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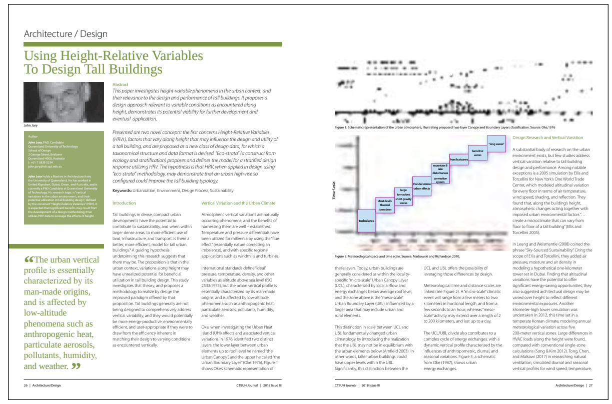


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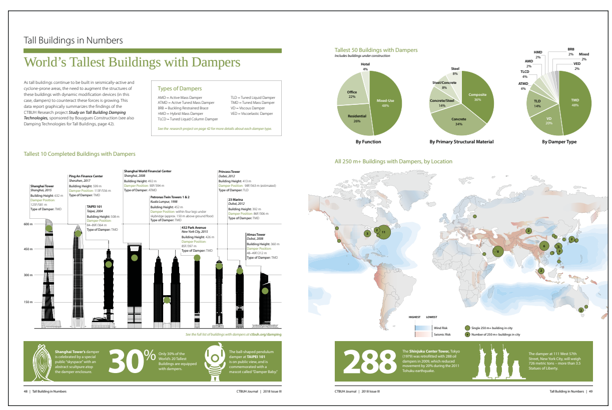



> "The tall building industry relies on anecdotal evidence to plan for vertical transportation needs in the construction phase. While these experiential methods are well-established, they seldom facilitate a detailed understanding of the time-based supply/demand profiles."

Grange & Savage, page 20

*Visit the daily-updated online resource for all the latest news on tall buildings, urban development, and sustainable construction from around the world at:* ***http://news.ctbuh.org***

## Americas

The ever-changing skyline of New York City reported three significant structural topping-outs recently. In descending order of height and position from north to south on Manhattan island, they are 53W53, and 35 Hudson Yards, and 121 East 22nd Street. In Midtown, adjacent to the Museum of Modern Art, 53W53 has achieved its ultimate structural height, on the way up to a 320-meter ultimate architectural height. The Hudson Yards tower is the first residential supertall to be constructed in the 15-hectare megaproject. David Childs, chairman of Skidmore, Owings & Merrill, is responsible for the design. Further east, the 22nd Street tower is the first in New York by Dutch practice OMA. The building's external form and internal organization is defined by a "prismatic corner" of glass that contrasts with the rest of the building's more conventional window layout.


121 East 22nd Street, New York. © Tdorante10 (cc by-sa)


Aria on The Bay, Miami. © Schwartz Media Strategies

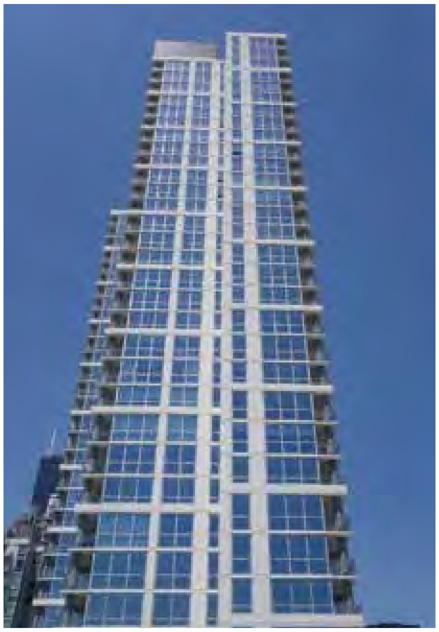
Following months of piling and excavation subterranean work, one of the tallest towers in downtown Miami's East Edgewater neighborhood is officially ready to go vertical. On June 15, a crew of about 75 construction workers poured the foundation for Elysee, a 57-story luxury condominium under construction, paving the way for vertical development of the waterfront high-rise to begin. Completion is set for 2020. Not far away, Aria on the Bay, a 53-story condo tower, completed construction with more than 90% of its 648 units sold. Both projects were designed by Arquitectonica.

Detroit is best known as the "Motor City" due to its role as an auto-manufacturing hub, but it was also a key rail hub. The decline of both industries, and the city in general, had long been embodied in the abandoned 18-story Michigan Central Station, once the world's tallest train station. But it was recently announced that Ford Motor Company will purchase the building and make it part of a major technology center in the urban core. The building will be fully restored and its first floor re-opened, Ford said. There will be restaurants, shops, bars and cafés, with offices on the floors above.

