOOD, A. (2010). **The Re-Making of Mumbai: A CTBUH-IIT Collaborative Architectural Design Studio.** *CTBUH Journal: The International Journal on Tall Buildings and Urban Habitat.* 2010 Issue 1. pp 22-33. January 2010. Council on Tall Buildings and Urban Habitat, Chicago, USA. ISSN: 1946-1186

Support Material: *(7)* WOOD, A. (2009). **Antony Wood. CTBUH Exec. Director. Resume & Publications.** Published by the Council on Tall Buildings and Urban Habitat, Chicago, 2009.
325 pages, showing other published works, research output and media coverage.

Note on Research: All research informing papers 1-5 listed above was undertaken whilst Mr. Wood was an academic at the University of Nottingham, though paper (5) was published in the year after he left Nottingham. The research informing paper (6) above was undertaken whilst an academic at the Illinois Institute of Technology, but is included here since it concludes much of the earlier research work on both skybridges and environmental high rise design.

Supporting Narrative

(Note: references that are included in the actual papers submitted are not generally duplicated in this Narrative. Some subsequent research which has been undertaken following paper publication is included here and indicated as such).

Tall Buildings: Search for a New Typology

The thread that binds the research submitted here together is based on my belief that tall building design, despite 130 years of development, has not advanced to a satisfactory state, especially on environmental/sustainability grounds. Most Tall Buildings historically seem to have been designed as either vertical extrusions of an efficient floor plan (the ‘commercial’ approach), or as stand-alone pieces of high-rise urban ‘sculpture’ (the ‘sculptural-iconic’ approach). In both cases the main relationship with the urban setting is either a commercial or a purely visual one, with the tall building usually dominating.

This has led to the syndrome of tall buildings as ‘isolationist’ architecture – stand-alone, non-site specific models that are readily transportable around the cities of the world. This has served to create an alarming homogeneity across global urban centers – a creation of a ‘one size fits all’ skyscraper ‘mush’ which rejects, in some places, thousands of years of local vernacular traditions. This is especially true of cities in developing nations, where to import all things ‘western’ is often to be seen as progressive and modern. Thus the vast majority of tall buildings internationally follow the standard template of the rectilinear, air-conditioned, western ‘box’.

In addition, tall buildings have become synonymous with the greatest excesses of energy expenditure – in both embodied construction and operation. Though there are definitely advantages tall buildings can offer, both in creating more sustainable patterns of life through higher density and also through the potential for greater renewable energy generation at height, there is no doubt that in their current form, most tall buildings are energy-profligate. In short then, many of these tall buildings are contributing to the degradation of both the local (cultural) and the global (climate change) around the world.

It does not, however, need to be this way. Tall Buildings have the opportunity to reinvent themselves as the typology for a sustainable urban future – focused centers of live, work and recreation with innovative forms, technologies and environments to face the challenges of the future climate-changed world, whilst also contributing to the continuing local culture of a place. This new typology needs be inspired by the cultural, environmental and vernacular traditions of the location. This is important in maintaining the cultural integrity and continuity of any urban domain, but especially in developing countries which are at risk of adopting wholesale western urban models (and mistakes) at the expense of more appropriate local solutions.

In short, tall buildings and cities need to be inspired by the specifics of place – physically, culturally and environmentally. The following Narrative – and the six papers here submitted – explain how the author’s research has contributed to this central thesis; the quest for a new typology for tall buildings which are appropriate to the local, the global and the major challenges of the age.

Paper 1: Pavements in the Sky: Use of the Skybridge in Tall Buildings.

Published in *Architectural Research Quarterly* (ARQ), 2003.
Vol. 7. Nos. 3 & 4. 2003. pp. 325 -333. Cambridge University Press, UK. ISSN: 1359-1355.

This first paper in the submission gets to the very core of this problem by recognizing that one of the major failings of tall buildings 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 ground, and often the very objective of the project brief is to 'stand out', rather than 'fit in'.

Whilst it may be acceptable for a building to aim for iconic status, it seems completely nonsensical that cities are making a push for ever-denser, ever-taller urban form, but allowing only the ground plane to be the sole physical plane of connection. If cities are looking to concentrate perhaps ten or a hundred times more people on the same district of city through building tall, then don't they need to replicate the facilities that exist at the ground plane up in the sky, including the parks and the sidewalks, the schools and the doctor's surgeries, the other public and civic functions? Doesn't the ground plane need to be considered as an essential, 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 in place of the ground plane but in support of it? This idea of connections between buildings and replication of the ground plane in the sky is the central thrust of this paper, through the proposition of *skybridges.*

Though this idea might seem a fantastical proposition (and, as demonstrated in this paper, has been proposed as such for at least the past 150 years), skybridges are increasingly being realized – albeit in a piecemeal way – in cities around the world. The potential benefits of these "pavements in the sky" are discussed in Paper 1 and generally fall into four areas, as summarized below (*Note: A longer list of the specific potential benefits of skybridges are given in the Paper 3 section of this Narrative on Subsequent Research – please see Page 15):*

- for the improved experience of our cities, through urban enrichment (e.g. through the introduction of other public-civic uses into the predominant office-residential-hotel scenarios that currently dominate the sky, plus the greater access to views, light and air offered at height)
- for improved energy performance (e.g. people not having to travel the vertical length of the building to enter/exit/use 'ground' facilities),
- for the improved safety of tall buildings, through greater evacuation efficiency (see elaboration on this subject below),
- for the improved quality of tall buildings, through increased physical connections reducing isolationist architectural design approaches.

It is this last element which is perhaps most relevant to the central theme of this Narrative and the research overall i.e. the search for a new tall building typology. Through needing to consider a tall building as just one element in a linked network – an 'urban plan' – in the sky, the designer would perhaps be able to move beyond the isolationist, ego-centric approaches to tall building design which dominate currently, hopefully resulting in a high rise urban fabric where the elements relate – and respond – to each other.

The proposition of the skybridge is a strong, recurrent theme running throughout the material submitted for consideration, and specifically binds together papers (1), (3) and (6). It is thus perhaps helpful to elaborate a little on the concept of skybridges here. Firstly it is necessary to understand what a skybridge is and thus the author defines a *skybridge* as:

"a primarily-enclosed space linking two (or more) buildings at height"[1].

As demonstrated in Paper 1 and in subsequent research by the author since then, there are now in excess of 50 tall buildings in existence around the world which already employ skybridges, the most high profile example being the 1996 Petronas Towers, Kuala Lumpur, Malaysia (see *Subsequent Research: Petronas Towers; An Evacuation Case Study*, below).

The potential of the skybridge as an idea came to the author in the immediate aftermath of the 9/11 collapse of the World Trade Centre towers, New York. For the author personally, 9/11 coincided with his first day's employment as a Lecturer in Architecture at the University of Nottingham, and the concept of the trapped occupants of the World Trade Center towers with no evacuation options, spurred him into research in this field. The events of 9/11 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.

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. However most of the international safety research in the wake of September 11th has focused on improving the following three 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.

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[1] The important factors to note in this author's definition of the skybridge 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 the studies submitted here, generally regarded as skybridges. It should be however, that this is not a strict classification and in some instances, where the design and/or technical aspects of the bridges are relevant to the study, they are included in the research and papers presented here. Thus, in the case of the Hong Kong elevated urban network – see the section on *Subsequent Research* under Paper 3 of this Narrative - the skybridges are neither particularly high-level (one storey up) and many of them are open / pedestrian, over-road bridge in nature. The scale of urban achievement of the Hong Kong network however, and the lessons it holds in management and operation, warranted its inclusion in the research.

One strong potential benefit of the *skybridge* then is as a possible solution for improving the safety of tall buildings by introducing horizontal evacuation at height through 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. Further, the events of 9/11 have had a major impact on the psychology of tall building occupants, calling significantly into question regulations governing the evacuation design of tall buildings internationally [2].

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 (see *Subsequent Research: Petronas Towers; An Evacuation Case Study* below), very little research had been conducted to date into the issues and potentials of skybridge incorporation [3]. The research presented here (specifically in Papers 1 and 3) very much addresses this gap. Prior to this research being published, there had been no publication holistically examining the increased safety/evacuation potential of skybridge connections, or comprehensively establishing the multi-disciplinary case for the skybridge. Thus this research has contributed to the safety debate in tall buildings and led to governmental bodies such as the US-based National Institute of Standards and Technologies (NIST – who conducted the investigation into the World Trade Centre towers' collapse) explicitly considering the potential of skybridges.

Paper 1 thus begins this study of "Pavements in the Sky" by examining the main drivers behind the proposition of skybridges historically in the theoretical realm, and in so doing builds up a rationale as to the benefits they could bring to our cities. The picture begins with the early 20th Century New York visions of people such as Moses King[4] and charts up to 2003 (the date of paper publication), and proposals for the future announced at the time. In doing so, it embraces many of the major architectural movements of the late 19th / 20th centuries; the rise of the American skyscraper as a building form, the translation into cinematography, Italian Futurism, Russian Constructivism, British New Brutalism, Japanese Metabolism, etc – many of which embraced the idea of connection between buildings in some form.

The paper also presents some of the case studies from the built realm, starting with Antonio Contino's sixteenth century Bridge of Sighs at the Palazzo Ducale Venice, and moving to the current times through Niemeyer's 1958-60 National Congress Brasilia, Hiroshi Hara's 1993 Umeda Sky Building Osaka, and of course Cesar Pelli's 1996 Petronas Towers Kuala Lumpur. In examining some of the built skybridge proposals in completed projects, as well

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[2] Perhaps the most significant challenge to existing tall building evacuation design posed by the events of 9/11 is the continued reliance on *phased* evacuation strategies i.e. the concept where building occupants directly-affected by the fire are evacuated but the remainder of the building population is left in place. This phased strategy is fundamental to the evacuation design of tall buildings since the fire stairs and holding (refuge) areas are sized according to the evacuation of small sub-populations of the building, rather than the total population of the building at once. The events of 9/11 have, however, challenged this. The sight of such a high-profile building collapsing in a relatively short period of time has had an influence on the occupant psychology of other tall building inhabitants and their perception of the time available to them in an evacuation. Prior to 9/11, encouraging people to *leave* their workplaces in order to evacuate was a major issue. Now, persuading tall building inhabitants to remain in the building in the event of an emergency – especially an emergency with high visual clues – could prove to be impossible. This potential for *simultaneous mass evacuation* is something that most existing tall buildings are unprepared for.