Though it has fared better than its onetime rival, Chicago nevertheless has substantial abandoned sites near its central core that have gone undeveloped for decades, left over from a once more-sprawling rail industry. The most significant of these, a 25-hectare site just south of the Loop CBD, is about to be transformed into The 78, so named because its size will equate to that of a new neighborhood, of which Chicago currently has 77. Skidmore, Owings & Merrill


Michigan Central Station, Detroit. © Albert Duce (cc by-sa)


The 78, Chicago master plan. © Related Midwest



Alta Roosevelt, Chicago. © Daniel Safarik

400 Lake Shore Drive, Chicago. © SOM

master-planned the Related Midwest project, which is to eventually contain more than one million square meters of development, including up to 4,600 homes, a 2,000-student joint university center, a new subway station, a revitalized riverfront and street grid, and towers of up to 290 meters. Though it might be years before The 78 is fully realized, the South Loop area is already building out toward the site. **Alta Roosevelt,** a 33-story rental apartment building designed by Pappageorge Haymes Partners, held its grand opening in spring, squarely catering to a class of tenant that wants a high level of amenities on site as well as proximity to transit. The project's podium-top amenity deck overlooks La Salle Street Station in one direction, and towards The 78 in the other, while higher units support views of both Lake Michigan and the Loop. Related and SOM also unveiled plans for the site of the defunct Chicago Spire, a megatall residential tower that stalled out after the 2008 recession. Instead, **400 Lake Shore Drive** will consist of two tapering towers, rising to 335 and 259 meters, respectively. A four-level podium below them will include levels for vehicle entrances, parking, meeting rooms, and a ballroom.

Always a crane-watcher's delight, **Toronto** did not disappoint this spring. Among the more ambitious plans was the announcement of a hybrid timber tower for the University of Toronto, which could become the tallest mass-timber-and-concrete hybrid building in North America. **The Goldring Centre** would house the university's School of Global Affairs, among other departments. Financed in part by government grants intended to promote mass timber buildings, the project will require a zoning change to go forward. Meanwhile, in the burgeoning Bay Street corridor, Foster + Partners announced plans for **50 Scollard,** a 41-story residential tower that will feature a new public plaza where a heritage building currently stands. The proposal seeks to relocate the entire building to the southeastern corner of the site, thereby freeing up space in front of the residential tower.

50 Scollard, Toronto. © Foster+Partners

In **Los Angeles,** a long-undeveloped hillside site at Angels Landing in the central business district is to host a twin-towered development, one of which would be a supertall at 311 meters. Designed by Handel Architects, the project would bring 120

**THEY SAID**

"In these dense cities like Chongqing, there's no room for big public parks [on the ground], so we have to lift them into the sky."

*Moshe Safdie, discussing Raffles City Chongqing. From "Is Chongqing's 'Horizontal Skyscraper' The Answer to Overcrowded Cities?" The Guardian, June 4, 2018.*

# A Tall Prototype for the Tropics

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**Richard Hassell** is the co-founding director of WOHA. He graduated from the University of Western Australia in 1989, and was awarded a Master of Architecture degree from RMIT University, Melbourne, in 2002. He has served as a Board Member of DesignSingapore Council, the Board of Architects, as well as the Building and Construction Authority of Singapore. He has lectured at many universities, and served as an Adjunct Professor at the University of Technology Sydney, and the University of Western Australia.

**Hong Wei Phua** joined WOHA upon graduation from National University of Singapore in 2006. He was promoted to Associate in 2014 and made Director in 2018. Hong Wei has been involved in a variety of projects, notably Crowne Plaza Changi Airport Hotel, Kampong Admiralty, Oasia Hotel Downtown and Enabling Village. He is currently working on a 340-room hotel and a 730-unit condominium building, both in Singapore.

Abstract

*Oasia Hotel Downtown (see Figure 1) is a prototype of land use intensification in the tropics. Unlike the sleek and sealed skyscrapers that evolved in the temperate West, this tropical "living tower" is designed to soften the hardness of the city and to reintroduce biodiversity into the urban jungle.*

*Responding to the client's requirement for distinct offices, hotel and club rooms, the tower comprises lushly landscaped sky terraces, inserted in naturally ventilated breezeway atria between room blocks. These provide guests and occupants generous amenity spaces throughout the high-rise with dynamic internal views that frame, soften and distance the surrounding dense urban fabric.*

**Keywords:** Green Walls, Mixed-Use, Sustainability, Urban Habitat

## From Vertical City …

The relentless tide of rapid urbanization and overcrowding in cities has caused green, open and civic spaces to shrink at an unprecedented rate, while chronic traffic congestion and pollution further compound the city's environmental conditions. Cities have become harsh concrete jungles with densely-packed vertical structures and reduced green spaces. Buildings are in a constant race to extend vertically. This pressure is exacerbated by the short-term, superficial requirements of private capital and investment, which mostly translates to inward-looking towers with a diminished public realm, or glossy sculptures that vie for height and symbolic status.

The modern tower has evolved as a suite of engineered solutions and financial efficiencies – maximized volume-to-surface-area ratios, compact centralized core, open-plan floor plates and high-performance, shiny skins. Inhabitants are kept comfortable by mechanical means. While boasting efficient structures and systems, buildings still account for nearly 40% of global energy consumption; of this, up to 60% is consumed by the common areas in buildings.

In a "vertical city," people are stratified and confined, leading increasingly insular lives, with minimal contact with nature.

## … To Garden City

Since 1994, the authors have produced a series of projects that explore reintroducing nature into buildings and cities, not only for human comfort, but also to improve the quality of the environment.

"Re-greening" is vital to address the problem of urban heat islands and global warming. Re-greening can make cities net positive contributors to the environment and for climate stabilization. Re-greening also restores biodiversity into cities and keeps the natural balance of ecosystems and wildlife habitats.

The modern tower, as a building block of cities, can be reinterpreted as infrastructure, with greenery and amenities that support and contribute to the overall urban environment. It can be systemically incorporated as part of the master plan and an overall urban design for reinvigorating cities. By incorporating greenery beyond the ground plane, buildings can become biophilic environments that visually and emotionally engage the inhabitants and public. Research into biophilia shows that there is an innate relationship between humans and nature, and that humans have a fundamental need to be continually connected to nature in order to maintain a sense of positive well-being, productivity, creativity and delight. The availability and

Figure1. Oasia Hotel Downtown, Singapore. © K Kopter

experience of green environments make cities more humane, healthy and livable.

Imagine cities filled with high-rise greenery and public amenities in the sky. Imagine Ebenezer Howard's Garden City principles hybridized with the megastructures and organic growth patterns championed in the Metabolism movement. Threads of this alternative conception can be found in the tropical city of Singapore.

"With the cores located in the corners, the sky terraces allow a unique 360-degree view through gardens to the city, which would not have been possible with a typical center-core tower."

# A Vertical Transportation Analytical Tool For the Construction of Tall Buildings

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**Oscar Savage** works for Multiplex Construction Europe on its 22 Bishopsgate project in London. Continuing his life-long passion for building, he studied construction management at the Royal Melbourne Institute of Technology. In the final year of his studies, he won the CIOB Global Student Challenge. This allowed him to explore international employment opportunities; he has since joined the Multiplex team in London. Savage enjoys a challenge and tackles problems with an innovative, hands-on approach.

## Abstract

*The construction phase of 22 Bishopsgate, London, presented many challenges, but one of the greatest issues to overcome was the requirement to ensure comfortable and efficient labor movements, material deliveries, and waste disposal, as well as plant and equipment transportation throughout its construction. This study introduces the Vertical Logistics Planning System (VLPS), an innovative real-world solution developed to overcome this challenge, demonstrating how the construction-phase vertical transportation strategy was assessed and optimized on the project. It is hoped that this paper will catalyze the development of further advancements in this field, assisting the transfer from an experiential approach to a predictive, data-driven methodology.*

**Keywords:** Construction, Vertical Transportation

## Introduction

The successful delivery of tall building projects is inextricably linked to the efficiency of construction-phase vertical transportation strategies. Although it is a widely-known challenge, vertical transportation during construction has attracted limited attention in academic and industrial literature to date. Presently, the construction industry relies on anecdotal evidence to plan for such critical operations. While these experiential methods are well-established and are often perceived to provide suitable guidance, they seldom facilitate a detailed understanding of the time-based supply/demand profiles, leaving projects greatly exposed to significant delays and unnecessary lifting infrastructure costs.

## Limitations of Existing Methods

Current methods for conceiving and planning the vertical logistics strategies for tall building construction projects are broadly based on intuition and experience, and often fail to address the specific needs of a construction site, leading to potential inefficiencies in the distribution of labor, materials and equipment throughout the building. A typical set of assumptions for vertical logistics calculations (Shin, Cho & Kang 2010) can be found in Table 1.

Existing traditional methods present three main weaknesses:

1. They often lack numerical back-up and are largely based on anecdotal evidence
2. They are short-sighted, only considering peak demands, while other phases of the construction might prove to be more critical
3. They lack flexibility and adaptability over time and do not match supply to demand in any intelligible way

The approach to optimizing the vertical logistics strategy at 22 Bishopsgate, London, consisted of an extensive data-backed model, which provided the project team with an overall view of challenges over time and granted the team the necessary flexibility to re-assess needs at any given time. It also allowed "what-if" questions to be asked and answered, and for multiple scenarios to be assessed with one click.