[3] 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.

[4] KING, M. (1908), *Moses King, King's Views of New York, 1896-1915 & Brooklyn 1905: an extraordinary photographic survey.* First published Boston 1896, 1903, 1905, 1908, 1911,& 1915. Reprinted 1977 by Arno Press, New York, with an introduction by A.E. Santaniello.

as the theoretical propositions, the paper explains some of the considerable challenges of incorporating skybridges, and suggests these as areas for further research. Some of these challenges are summarized below:

1. impact on client brief (who would own the skybridge, pay for it, construct it and maintain it?)
2. impact on internal planning (where to place the skybridge in plan, considering the direction of adjoining buildings?. What is the impact on the building operation of having potentially 'the public' entering/exiting the building at numerous levels?)
3. impact on the building section (where to place the skybridge in height – presumably at the centre of tower population density if just one skybridge, but also logically at the elevator sky lobby changeover level?)
4. impact on strategic planning (impact of buildings housing different functions being linked? The provision for later linkage between two – or more – buildings built at different times?)
5. impact on structure (how could buildings physically support spanning connections between them? How about later connections – would structural 'skynodes' need to be provided within building structures ready to accommodate later skybridges?)
6. impact on structural dynamics (what would be the effect of connecting buildings that usually need to move independently?)
7. impact on envelope & fabric (again, 'sky-portals' would need to be created within the envelope to accommodate later skybridge connection)
8. impact on urban environment (would there be a detrimental impact on the ground floor plane, through over-shadowing etc?)
9. impact on existing buildings (could existing buildings be linked into the network retrospectively?).
10. impact on architecture (how would the skybridge be handled architecturally, existing between two buildings of perhaps vastly contrasting architectural styles?)

Subsequent Research: Petronas Towers: An Evacuation Case Study (unpublished)

The 452-metre, 88-storey Petronas Towers in Kuala Lumpur, Malaysia [5] – designed by Cesar Pelli Associates – contains perhaps the best known example internationally of a high-rise skybridge [see images next page]. The skybridge itself is two-storey in nature and connects the two towers at the 41st and 42nd floors. These levels are consistent with the 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 thus 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 whilst those requiring even-numbered floor access at a first floor mezzanine level), this skylobby also needs to occur across two levels – 41 and 42.

Whilst this 41st / 42nd level zone contains large open spaces to facilitate the circulation of the hundreds of people who pass through each day, the floors above and below contain 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

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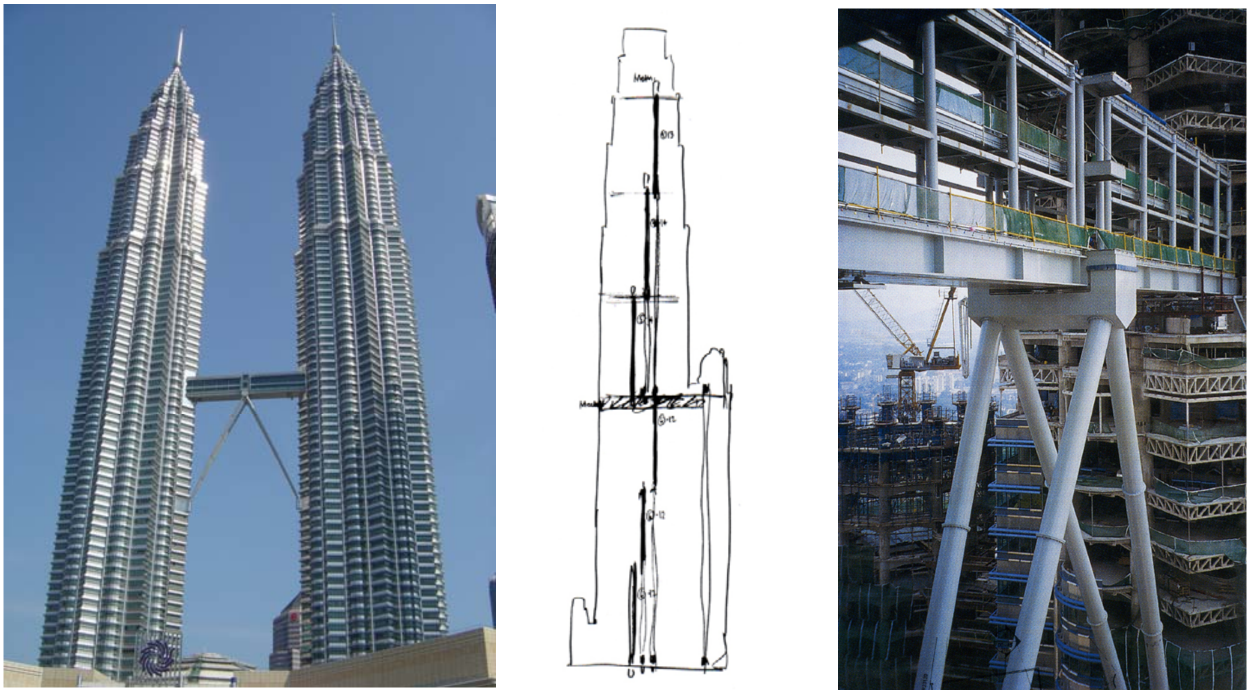
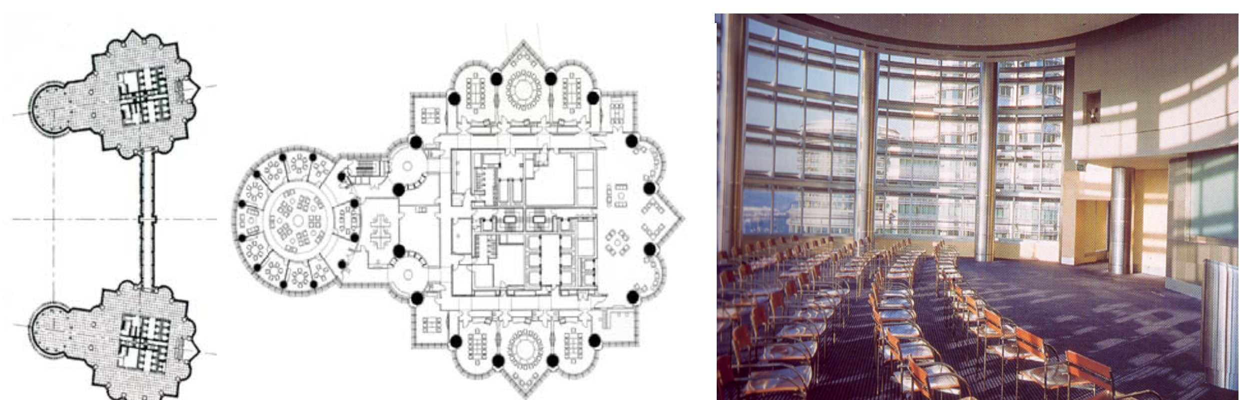
[5] More information on the building can be found in PELLI, C. & CROSBIE, M.J. (2001). ***Petronas Towers: The architecture of high construction.*** Wiley-Academy. UK. The focus here is on its role of the building's skybridge in the evacuation procedures of the two towers.

facilities contained in each tower at these levels [see images towards bottom of page]. Operationally, Tower 1 houses the employees of the Petronas Corporation, whereas Tower 2 is a multi-let office tower.



1996. *Petronas Towers* Skybridge, Kuala Lumpur; (a) View of towers showing skybridge connecting at 41^{st} & 42^{nd} floor (source: author), (b) Lift zoning sketch diagram, showing 'skylobby' elevator change-over at 41^{st} & 42^{nd} floor levels (source: Pelli & Crosbie, 2001, p.114), (c) Double deck nature of skybridge (source: Pelli & Crosbie, 2001, p.54)

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 [see plan below]. A third stairwell is located in the 'bustle' [6] and serves floors 43 and below. Since Malaysian Building Codes [7] are based largely on the British Regulations due to the country being a British colony for many years, two dedicated firefighters' 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:



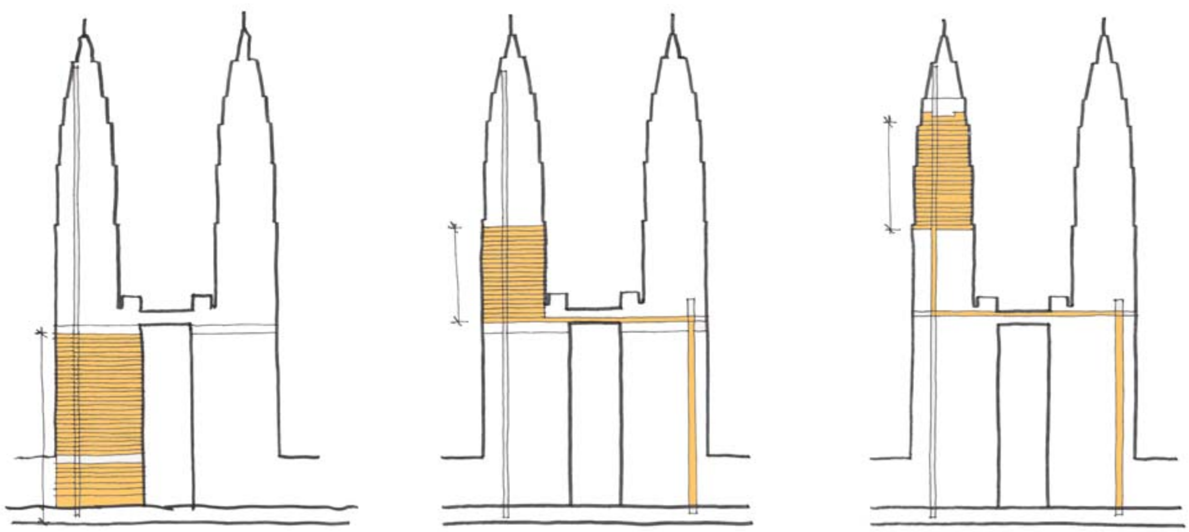
The Skybridge links communal facilities shared between the two towers at the skylobby zone (a) Skybridge Plan at 41^{st} floor (source: Pelli & Crosbie, 2001, p.67), (b) 40^{th} floor Plan, showing conference facilities, (source: Pelli & Crosbie, 2001, p.90) (c) Interior view of conference room at bustle top – 43^{rd} floor level (source: Pelli & Crosbie, 2001, p.115)

[6] The 'bustle' is the projecting circle of office space appended to the typical floorplan from levels ground up to 43.
[7] Building By-Laws for the Federal Territory of Kuala Lumpur (UBBL) 1985 & the uniform Building By-Law 1984.