> "The devised system integrated the project's labor histogram, expressing demand as a function of the number of operatives present on the construction site throughout its duration."

| Phase description | Formula | Remarks |
|---|---|---|
| Transportation frequency (*Ft*) | *a* x *b* | *a*: transportation frequency per unit area based on historical data of similar project<br>*b*: gross areas of actual project |
| Transportation frequency per day (*Fd*) | *Ft*/*n* | *n*: total construction duration, days |
| Average height of transportation (*Ha*) | *H* x (1 + *c*) | *H*: height of building<br>*c*: charged rate for handicap |
| Cycle time of transportation (*Tc*) | *T1* + *T2* + *T3* + *T4* | *T1*: time of loading<br>*T2*: time of dumping<br>*T3* ( = *Ha*/*v*): time for lifting up<br>*T4* (= *Ha*/*v*): time for lifting down<br>*v*: speed of hoist |
| Available transportation frequency per day (*Ta*) | (*Tw*/*Tc*) x *d* | *Tw*: available work time per day<br>*d*: operation ratio of temporary hoist |
| The adequate number of temporary hoists | *Fd*/*Ta* | |

Table 1. An example of a typical ad-hoc construction hoist planning formula. Source: Shin 2011.

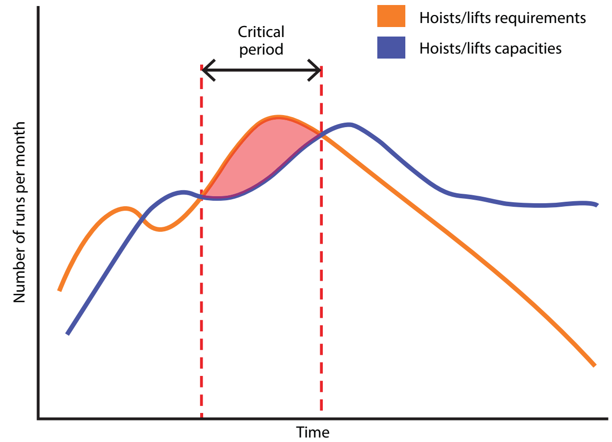


Figure 1. Graph illustrating the team's initial thinking behind the Vertical Logistics Planning System (VLPS).

As an example, the project was expected to experience its peak construction traffic in October 2018 with approximately 1,700 workers coming to site every morning of the month. October 2018 was also expected to be the busiest month for material deliveries as well, with almost 4,000 pallets requiring delivery to the relevant floors. While these statistics would be significant in any construction project, their importance increases tenfold when applied to a tall building construction project.

However, those peaks weren't necessarily going to be the most critical periods in the construction phase, and it was proved that the construction team had to be focused on different phases. The overall understanding of the challenges through time allowed the team to make informed adjustments that permitted increasing the efficiency of the temporary hoisting infrastructure by approximately 30%, which saved the project a significant portion of its hoisting budget, without penalizing the demand on-site. The remainder of this paper focuses on establishing an efficient, flexible, and data-backed predictive solution to plan vertical transportation during the construction phase of any tall building project, based on the 22 Bishopsgate example.

## Vertical Logistics Planning System (VLPS)

The Vertical Logistics Planning System (VLPS) developed at 22 Bishopsgate, consists of an adaptable data-driven model, using known inputs to generate a time-based interpretation of the supply and demand profile throughout the construction phase. Figure 1 illustrates the initial thinking behind the model. The orange curve shows the project's requirements (demand) in terms of labor movement and material, waste, plant, and equipment (MWPE) transportation, while the blue curve describes its hoisting/lifting capacity (supply) over time. Both sets of data were to be expressed in the same unit: the number of lift runs required on a monthly basis. Each time the "requirements curve" is above the "capacity curve", it shows that the project is going to suffer from potential under-capacity. The specifics of the project, as well as the intricacy of the inputs, led the team to develop a model with slightly more complex outputs, but the essence remained the same. This bespoke model facilitated the holistic testing of a variety of scenarios, with the primary focus of identifying and understanding the variety of known and unknown constraints associated with the vertical transportation of labor, materials and plant. The model outputs are presented in an intelligible way, allowing the user to quickly identify, and respond to, under- or over-capacities in the vertical logistics supply profile.

## Understanding Vertical Transportation Requirements

To produce the demand curve shown on Figure 1 shown in orange, the first step of the study was to fully understand the requirements over time in terms of labor, and MWPE transportation for each trade. This exercise was conducted in close collaboration with package managers and planners, to understand both the assumptions of each trade and the detailed program. Once established, the data inputs were gathered and inserted into the model.

### Labor requirements

Grasping the main trends of labor movement throughout the duration of the project is essential to a well-functioning vertical transportation strategy for a construction site. During the development of these strategies, which are often conceived at the tender stage, it is common for the author to make a series of informed decisions based on anecdotal evidence, as opposed to firm data. The VLPS overcomes this issue through integrating the project's labor histogram, expressing demand as a function of the number of operatives present on the construction site throughout its duration. To ensure robust outputs, the model was designed to utilize simple inputs, including;

- The average number of operatives per active floor on any given day

# Using Height-Relative Variables To Design Tall Buildings

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**John Jory** holds a Masters in Architecture from the University of Queensland. He has worked in United Kigndom, Dubai, Oman, and Australia, and is currently a PhD Candidate at Queensland University of Technology. His research topic is "vertical variations in the urban environment, and their potential utilization in tall building design," defined by the construct "Height-Relative Variables" (HRV). It is expected that significant benefits may result from the development of a design methodology that utilizes HRV data to leverage the effects of height.

## Abstract

*This paper investigates height-variable phenomena in the urban context, and their relevance to the design and performance of tall buildings. It proposes a design approach relevant to variable conditions as encountered along height, demonstrates its potential viability for further development and eventual application.*

*Presented are two novel concepts: the first concerns Height-Relative Variables (HRVs), factors that vary along height that may influence the design and utility of a tall building, and are proposed as a new class of design data, for which a taxonomical structure and data format is devised. "Eco-strata" (a construct from ecology and stratification) proposes and defines the model for a stratified design response utilizing HRV. The hypothesis is that HRV, when applied in design using "eco-strata" methodology, may demonstrate that an urban high-rise so configured could improve the tall building typology.*

**Keywords:** Urbanization, Environment, Design Process, Sustainability

## Introduction

Tall buildings in dense, compact urban developments have the potential to contribute to sustainability, and when within larger dense areas, to more efficient use of land, infrastructure, and transport. Is there a better, more efficient, model for tall urban buildings? A guiding hypothesis underpinning this research suggests that there may be. The proposition is that in the urban context, variations along height may have unrealized potential for beneficial utilization in tall building design. This study investigates that theory, and proposes a methodology to realize by design the improved paradigm offered by that proposition. Tall buildings generally are not being designed to comprehensively address vertical variability, and they would potentially be more energy-productive, environmentally efficient, and user-appropriate if they were to draw from the efficiency inherent in matching their design to varying conditions as encountered vertically.

## Vertical Variation and the Urban Climate

Atmospheric vertical variations are naturally occurring phenomena, and the benefits of harnessing them are well – established. Temperature and pressure differentials have been utilized for millennia by using the "flue effect" (essentially nature correcting an imbalance), and with specific regional applications such as windmills and turbines.

International standards define "ideal" pressure, temperature, density, and other variables as altitude above sea level (ISO 2533:1975), but the urban vertical profile is essentially characterized by its man-made origins, and is affected by low-altitude phenomena such as anthropogenic heat, particulate aerosols, pollutants, humidity, and weather.

Oke, when investigating the Urban Heat Island (UHI) effects and associated vertical variations in 1976, identified two distinct layers: the lower layer between urban elements up to roof level he named "the Urban Canopy", and the upper he called "the Urban Boundary Layer" (Oke 1976). Figure 1 shows Oke's schematic representation of

"The urban vertical profile is essentially characterized by its man-made origins, and is affected by low-altitude phenomena such as anthropogenic heat, particulate aerosols, pollutants, humidity, and weather."

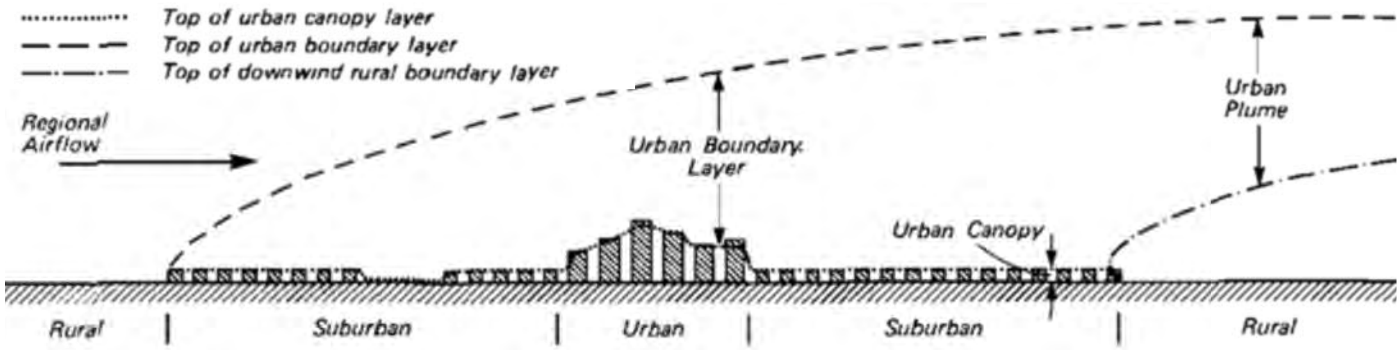


Figure 1. Schematic representation of the urban atmosphere, illustrating proposed two-layer Canopy and Boundary Layers classification. Source: Oke,1976