In the event of an emergency that is able to be contained on a single floor, a 'Stage 1 Evacuation' is mobilized[8]. 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. The diagrams below illustrates this total building evacuation, in terms of 4 recognised zones:

- *Low Zone* (Levels Ground to 37[9]); occupants evacuate down fire stairs to Ground level Concourse and immediately exit the building.
- *Middle Zone* (Levels 40 to 60); occupants evacuate down / up 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* (Levels 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* (Levels 78 to 86); as with *High Zone*.



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 procedure [10]. 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

[8] ARIFF, A. (2003). ***Review of the Evacuation Procedures for the Petronas Twin Towers.*** CIB-CTBUH International Conference on Tall Buildings: "Strategies for Performance in the Aftermath of the World Trade Centre". Kuala Lumpur, October 2003. CIB Publication No: 290. pp.35-42

[9] Levels 38-39 are occupied by the mid-zone mechanical floor, with thus no ordinary office population.

[10] Though the skybridge contributes significantly to the evacuation efficiency of the towers, it was not originally conceived for that reason – as disclosed by Arlida Ariff, Chief Executive of KLCC; the holding company for Petronas Towers in an interview with the author in 2004. 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 of Cesar Pelli & Associates, 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, L. (2003). ***Life Safety System design for the Petronas Twin Towers.*** CIB-CTBUH International Conference on Tall Buildings: "Strategies for Performance in the Aftermath of the World Trade Centre". Kuala Lumpur, October 2003. CIB Publication No: 290. pp.43-46.

‘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, including increased fire-resistance of the thresholds between skybridge and towers, and pressurisation of the space (and adjoining sky-lobbies) to prevent smoke-ingress.

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 as-then current evacuation procedures as outlined above to enable the simultaneous evacuation of both towers at once. In this case the skybridge is effectively rendered unusable [11] and the strategy below is adopted:

- *Low Zone* (Levels Ground to 37); occupants evacuate down fire stairs to Ground level Concourse as in the single building Stage 2 evacuation.
- *Middle Zone* (Levels 40 to 60); occupants descend down / up the fire stairs to level 41, where they use designated shuttle elevators in the same tower to access Ground level.
- *High Zone* (Levels 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.
- *Top Zone* (Levels 78 to 86); as with *High Zone*
- The obvious implication of the total evacuation of both towers simultaneously as outlined above is that the shuttle elevators are used in the event of a fire, in the building at risk.

Additional Benefit – a significant space/cost saving

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 floor [12]. 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 [13]. This, in purely space-saving terms, went a long way to financing the cost of the skybridge, and is an important potential benefit for other buildings considering incorporating skybridges in the future.

Note: For a longer list of potential benefits (holistically and multi-disciplinary) in the use of skybridges, see Subsequent Research: Summarizing the Case for the Skybridge at the end of Paper 3 of this Narrative, page 15.

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[11] 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: Transport, Local Government and the Regions Committee. (2002) ***Tall Buildings.*** 16th Report of Session 2001-02. Volume 1. HC 482-I.). 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 48 seconds per floor to evacuate, approximately twice that observed in non-emergency evacuation drills (NIST (2005). ***Final Report on the Collapse of the World Trade Centre Towers***. National Institute of Standards and Technology. USA. Report NIST NCSTAR 1, published September 2005 as part of the federal Building and Fire Investigation of the World Trade Center Disaster. p.190).

[12] 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 – disclosed in interview between author and Arlida Ariff, Chief Executive of KLCC, 2004.

[13] 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”. 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).

Paper 2: New Paradigms in High Rise Design

Published in *CTBUH Review: the Journal of the Council on Tall Buildings and Urban Habitat,* 2004. Issue No. 3. Fall 2004. pp. 16-24. Council on Tall Buildings and Urban Habitat, Chicago, USA.

This paper is focused on another strong theme running throughout this submission – that of ‘research by design’ i.e. utilizing the crossover between teaching and research by testing out research ideas in the architectural design studio together with advanced architectural students. This research-by-design approach specifically informs Papers 2 and 6 of this submission.

The author has conducted numerous high rise design studios in the past eight years, at both the School of the Built Environment, University of Nottingham and the Illinois Institute of Technology Chicago. A wider selection of the resulting output from these studios is shown in the supporting document included with this submission (*Antony Wood. CTBUH Executive Director. Resume & Publications*). Paper 2 here is focused on the first of these design studios conducted in 2002 at the University of Nottingham. The project undertaken was based on the real project for the Heron Tower site in the City of London, and had the tutorial support of planning staff from the Corporation of London, and the Project Architect for the actual project from Kohn Pederson Fox Architects London. Whilst many of the projects presented in the paper involved ideas that were quite radical at the time, the reader should note that this studio was undertaken eight years ago (a long time in the fast-moving field of sustainability), and each project was a result of one student working in conjunction with the author for a period of just eight weeks. Thus, although the ideas still have value in current discourse – hence the inclusion of the paper in this submission – the detailed development of the ideas are limited and have been surpassed by subsequent research since (by both author and others).

The Paper presents ten projects which are grouped according to four predominant design approaches; (i) those inspired by the physical characteristics of place; (ii) those inspired by the environmental characteristics of place; (iii) those inspired by an attitude towards the building brief and internal spaces; and (iv) those inspired by an abstract / practical philosophy.

Project concepts in the second and third categories ranged from a project (“The Preferable Corner”) based on maximising the ‘preferable’ situation of a corner office in the plan form of the building, to another (“The Tree House”) attempting to recreate the concept of the tree-house on a large scale. But it is the projects that fall into categories (i) and (ii) as defined above that are most relevant to the central thesis of this submission, and are elaborated on below.

One of the major differences – and thus design opportunities – between a high-rise and a low-rise building is that a low-rise building can rarely relate physically or visually to a site much beyond its immediate surroundings. A high rise building, on the other hand, potentially has a visual relationship with a myriad of places in the city (differing at each horizon within the building) and this recognition became a driving force for several designs within the studio. One project (“Urban Axes”) based its entire plan on two major viewing corridors in the city, whilst another (“Building as Billboard”) manipulated its form and skin so that different parts of the building set up a visual relationship with places far and wide in the city. For example a huge façade digital screen addressed a small park across the street, whilst an active atrium space responded to the view from (and of) the building from Primrose Hill.

Other projects were inspired directly by the environmental opportunities of the site, one project ("Wind Tower") working with the harnessing of wind energy, whilst another ("The Sun Splice") created a huge slice in the building mass so as to maximize light and air to the spaces adjoining the site (something tall buildings very rarely do). Another project worked with the concept of maximum prefabrication of the building elements ("Prefabrication"), whilst another introduced hydroponic greenery into the building plan ("Hydroponic Tower"). A final one recreated the mixed uses typical of the ground floor in a scheme that attempted to sweep the city up into the sky ("High Rise Villages"). What bound all these varied projects and design approaches together was a clear rejection of the banal rectilinear box that typifies most high rise, and a desire to firmly relate the building to the specific site/city context.

The project concludes by reflecting on the designs created – as well as the predominant design directions in the built industry – by categorising ten common design approaches for tall buildings. These categories are either in existence already, or have great potential for the future. The value of each approach for the future is implied by the author in the paper, and formed the basis of the direction for future studios to follow (as an indication of where this led to, see the studio work that resulted seven years later, as outlined in Paper 6). These ten design approaches are summarized below:

1. **Abstract Sculpturalism.** Tall Buildings which are pre-occupied with their role in the city as purely pieces of 3-dimensional art (but at least are more interesting in form than the commercial 'box' approach).
2. **Cultural Symbolism.** Tall Buildings which are inspired by an element of indigenous culture (often a vernacular form) which is then usually extrapolated quite literally into high-rise form.
3. **Abstract Symbolism.** Tall Buildings which are inspired by an element of indigenous culture which is then incorporated into the design in an abstract way (often resulting in no apparent connection with the culture in aesthetics / three dimensions).
4. **Abstract Conceptualism.** Tall Buildings that are inspired by a philosophical idea that is not related to place (note: often the building become synonymous with place', though it is not necessarily inspired by it).
5. **Structural Expressionalism.** Tall Buildings whose predominant aesthetic and organizing principle is informed by an expression of the structural system.
6. **Locationalism.** Tall Buildings that are rooted in their context by responding to the physical characteristics of the site and surrounding area.
7. **Environmentalism.** Tall Buildings that are inspired directly by the climate in which they are located, responding to the opportunities offered by sun, wind, rain etc.
8. **Sustainabilism.** Closely related to the previous category, but the design takes on the additional specific agenda of energy/carbon reduction in either (or both) the embodied and operation aspects of the building.
9. **Internalism.** Tall Buildings which are inspired by a concept / organizing principle for the internal spaces of the building, which then dictates the design, external expression etc.
10. **Materialism.** Tall Buildings which are concerned predominantly with an expression of materials and, often, envelope – which may or may not be linked in to the environmentalist / sustainability debate.

(Note: Actual examples of the above categories are given in the Paper itself)

Paper 3: Bridging the gap: An analysis of proposed evacuation links at height in the World Trade Centre design competition entries.