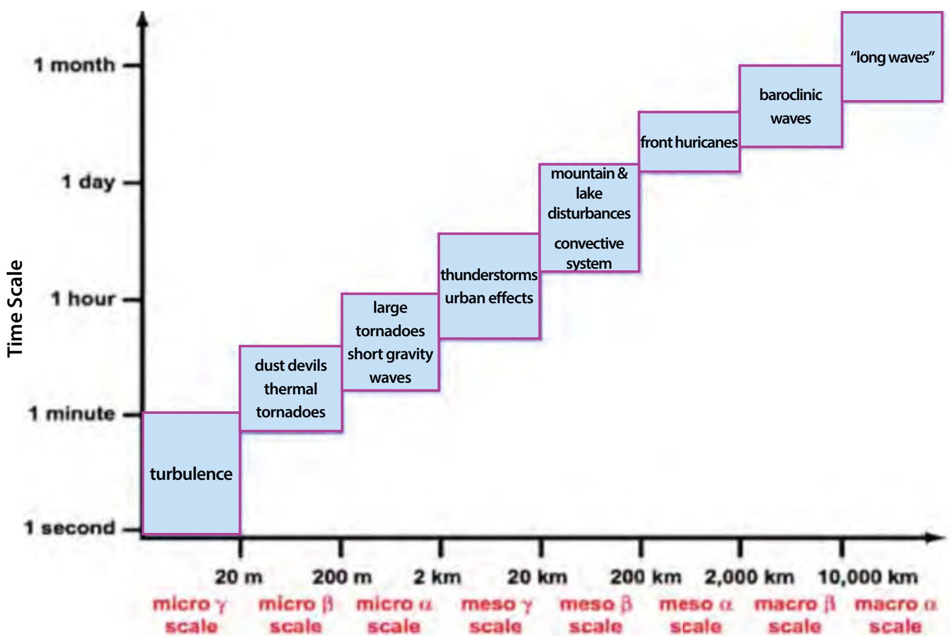


Figure 2. Meteorological space and time scale. Source: Markowski and Richardson 2010.

these layers. Today, urban buildings are generally considered as within the locality-specific "micro-scale" Urban Canopy Layer (UCL), characterized by local airflow and energy exchanges below average roof level, and the zone above is the "meso-scale" Urban Boundary Layer (UBL), influenced by a larger area that may include urban and rural elements.

This distinction in scale between UCL and UBL fundamentally changed urban climatology by introducing the realization that the UBL may not be in equilibrium with the urban elements below (Arnfield 2003). In other words, taller urban buildings could have upper levels within the UBL. Significantly, this distinction between the UCL and UBL offers the possibility of leveraging those differences by design.

Meteorological time and distance scales are linked (see Figure 2). A "micro-scale" climatic event will range from a few meters to two kilometers in horizonal length, and from a few seconds to an hour; whereas "meso-scale" activity may extend over a length of 2 to 200 kilometers, and last up to a day.

The UCL/UBL divide also contributes to a complex cycle of energy exchanges, with a dynamic vertical profile characterized by the influences of anthropometric, diurnal, and seasonal variations. Figure 3, a schematic from Oke (1987), shows urban energy exchanges.

## Design Research and Vertical Variation

A substantial body of research on the urban environment exists, but few studies address vertical variation relative to tall building design and performance. Among notable exceptions is a 2005 simulation by Ellis and Torcellini for New York's One World Trade Center, which modeled altitudinal variation for every floor in terms of air temperature, wind speed, shading, and reflection. They found that, along the building's height, atmospheric changes acting together with imposed urban environmental factors "… create a microclimate that can vary from floor to floor of a tall building" (Ellis and Torcellini 2005).

In Leung and Weismantle (2008) coined the phrase "Sky-Sourced Sustainability." Citing the scope of Ellis and Torcellini, they added air pressure, moisture and air density in modeling a hypothetical one-kilometer tower set in Dubai. Finding that altitudinal variations have the potential to offer significant energy-saving opportunities, they also suggested architectural design may be varied over height to reflect different environmental exposures. Another kilometer-high tower simulation was undertaken in 2012, this time set in a temperate Korean climate, modeling annual meteorological variation across five 200-meter vertical zones. Large differences in HVAC loads along the height were found, compared with conventional single-zone calculations (Song & Kim 2012). Tong, Chen, and Malkawi (2017) in researching natural ventilation, simulated diurnal and seasonal vertical profiles for wind speed, temperature,

# Out of Thin Air: The Potential for High-Rise Housing Over Rail Lines

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Abstract

*Cities are facing a crisis in providing housing and managing population growth. The author's team has identified sufficient land associated with railway infrastructure to yield more than 250,000 new homes in London built above rail lines, providing around five times the annual minimum needed by the capital. This paper illustrates several feasible scenarios and real-life projects that could serve as guides for providing housing to space-constrained cities around the world.*

**Keywords:** Infrastructure, Urban Design, Transit-Oriented Development

## Why We Should Build Above Rail Infrastructure

Compared to building major new infrastructure projects, rail overbuilds could be a quicker and less costly way to unlock large housing schemes. No new land is required for such developments – they can be undertaken where planning controls allow building over the rail environment.