Published in *Architectural Science Review,* 2007.
Volume 50.2. June 2007. pp.173-180. University of Sydney, Australia. ISSN: 0003-8628.

This paper builds on the initial skybridge research presented in Paper 1 by explicitly studying the numerous proposals for the replacement for the World Trade Centre towers following the events of 9/11. Since the ideas for the skybridge were largely inspired by this event, it is fitting that many of the competition entries to replace the towers embraced skybridges in a significant way. 27 proposals (including five of the final seven competition entries) suggested some form of connection between a number of towers at height, ranging from the rectilinear five-tower gridded matrix of the Richard Meier team, to the 'Kissing Towers' scheme of Foster & Associates.

The paper describes the five final competition entries employing skybridges / connections, and analyses the design and technical approaches so as to suggest possible ways forward for overcoming the logistical challenges of incorporating skybridges in tall building design. One of the conclusions is that an urban-scale competition such as that at the WTC site offers a prime opportunity for implementation of the skybridge, since it presents the rare chance for the design of several towers over a large urban area to be realized together, thus partly overcoming the logistical challenges of towers being built by different owners/developers/architects, at different periods in time and housing different functions.

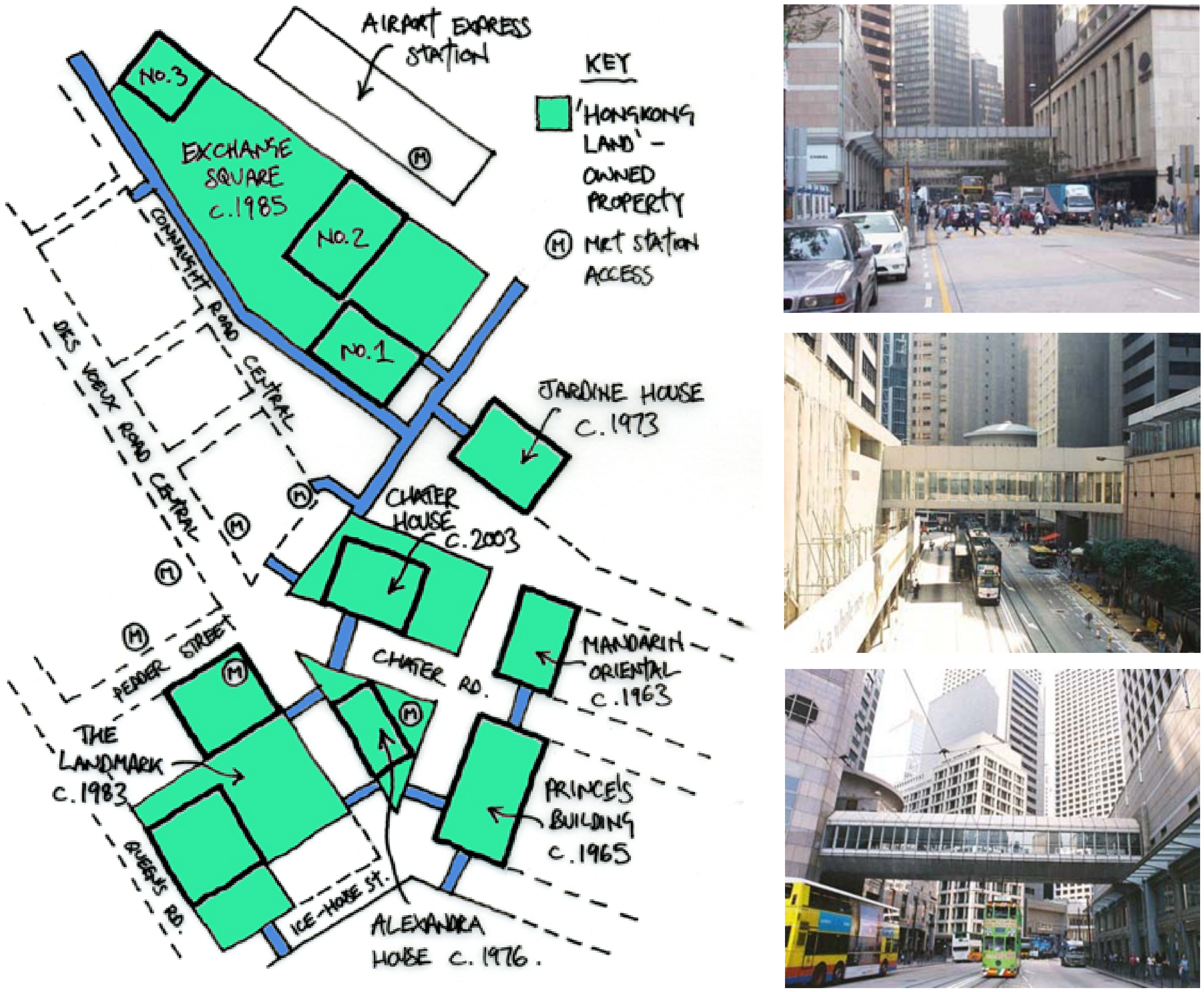
As a counter-point to this conclusion on the benefits of the larger, urban-scale development however (i.e. to demonstrate that it is possible in an incremental way), the Paper also presents the case study of the Hong Kong Central district skybridge network, which evolved over several decades. On this network one can walk above the ground plane for several square kilometres without touching the ground – a transparent, public route through traditionally non-public buildings (office towers, bank headquarters, hotel lobbies etc). This route spreads for some seven kilometers and brings into contact approximately 40 buildings. The network has overcome many of the logistical challenges of implementing skybridges at height – especially the merging of the public / private realm which has essentially elevated and extended the public domain upwards. It is thus worthy of further study and subsequent research is presented below, following publication of Paper 2.

Subsequent Research: Urban-scale case study: Hong Kong (unpublished)

It is perhaps fitting for commercially-focused Hong Kong that the concept of an elevated walkway linking buildings that is now in evidence extensively throughout the city began life as a purely commercial proposition. The network began in the 1960's with the building developer HongKong Land who, in the period between 1963-65 completed two buildings on adjacent plots to the west of Statue Square in the heart of Central district; the twenty-six storey Mandarin Oriental Hotel and the twenty-eight storey Prince's Building. Recognising the potential benefit for sales in the six-storey retail podium beneath the Prince's Building by encouraging guests from the adjacent Mandarin Hotel to circulate directly from the adjacent site, HongKong Land constructed an enclosed, air-conditioned bridge across Chater Road linking the two properties at the second level. Thus, in 1965, the first skybridge in Hong Kong was born [see images below].

This move proved so successful both financially and operationally that, as HongKong Land acquired or built other buildings in the vicinity, further bridge links were constructed to connect the buildings to the network. The 37-storey

Alexandra House, completed in 1976, became an important piece in the jigsaw, since this opened up extension of the network to the 1962 twenty-storey Swire House (later replaced by Chater House) and further over Connaught Road in 1973 to the tallest building in Asia at the time, the 52-storey Jardine House (then known as the Connaught Centre).



The birth of the Hong Kong skybridge network – the linking up of properties from the HongKong Land portfolio in the 1960's / 70's: (a) Plan of HongKong Land properties (Source: compiled by author, from information provided by HongKong Land) (b) 1965. The first skybridge in Hong Kong, connecting the Mandarin Hotel to the Prince's Building, (c) 1983. Skybridge between The Landmark and Alexandra House, (d) 1990. Skybridge from Prince's Building over Des Voeux Road Central. (source for all: author).

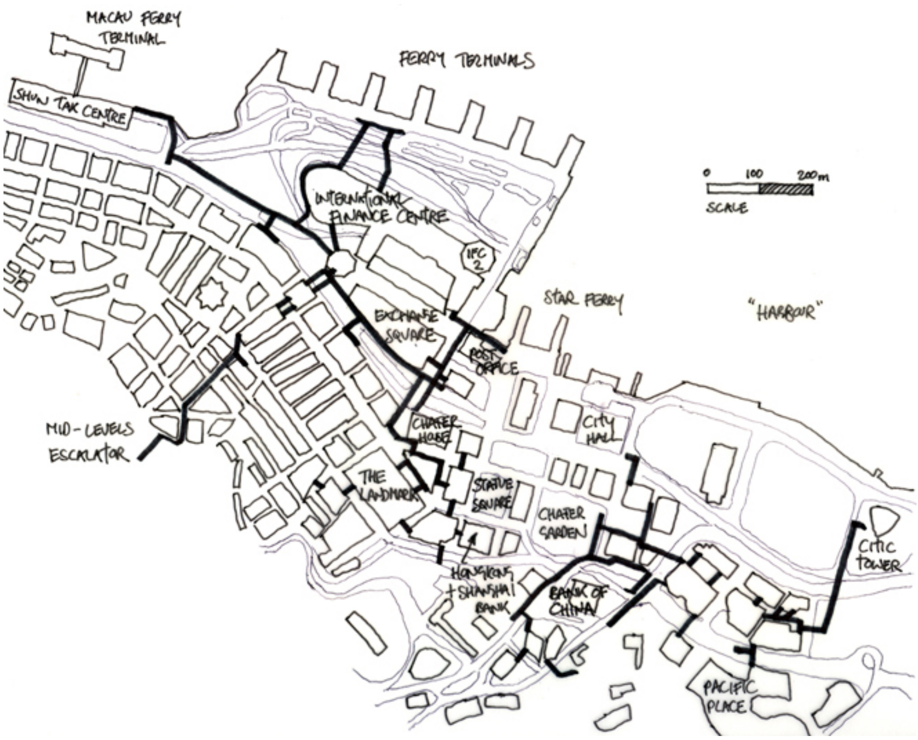
The 1980's saw further expansion of the network to include the Landmark complex in 1983 (comprising the 46-storey Gloucester Tower, 1980, and the 45-storey Edinburgh Tower, 1983), and the Exchange Square complex in 1985 (comprising two 52-storey towers; No.1 & 2 Exchange Square, 1985, and the 32-storey No.3, 1988). The final piece of the jigsaw was the 30-storey Chater House replacing Swire House (including replacement of the original skybridges) in 2003.

Today the portfolio of skybridge-linked HongKong Land buildings in the Central district draws together seven separate major building complexes, over 450,000 m2 in gross floor office / retail area and a working population of over 20,000 people [14]. In terms of the linked shopping areas – the original motivation for connecting the complexes with skybridges – approximately 35,000m2 of gross retail floor area is now linked over five separate sites – Prince's, Alexandra, The

[14] Figures interpreted by author, from information provided by HongKong Land.

Landmark, Chater and Exchange Square. This gives the collective retail offer a 'critical mass' which would be significantly diminished if it was housed in five isolated buildings.

Whilst HongKong Land was busy creating this network of linked buildings in the 1960's and 70's, other organisations in Hong Kong – including local planning administrations and other building owners – began to realize the positive potential offered by skybridges; i.e. diminished pedestrian congestion, increased mobility, improvement of pedestrian environment, the potential for overlap/connection of functions between buildings, etc. The concept of skybridges thus became adopted unofficially as a planning tool and the network began to significantly expand. This has continued up to the present day where now, in the Central district alone, the network spreads for some seven kilometers and connects approximately 40 buildings [see plan left].



Extent of skybridge networks in Central District of Hong Kong today (source: by author)

The skybridge route itself is varied. Almost without exception, if not enclosed, all bridges within the network are at least covered, with many being internal, air-conditioned links. This 'climate moderator' network makes sense in a predominantly hot, humid, busy-vehicular traffic environment such as Hong Kong and is very much a realization of Yeang's 'Tropical Verandah City'; a shaded, pedestrian network protecting from the heat, noise and pollution of the city. Other elevated pedestrian networks exist around the world for similar but inverse climatic reasons. In both Minnesota [15] and Calgary in North America, for example, an extensive network of heated, enclosed bridges link buildings at first floor level throughout the downtown city centre to protect pedestrians from the harsh external environment during the winter months.

A further benefit of the skybridge links between buildings in Hong Kong is the alternative routing – and possibly paths of redundancy – offered in terms of service supplies[16]. When Hong Kong Land decided that they would install air conditioning into the Landmark Building in the 1980's, for example, rather than dig trenches in the streets for the pipes needed to transport seawater (used for as a coolant in the water-cooled systems), they installed the pipes within their

[15] In the case of Minneapolis, this 'skyway' network began in 1962 and now extends for some 11 kilometres, giving access to 200 stores, 34 restaurants, 1500 apartments, 4000 hotel rooms, 19 million square metres of office space and 230,000 square metres of retail space, all without having to touch the ground (MVRDV (2005). ***KM3: Excursions on Capacities.*** MVRDV in conjunction with the Berlage Institute. Actar-D, Barcelona. p.491).

[16] This potential for 'alternative routing' for power and other utility-services at height through skybridges is interesting, since it has very direct relevance to the post-9/11 world we inhabit today. One of the recommendations of the report into the World Trade Centre disaster (NIST, 2005) is that redundancy (i.e. multiple routing) for essential service supplies (e.g. sprinkler supply) needs to be introduced into tall building design. Skybridges certainly offer this potential, as demonstrated by several of the Hong Kong skybridges.

covered walkways, connecting services from building to building at a much lower construction cost. This is made possible through much of the network being owned and operated privately. Control of the 'skybridges' (e.g. to run services through) is thus within the private – as opposed to governmental – realm. This control element has a significant impact on the success of the skybridge network, since the form of the skybridge and space it encloses is seen as an extension of the tower lobby and/or retail mall. Each owner-operator thus puts in significant resources (probably much greater than that financial contribution which could be afforded by typically resource-stretched local governments) to ensure high levels of cleanliness, maintenance and security of the skybridges both internally and externally. This, in turn, has a significant effect on maintaining a high-quality environment for the pedestrian.

Today, then, the elevated skybridge network of the Central district, and other areas, of Hong Kong, is a significant urban gain for pedestrians. Although the network began life as a commercial enterprise to link and expand retail floor areas, now the network is much more than an extrapolated shopping mall. Many of the urban benefits of this raised public route in Hong Kong – as well as other urban networks and skybridges – are summarized in the section following.

Subsequent Research: Summarising the Potential Benefits of the Skybridge (unpublished)

More extensive research has been conducted by the author into the myriad aspects of the skybridge than is able to be presented as part of this submission. As a part-conclusion to the work on skybridges presented here, some of the potential benefits are highlighted below:

1. Offer alternative circulation routes for pedestrians in increasingly congested cities
2. Offer protection from extreme climatic elements (hot / cold / humid / rain / wind etc)
3. Allow the more efficient (and energy-efficient) circulation of occupants between neighbouring towers.
4. Offer improved evacuation efficiency (and multiple routing options) in tall buildings.
5. Offer improved Emergency Responder Access to tall buildings (i.e. firefighters can access at risk tower at high level through elevators in adjoining 'safe' tower)
6. Offer access to a better environment at height in increasingly denser cities (light / air / view)
7. Offer the opportunity for a greater sense of 'community' to develop than in tall buildings generally (skybridges as 'streets in the air' social-interaction spaces).
8. Offer the potential for creating gardens at height – 'skybridge as skygarden'.
9. Allow the linear migration of plants (and possibly animals) within cities encouraging bio-diversity: the 'skybridge as landscaped corridor'.
10. Allow easier access to functions shared between towers, thus increasing the viability of those functions.
11. Allow the expansion of commercial or retail space into a neighbouring building.
12. Offer the potential for increasing floor space in a building – 'skybridge as floorplate' between towers
13. Allow the accommodation of potentially noisy renewable energy-generating / environmental technologies outside the footprint of the tower (e.g. wind turbines).
14. Offer redundancy and alternative routings for services provision
15. Offer a gain in commercial floor space / building revenue, through less need for multiple fire stairs and refuge floors
16. Offer the opportunity for a better urban fabric related 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.

Paper 4: Sustainability: A New High Rise Vernacular?

Published in the *Journal of the Structural Design of Tall and Special Buildings.* 2007.
Vol. 16, Issue No. 4. December 2007. pp. 401-410. John Wiley & Sons Ltd., UK. ISSN: 1541-7794

This paper, perhaps more than any of the six submitted here, encapsulates directly the over-riding theme of this submission – the search for a new typology for tall buildings. The paper, when published, broke new ground in the field of tall buildings by, for the first time, considering the evolution of the skyscraper in environmental terms, rather than architectural or technical terms. The paper begins with a study of the sustainability credentials of tall buildings – both the case 'for' and the case 'against'. It needs to be understood that tall buildings are by no means accepted by all as a sustainable building type moving forward – in fact many consider the typology to be anti-sustainable – and many of the reasons cited have significant substance (shown in the extracted table below, together with the case 'for'). At the same time, many of these individual points fail to recognize the bigger picture beyond the single building i.e. denser cities with concentrated land use and infrastructure offer more sustainable patterns of life generally (though tall buildings are not the only solution for creating denser cities[17]).

Case 'Against' Tall Buildings - according to Roaf[18]	**Case 'For' Tall Buildings - according to Author**
Higher embodied energy in constructing at height – structure, materials etc.	Denser cities = reduced transportation (and consequential impact on environment).
High energy consumption in operation – elevators (up to 15% of bldg energy use), services etc.	Efficient land use in population concentration = reduced suburban spread / loss of countryside.
Higher energy consumption for both maintenance and cleaning (e.g. replacement of façade silicon joints).	Concentrated cities = reduced size of infrastructure networks (urban / suburban, power, services, waste etc).
Impact on urban scale; wind downdrafts, overshadowing (solar rights), wind rights, right to light, etc.	Proximity of residence and workplace = less travel time (less wasted time?).
Overpopulation in certain localities / greater demand on existing urban services and infrastructure.	Greater potential for mixed-use = less travel time, less duplication of building form / resources.
Anti-social internal environment – lack of open, recreational, communal space (especially in residential).	Standardisation of floor plates and use of materials = material (prefabrication?) efficiencies.
Greater wind loading at height (impact on size of primary structure, façade design etc).	Higher wind velocities at height = greater potential for harnessing wind energy.
'Sealed' environments at height; requirement for air conditioning, artificial lighting etc.	Higher atria / volume of space = potential for natural ventilation through increased 'stack effect' etc.
Less net usable area to gross area and restrictions on internal planning; vertical circulation core etc.	High 'thermal mass' = potential for use in natural ventilation / heating / cooling strategies.
Safety and Security fears (especially post 9/11) – including safety during construction.	Long, narrow floorplates = potential for good internal daylighting (and thus reduced energy).
Low ratio of external building surface area per floor area – impact on potential for solar arrays etc.	Space in the Sky = potential for 'secure' communal /recreational spaces, away from traffic, pollution etc.
Implications of power failure (impact on vertical circulation, safety etc).	Potential for more efficient energy production and distribution systems
Increased travel time (wasted time?).	Urban densification adds value and vitality to cities
People suffering from vertigo – building occupation / human rights legislation?	Urban signposting / way-finding
Recycling potential / urban impact of demolition / disposal of materials after demolition.	Increased access to view, light and air at height

Table: Summarised cases 'For' and 'Against' Tall Buildings as an appropriate typology in urban centres

[17] It needs to be noted that this whole issue of dense, sustainable city versus unsustainable suburban sprawl is by no means universally accepted by all as the way forward and there is much debate on the issue. Many individuals and organizations – the New Urbanists in particular – tout the benefits of the medium density, compact, walkable suburb as striking the right balance between more efficient energy use and an acceptable social environment in which to live/work. This debate is touched on in several areas in the papers submitted here. The author is of the opinion that it should not be a case of 'either/or', but of 'both'. Whilst the ultra-dense high rise city may be an option for many of the brand new cities being considered and created around the world, the fact remains that most existing cities have both city core and suburb. We need to find denser, more efficient, more sustainable solutions for both city core and suburb moving forward.

[18] ROAF, S., CRICHTON, D. & NICOL, F. (2005). ***Adapting Buildings and Cities for Climate Change; A 21st Century Survival Guide.*** Architectural Press Oxford.