In this research effort, the author's team has assumed that only 10% of the land identified is actually developed, with residential accommodation built directly above rail/metro lines and stations. However, this could increase even further if it unlocks and connects to further developments adjacent to rail lines or above a station. This sort of overbuild is now being seen as increasingly viable and attractive.

Rail overbuild is a potential way to start addressing challenging urban issues. It can increase the supply of housing, offices, retail, other social infrastructure, as well as connecting previously divided communities. Existing projects show that the engineering is possible, which means rail overbuilds can be delivered now.

Housing is one of London's most intractable problems. Even by the government's own admission, the UK housing market is broken (MHCLG 2017). Yet London, like many urban centers globally, continues to be a highly attractive place to live and work: since 2000, its population has grown by around 95,000 every year on average, and by more than 100,000 every year since 2008/2009 (GLA Economics 2016).

The shortage of housing in or near the center means many Londoners are housed far from their workplaces, often facing a long, daily commute. This is stressful and creates more overcrowding on an increasingly fragile and strained transport system.

Rail overbuild offers a more creative use of land, allowing more people to live in the city; tube/metro and/or rail services will be close by, and so using public transport will be a better experience. Indeed, these developments should have very favorable public transport accessibility levels (PTAL).

Proximity to stations may also mean residents choose to forego car ownership. Fewer cars on the streets (less congestion and lower emissions) could prompt residents to walk and cycle more, especially if new developments have cycle storage. These factors will contribute to the healthier streets and lifestyles envisaged by the Mayor of London.

As well as contributing to greater public transport use, car-free zones and more walking and cycling, rail overbuilds can provide a pleasant environment that supports new homes and jobs, especially as the development unlocks growth in the immediate vicinity. Such a strategy could provide some of the housing and healthier environments that London urgently requires.

“London needs 50,000 new homes to be constructed every year until 2025, just to keep up with projected housing demand. Yet between April 2016 and March 2017, only 6,423 homes were completed.”

## Housing Deficit Data

London needs 50,000 new homes to be constructed every year until 2025, just to keep up with projected housing demand. Yet between April 2016 and March 2017, only 6,423 homes (affordable and open-market) were completed (GLA 2017a). Making up the shortfall demands more innovative approaches to development.

Creating more homes in the city center has been an ongoing process – since 2001, 90% of homes in London have been built within one kilometer of a rail station. In 2013, the former Mayor of London's New Draft Housing Strategy recommended that more homes could be delivered by increasing the density of new schemes and using infill developments. Part of the current Mayor's draft strategy to increase housing provision is to identify and bring forward more land for housing, supporting a more intensive use of London's available land (GLA 2017b). Rail overbuild complements such policies by creatively utilizing land and increasing the densification of urban areas.

Rail stations (including connecting tracks and rail yards) sometimes occupy large tracts of land. Given their status as multi-modal interchanges with high passenger throughputs, they offer excellent opportunities for oversite developments. An overbuild might involve building over a station, rail tracks and adjacent land. When it encompasses a broader area beyond the immediate station, it can unlock greater development potential (see Figures 1 and 2).

Like many landlords, owners of railway land normally have air rights above their real estate, which gives them the opportunity, subject to planning policy considerations, to develop above the facility. This prospect may be sold or leased to other parties. Using air rights to create new developments above railway assets offers many benefits, especially as no new land is required. One is literally creating land "out of thin air," which can increase the availability of residential accommodation and help alleviate the current housing shortage.

Figure 1. Victoria Station, London, with platforms already partially overbuilt with low-rise commercial development and a coach station. Source: Google Earth.

Figure 2. Victoria Station, London, with further decking, supporting a mixed-use development located over the approach tracks.

Given the ongoing concerns with tall buildings over 20 stories currently occupying London, particularly speculative residential developments (Pipe 2018, Weiss & Cook 2017), a conservative proposal might advocate overbuild schemes comprising 12-story developments that could equally be given over to residential or commercial purposes. These oversite developments could also form part of adjacent site developments (ASD) that create new communities, fuel economic growth and jobs, and generate revenue for both local authorities and land owners.

Rail overbuild should appeal to rail asset owners who seek to increase non-fare revenue by attracting residential, commercial, retail and leisure developments in, above and around their assets (see Figure 3).