The paper next goes on to chart the rise of an ‘Environmental Conscience’ in tall building design i.e. looking to those built tall building projects which have gone beyond the commercial or iconic approach which predominates internationally. The study begins with Frank Lloyd Wright’s 1956 Price Tower (which, despite its failings, was a building which looked for social sustainability in its incorporation of both office and residential function on each floor, as well as environmental attitudes towards skin and shade), before charting a dozen or so other ‘environmental high rise’ projects up to the current day and beyond. These case studies include Skidmore Owings and Merrill’s 1984 National Commercial Bank Jeddah (a demonstration of the far more sensible solution of building stone, rather than glass, towers in the intense solar desert environment of the Middle East); BEP’s 1986 Dayabumi Tower in Kuala Lumpur (a building that uses the Islamic ‘Jalil’ as external skin and manages to create an expression which is distinctly ‘local’ as well as environmental); Norman Foster’s 1997 Commerzbank Frankfurt (possibly still the best high rise building built in terms of both sustainability and quality of internal space); and the high-rise portfolio of Ken Yeang of Hamzah & Yeang.

The Paper also looks – with some critical analysis – to current and future ‘environmental’ high-rise proposals. One interesting development recognized is how sustainable technologies – as exemplified by Atkins’ 2008 Bahrain World Trade Centre towers with their three huge turbines slung between two towers – seem to be increasingly influencing the aesthetics of tall buildings. In the worst cases (of which the Bahrain project is not), these environmental technologies seem to be being used as ‘trophies’ to suggest ‘green’ credentials in the building which are often sadly lacking beyond this ‘applied technology’ layer.

In studying these positive and negative examples, the paper also draws on the classification of tall building design approaches (or ‘isms’) that was suggested by the author in Paper 2 (e.g. Literal Cultural Symbolism). It suggests that, to date, most tall buildings that have attempted to relate to the culture in which they exist have taken either a ‘Literal Cultural Approach’ (i.e. taking an element from the local vernacular – e.g. the Chinese pagoda – and inflating that into a tall building), or the ‘Abstract Cultural Approach’ (i.e. being inspired by some aspect of the local culture which is then abstracted into the plan or expression of the building). However neither of these approaches have, in the author’s view, resulted in completely satisfactory results. The paper suggests that designers need to go back to the influences that created the vernacular in the first place (usually practical and climatic), rather than try to recreate the vernacular, as very eloquently suggested by Yeang in the following quote:

> *“As the location’s most endemic factor, **climate** provides the designer with a legitimate starting point for architectural expression in the endeavour to design in relation to place, because climate is one of the dominant determinants of the local inhabitants’ lifestyle and the landscape’s ecology.”* [19]

The paper concludes by considering – in conjunction with the learning from the Design-Research undertaken in other papers (See Paper 2 as an example) – a set of design principles for the sustainable skyscraper of the future. This set of principles has been reconsidered and expanded by the author since the original 2007 publication of this paper, and is thus presented in its expanded form in the Conclusion to this Narrative (see Pages 24-25).

[19] YEANG, K. (1996). ***The skyscraper bioclimatically considered; a design primer.*** Wiley-Academy. UK.

Paper 5: Five Energy Generations of Tall Buildings: A Historical Analysis of Energy Consumption in High-Rise Buildings

Published in the *Journal of Architecture.* 2009.
Volume 14, No.5. October 2009. pp.591-613. Routledge, Abingdon, UK. ISBN: 9780415570077

This paper broke new ground when published by being the first paper to historically categorize tall buildings according to their environmental credentials and energy performance. Though there have been numerous historical studies categorizing tall buildings in terms of their architectural style, function, height or structural strategy, no previous study had sought to classify tall buildings according to common factors affecting their sustainability credentials – their shape and form, façade, attitude to natural lighting, ventilation strategies, etc. In undertaking this historical audit, the paper aimed to draw important lessons in factors affecting the energy performance of tall buildings, for the benefit of future projects.

By examining common elements across specific buildings from the last 125 years, the paper established five 'energy generations', as outlined below:

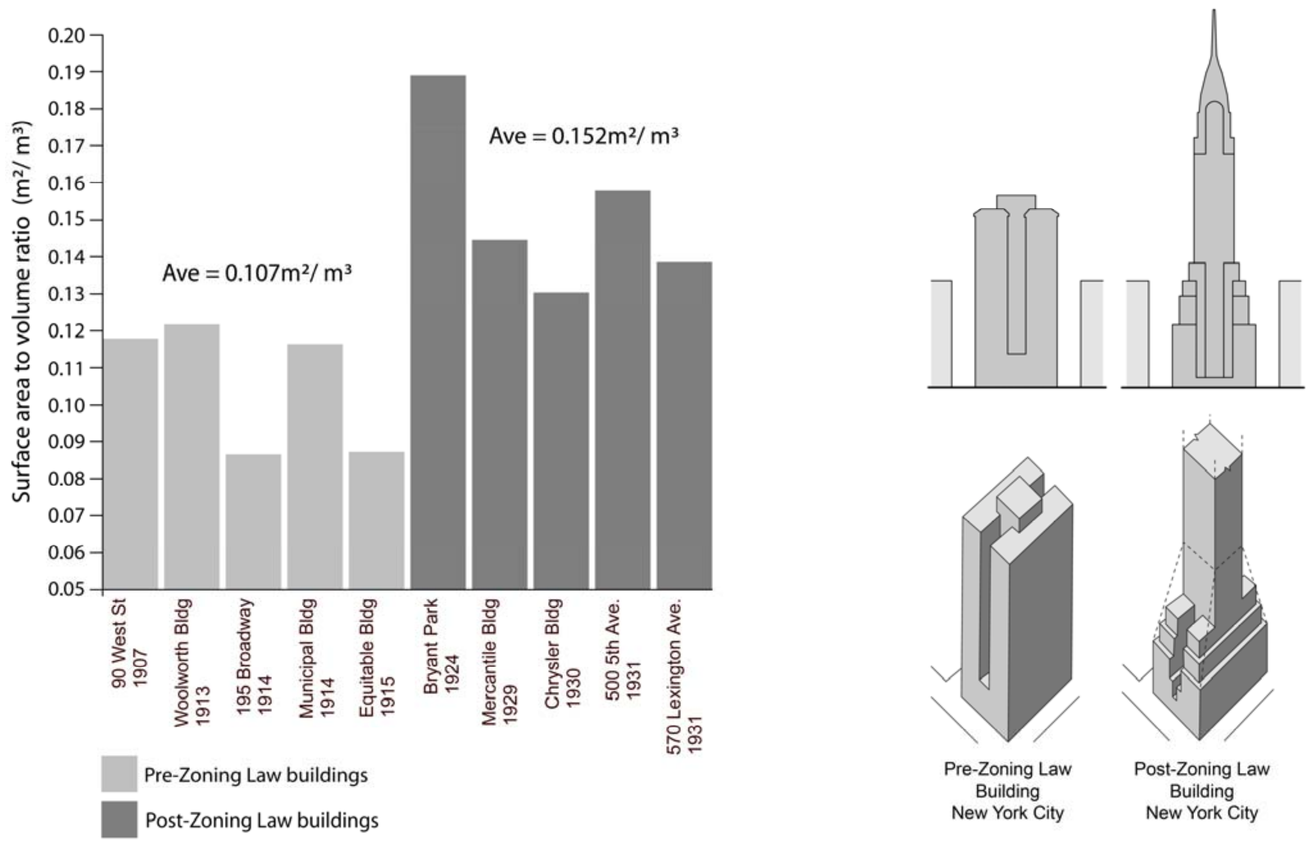
1. From the Birth of Tall Buildings in 1885, to the 1916 Zoning Law
2. From the 1916 Zoning Law to the Development of the Glazed Curtain Wall, 1951
3. From the Development of the Glazed Curtain Wall, 1951, to the 1973 Energy Crisis
4. From the Energy Crises of 1973, ongoing to the Present Day
5. From the 'Rise of an Environmental Consciousness' (1997), ongoing to the Present Day

These generations were established according to predominantly external factors: regulatory changes, developments in technology and materials, changes in architectural thinking, and economic / commercial drivers – all of which affected the energy performance of tall buildings in some way, as exemplified in summary below.

The characteristics of first-energy generation buildings (1885-1916) typically employed dense, masonry facades and were compact and bulky in shape, rising up in one straight volume from the building street frontage. This resulted in a small surface area to volume ratio which gave the building an inherent energy efficiency, since the lower surface area of façade per square footage of internal floor area acted to reduce heat loss[20] through the building envelope (which also contained a high degree of thermal mass through the typically heavy masonry employed). In addition, operating energy consumption was low because technologies such as flourescent lighting and air conditioning were relatively undeveloped (hence the development of the extruded, bay-type Chicago window to maximize natural light). Energy was thus predominantly consumed through space heating and vertical transport. The 1885 Home Insurance Building, Chicago (generally recognized as the first skyscraper) and most of the early Chicago-school buildings are typical of this first energy generation of buildings.

[20] It should be noted that, though space air conditioning did start to exist from the late 1920's, it did not become prevalent until the third energy generation (i.e. around the 1950's onwards). Thus winter heat loss was more of an issue than summer heat gain in first and second generation buildings, from an energy perspective. This was especially true since the building envelopes were predominantly constructed of masonry with smaller windows in comparison to most glass towers of the 1950's onwards. The high thermal mass in the envelope also assisted in creating generally naturally comfortable internal environments by maintaining warmth in the winter and absorbing excess heat gains in the summer months.

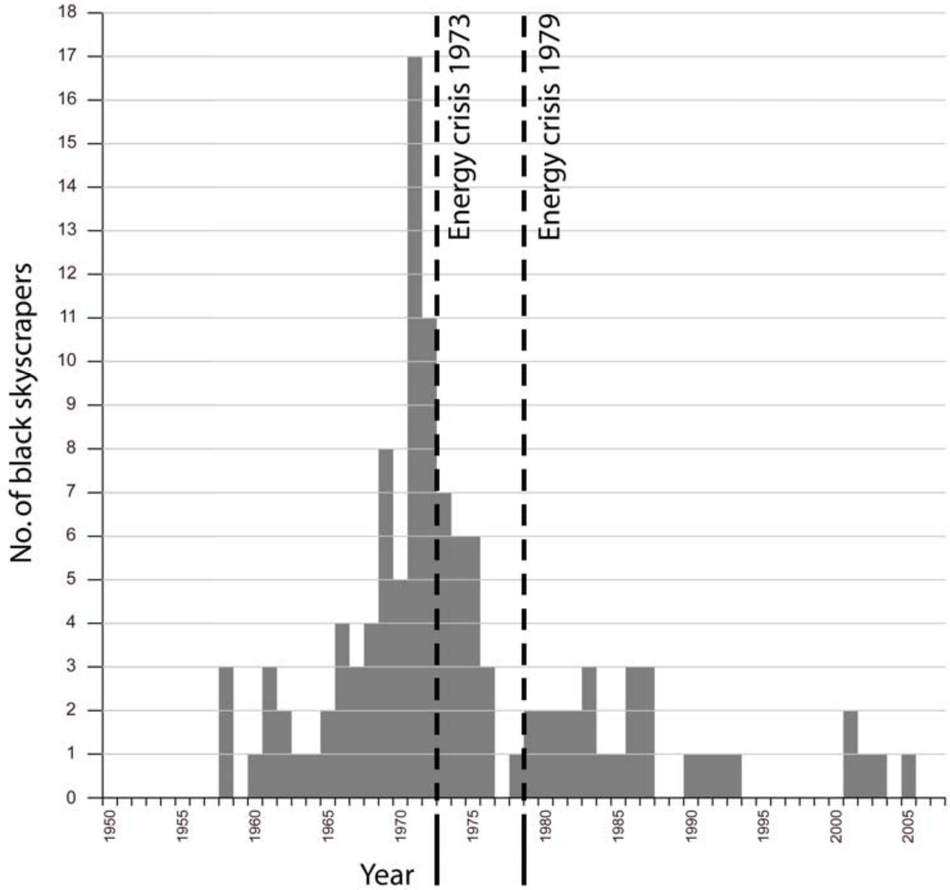
The relatively low energy consumption and inherent surface-to-volume sustainability of the first energy generation began to change, however, as a direct result of the New York Zoning Law of 1916, which ushered in the second energy generation outlined in the paper (1916 – 1951). The Zoning law was brought in to counter shear, massive buildings such as the 1915 Equitable Building New York, which was considered too massive for its impact on the street and the blocking out of light and air at street level. The new Zoning law thus required buildings to step back at certain levels above the street, creating the ‘wedding cake’ skyscraper shape, which resulted in a larger surface area per volume of space / floor area [see diagrams below]. This larger surface area resulted in higher heat loss through the envelope, and thus more energy required for space heating. At the same time, regulations were also requesting higher lighting levels, so although the slenderer second-generation buildings had better natural light penetration generally, the energy gains from this were offset by the requirement for more artificial lighting.



Diagrams showing differences in Surface to Volume Ratios in first and second energy generation buildings, pre- and post- 1916 New York Zoning Law (source: by authors).

Third energy generation buildings (1951-1973) were heavily influenced by the modern movement and the development of glazed curtain walls from the 1950’s onwards (a typical example being SOM’s 1952 Lever House, New York). Façade glazing percentages here increased from the 20-40% of overall façade typical previously, to 50 – 75% in these new, modern facades. Since this glazing was also predominantly single glazed and of poor U-value, this had a massive impact on heat loss/gain and thus energy consumption – especially since the internal spaces were typically hermetically sealed boxes, totally reliant on mechanical conditioning. Ironically, though the percentage of glass in the envelope was high, tinted glazing often resulted in low daylight penetration so that high artificial lighting levels were also required.

Another huge external influence which ushered in the fourth energy generation (1973, ongoing to the present day) were the energy crises of 1973 and 1979. For the first time these events challenged the notion of an endless supply of readily-available energy, and designers began to consider factors such as the U-value and thermal performance of the façade. Double and triple-glass facades began to be used within better technically-designed curtain wall systems, air conditioning and other technical equipment began to become more efficient, and energy consumption began to be reduced in comparison to third energy generation buildings. An interesting study presented in the paper and extracted here, which demonstrates the impact of the energy crises on tall building design, is the number of black skyscrapers constructed (and proposed) in the US in the years immediately prior and after the energy crises [see graph below]. Due to the higher heat loss / gain typical of black facades, the energy crises soon brought this fashion for dark facades in the US to an effective end.



Graph showing number of black skyscrapers completed in the US before and after the energy crises of 1973 and 1979

The fifth energy generation of buildings (1997, ongoing to the present day) has seen a progression of the attitudes towards more energy efficient techniques that were introduced during the fourth generation, though many of those gains have been offset by the requirements for increased energy by computers and other technical equipment. The paper suggests that buildings typical of this generation – such as Foster & Associates 1997 Commerzbank Frankfurt – perhaps give the best clues as to how to move forward with better energy responsibility into the future. The Commerzbank building demonstrates many of the characteristics typical of fifth generation buildings – a full building height central atrium providing natural lighting and ventilation to internal office spaces; the use of large, open skygardens to further increase daylight penetration to office areas and give internal communal, gathering spaces; a façade design that allows for natural ventilation for over half the year via operable windows; water-based cooling system of chilled ceilings, etc. Devices such as these and others - strategies to assist with natural and mixed-mode ventilation, high-performance and double-skin facades, the harnessing of renewable energy within the building skin and form, are suggested by the paper as worthy of further research and development into the future.

The paper concludes that, whilst the majority of tall buildings constructed today continue to demonstrate ‘fourth generation’ characteristics – meeting regulatory energy performance criteria but not bettering these by any substantial amount – there is a growing number of high rise designs and completed buildings that aim to go above and beyond the norm in terms of reducing primary energy consumption. In keeping with the search for a new, more appropriate tall building typology as suggested overall in this Narrative, this is the direction that tall buildings need to head in today.

Paper 6: The Re-Making of Mumbai: A CTBUH-IIT Collaborative Architectural Design Studio.

Published in *CTBUH Journal: The International Journal on Tall Buildings and Urban Habitat. 2010.* Issue 1. pp 22-33. January 2010. Council on Tall Buildings and Urban Habitat, Chicago, USA. ISSN: 1946-1186

This paper draws together much of the research presented in the other five papers presented here, and the central thesis of seeking a new typology for tall buildings, by demonstrating the application of many of the principles established to a theoretical high rise project in Mumbai. This research is the result of a design-research studio undertaken with architectural students at the Illinois Institute of Technology in early 2009.

The paper begins with an explanation of the studio objectives and the cultural setting of Mumbai following a 10-day fieldtrip with the students there. The project is set in the C-ward of Mumbai – an historic district which has seen no maintenance of the dilapidated buildings or infrastructure in many decades and is also one of the most densely populated places on the planet. As the paper explains, it is at best debatable whether the area is suited to tall buildings at all, yet high rise are a part of the real urban vision there and thus the studio accepted the premise and strove to create a cluster of tall buildings that were inspired by the specific cultural setting of Mumbai. Skybridge connections were a requirement of the brief.

The paper first explains the design processes undertaken in the studio and the struggle to find an appropriate solution for the site. This was especially difficult because of the challenge of getting 12 students to transcend individual ego to work together on one common scheme. The paper explains in detail how these challenges were overcome and how a common, agreed architectural framework was created – and how this evolved from a consideration of site, environment and culture. The paper then describes the six design schemes that resulted from the studio, and in particular the idea of ‘agenda’ that was embraced in each tower i.e. that aspect of the building that relates to the city and sense of place, and which gives something to the city beyond the program of the building itself.

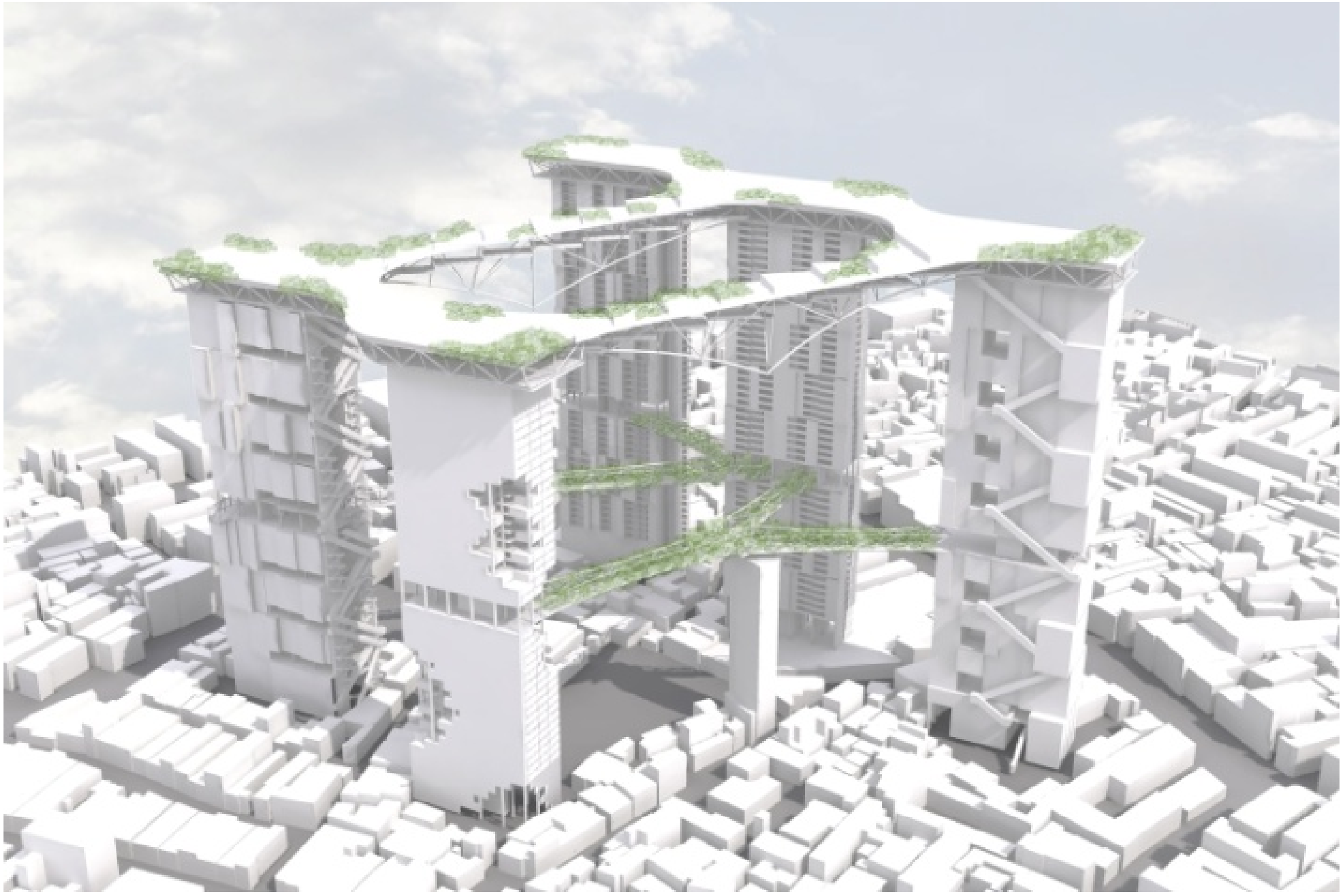


Image showing the Remaking of Mumbai design-research project, testing many of the principles presented in this submission

The *Annapurna* [Food] Tower sought to create a new vertical residential community based around the concept of urban agriculture; partly as a source of income for residents, partly as a device to introduce organic material and 'allotments' in the sky, and partly through a desire to create food at point of need. This latter aspect was particularly important, to help counteract the loss of agricultural farming land in India through urbanization, and to reduce the energy/carbon implications of transporting food from around the country / world. Thus the scheme incorporated a 'vertical farm'[21] at the tower's southern end, as well as a public escalator route which traverses the façade to the public skybridge levels, acting also as a continual landscaped corridor to allow migration of plant species throughout the scheme.

The *Bhangar* [Recycling] Tower is inspired by issues of waste management in Mumbai and creates a residential community bound together by aspects of material recycling and waste. Whereas wholesale waste management is lacking (along with most civic infrastructure) in Mumbai, there is an informal element of waste handling where local 'rag pickers' sort through waste and recycle anything of value. This concept is embraced into the tower, with local 'cottage industry' type operations handling different materials at different horizons within the tower; paper, plastics,

[21] The idea of the hydroponic-inspired vertical farm has been developed in several studios convened by the author. Though the concept poses considerable challenges in its implementation, the potential benefits are significant, including: (i) Year-round crop production, relatively free from climate fluctuations and pestilence, (ii) Elimination of chemical run-off typical of traditional farming – from pesticides, fertilizers etc, (iii) Production of food at point of need (i.e. cities) thus reducing the energy/carbon implications of food transport, etc. For more on the concept – and detail – of vertical farming, see DESPOMMIER, D. & ELLINGSEN, E. (2008). **The Vertical Farm – The origin of a 21st Century Architectural Typology.** CTBUH Journal 2008 Issue III. pp. 26-34. Council on Tall Buildings and Urban Habitat, Chicago. ISSN: 1946-1186

glass, metals, leather etc. These facilities handle waste for not only the occupants of the tower itself, but the entire linked community of five towers. The design also takes the agenda several stages further – the facades of the tower utilizing reclaimed bamboo for shading, etc.

The *Barsaat* [Rain] Tower looks to maximize the huge deluges of rain falling during the three months of the Mumbai Monsoon each year (and shortage of water at most other times of the year) by recycling and storing maximum rainwater from the building façade[22] and site. In addition the project embraces the important cultural relationship between people and water in India by incorporating bathing and other cultural activities into the tower.

The *Gyana* [School] Tower tackles head-on the dire shortage of schools / educational facilities in the C-ward by incorporating a high-rise school alongside the residential function. The two functions are split in plan by the shared vertical core, and are focused around three-storey atria; a private, residential garden atria to the north and the more active school atria to the south where many of the communal facilities take place at differing horizons within the sky – school canteen, library, sports facilities etc.

The *Swadeshi* [Textile] Tower is inspired by the *dhobi ghats* of Mumbai – the large, outdoor clothes washing areas that facilitate perhaps 90% of laundry in the city. The design is also inspired by the very Asian tradition of hanging clothes on poles from high rise apartments to dry. This latter aspect often gives the appearance of the façade itself being made of clothes, and this local tradition is embraced positively in the design of the new tower. In terms of the *dhobi ghat* operations, based on the concept that if we are making a push for the vertical city then all the aspects of the ground floor need to be swept up into the sky, the tower embraces the clothes-cleaning into the vertical realm, occupying the façade (where the clothes have the added benefit of solar shade to the residential spaces behind) and spreading out horizontally along the skybridge routes.

The *Yatra* [Procession] Towers is the scheme for the connecting skybridges and public realm between and around the towers. Based on the importance of ‘procession’ in the culture of India (religious festivals etc) the cluster of towers provides several continual public routes from ground to the vast new urban park created at roof level.

Though the project that resulted from these combined, place-inspired agendas is clearly a theoretical proposition and perhaps beyond the financial and governance realities of today, the ideas contained are, in the author’s opinion, all plausible and demonstrate many of the principles suggested in this submission. Tall Buildings need to engage with their sense of place in a far more fundamental way than they are currently, and go much further to intensify all aspects of the city in the sky so as to create the sustainable cities of the future that are needed.

A summary of the design principles for the sustainable skyscrapers of the future – developed from a reflection of the design-research projects as presented here, as well as the material in each of the research papers submitted – are presented in the Conclusion to follow.

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[22] There are several built high rise buildings that now incorporate rainwater recycling from their roofs. In the author’s opinion this is non-effective. The roof area of a tall building is negligible in comparison to the façade area and rain very rarely falls down vertically, especially at height. It is more often driven by wind and thus falls at an angle and therefore, if we are serious about recycling maximum rain water, it needs to be harvested from the façade, not the roof.

Conclusion; Design Principles for a New Tall Building Typology

What the six papers submitted here demonstrate is a clear line of research striving to move the typology of tall buildings away from its predominantly commercial preoccupation of the 20^{th} Century, to a more relevant, sustainable form for the future. Through a number of different studies and ideas – the benefits of physical skybridge connections; the need for buildings to relate to their setting physically, environmentally and culturally; the factors affecting energy performance in tall buildings, etc – the submission suggests a way forward for those conscious of creating tall buildings that meet the considerable challenges of the age. To reinforce this, and as a conclusion to the work and summary of the research submitted, the author offers the following principles for consideration in creating a new, more relevant typology for tall buildings:

1. **Variation in Form with Height.** Tall Buildings should not be monolithic vertical extrusions of an efficient floor plan, but should vary in form with height. This variance in form should be inspired by the building programme internally and/or the attributes of the location externally, both physically and environmentally. Since a tall building has a visual relationship with many places far and wide in the city, a visual dialogue with distinct places in the city can help inform a variance in form to further connect the building to its locale.
2. **Variation in Texture & Scale.** There should also be a variance in texture throughout the building, depending on the responsibilities of each different horizon within the form. The concept of scale should be introduced throughout the building - a tall building could be thought of (and designed accordingly) as a number of small buildings placed on top of each other within an over-arching framework of structure, systems, aesthetics etc, rather than one extruded, monolithic form inspired by a single plan. Each horizon of the building has different potential and opportunity.
3. **New Functions.** Traditional programmes for tall buildings should be challenged to increase the usefulness of the typology in sustainable cities of the future; This challenging of programme should occur on two levels (i) the type of functions that are traditionally accommodated within tall buildings, and (ii) the number of functions that are accommodated in a single tall building. Tall Buildings have the versatility to accommodate uses other than the standard office, residential and hotel functions that currently predominates. We could see the radical incorporation of functions such as sports (external solar control skin as rock-climbing wall?) or agriculture (hydroponic greenhouse? façade farms?) etc. In addition, cross-programming / mixed-use within tall buildings should be encouraged, to give opportunities for more sustainable live-work patterns (dualities of car parking, support functions, servicing etc) as well as variance in tall building form and expression to diversify urban form. The challenges of climate change require us to intensify every expenditure of carbon – i.e. create one thing but allow it multiple uses.
4. **Communal Spaces.** More open, communal, recreational spaces (hard or landscaped, large and small) need to be introduced into tall buildings, rather than an insistence on the maximum financial return on every square metre of floor space. Such spaces have been proven to improve the quality of the internal environment which has an impact on the productivity of workers, satisfaction of residents etc. This will have a direct financial return. In addition, the inclusion of these spaces will make tall buildings more suitable for socio-economic groups often marginalised from tall buildings through the lack of such vital spaces where a

sense of community can develop – families, the young, the old etc. Social Sustainability on an urban scale is a major challenge for our future cities.

5. **Envelope Opacity**. Tall Buildings should be designed with more envelope opacity, not as all-glass transparent boxes. Although the impact on both view out and natural daylighting internally needs to be balanced, excessive solar gain (and glare) should be reduced. In addition, greater façade opacity gives an opportunity for greater thermal mass to allow the envelope to be more insulated from external temperature and climate variations. More opacity also gives the opportunity for greater façade variance and expression.
6. **Organic Matter**. Vegetation should become an important part of the material palette for tall buildings, both internally and externally. The presence of vegetation will improve environmental quality on both the local scale (i.e. part of the shading / air cooling system of the building itself) and the city scale (quality of air, reduce heat-island effect etc).
7. **Skybridges**. As demonstrated in detail in this submission, skybridges have the potential to enrich both tall buildings and cities. More physical, circulatory, social and programmatic connections are needed, to help in intensifying the vertical realm and to make each tall building one element in a considered, overall urban framework.
8. **We need to bring ALL aspects of the city up into the sky.**