Local authorities may also welcome such developments as a way to both reduce housing shortages and regenerate inner-city areas. There are also financial benefits that can accrue to a local authority in the form of community and business taxes, land value capture, Development Rights Auction Models (DRAMs), community infrastructure levies and public-realm benefits.

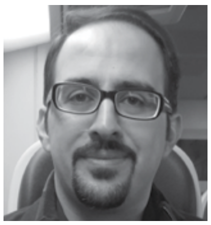
## Not A New Idea, However…

Air-rights development over rail lines is of course, not a new concept. Commercial real estate has been built over tracks and stations since the early 1900s, when William J. Wilgus, an engineer for the New York Central Railroad, proposed "taking wealth from the air" above the approaches to Grand Central Terminal in New York. (Gray 2010).

Structural Engineering

# Damping Technologies for Tall Buildings

Alberto Lago



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**Dario Trabucco** is the CTBUH Research Manager and researcher at the IUAV University of Venice, Italy. He is involved in teaching and research activities related to tall buildings, including the life-cycle analysis of tall buildings, service core design and issues pertaining the renovation/refurbishment of tall buildings. In 2009 he obtained a PhD in building technology with a thesis entitled "The Strategic Role of the Service Core in the Energy Balance of a Tall Building." From 2010 he has been the CTBUH Italy Country Representative.

## Abstract

*The scope of this paper is to review the possible solutions for modifying building motions through dampers. The three main categories of devices on the market for achieving this scope are "passive," "active," and "base isolation." The major solutions used by the tall building industry are reviewed here in relation to design principles, interaction with other building systems, testing, inspection and maintenance. Additionally, a study of the tall buildings over 250 meters constructed globally shows the wide utilization of these systems and the possible prominent applications they could have in the future.*

**CTBUH Research Project**

Sponsored by: Bouygues Construction

**Keywords:** Damping, Seismic, Wind

## Introduction

The tall building industry is always looking to enhance performance from the safety, comfort and sustainability points of view. In 2015, after receiving a US$230,000 grant from Bouygues Construction, CTBUH began a review of how building performance goals under earthquakes and strong winds can be improved, by looking at the current utilization of dynamic modification devices. The main goal of this technological solution is to modify the dynamic behavior of a structure (mainly through energy dissipation) to reduce possible damage and create more efficient solutions from a structural and environmental perspective. The goal was to create a document that would bridge a needed gap in knowledge about the design and construction of tall buildings equipped with dynamic modification devices. The scope of this paper is to summarize the major aspects studied in the research; most importantly, the utilization of dynamic modification devices to enhance building performance in terms of safety and sustainability. The findings of this research project will be further explored in ***Damping Technologies for Tall Buildings: Theory, Design Guidance and Case Studies*** (see Figure 1).

The paper explains in detail several different aspects, from understanding the basics of building dynamics to a review of the range of devices available on the market, evaluated against relevant design, installation and durability considerations. The basis of all these discussions is to reach a more reliable building performance goal for a given hazard level. This is considered one of the most prominent aspects of tall building design, as is evidenced by the requirements of the most recent national building codes.


Figure 1. *Damping Technologies for Tall Buildings: Theory, Design Guidance and Case Studies*, will be available in October 2018. Find out more at: store.ctbuh.org/dampingtechnologies.

After reviewing the major design criteria, the major steps involved in the design and construction process of tall buildings equipped with these technological solutions is discussed. Moreover, to comprehend the prominence of this topic in the tall building

| | | |
|---|---|---|
| Passive Systems | • Viscous Dampers<br>• Oil Dampers<br>• Viscoelastic Dampers<br>• Hysteretic Dampers<br>• Friction Dampers<br>• Re-Centering Dampers | Material-Based (Distributed) |
| | • Tuned Mass Dampers (TMD)<br>• Tuned Liquid Dampers (TLD)<br>• Tuned Liquid Column Dampers (TLCD) | Mass-Based (Discrete) |
| Base Isolation | • Isolation Bearings<br>• Sliding Bearings | |
| Active, Semi-Active & Hybrid | • Active Tuned Mass Dampers<br>• Hysteretic Mass Dampers<br>• Semi-Active Mass Dampers<br>• Semi-Active Fluid Dampers<br>• Semi-Active Stiffness Dampers<br>• Semi-Active Control of Base Isolation Systems<br>• Adaptive Tuned Mass Damper | |

Table 1. Types of dynamic modification devices used in tall buildings.

industry, the authors provide an in-depth analysis of the CTBUH Skyscraper Center database, revealing worldwide trends for buildings above 250 meters in height with dynamic modification devices. The paper concludes with a description of potential areas of future research and development.

## History of Dynamic Modification Devices

One of the first applications of a dynamic modification device in a tall building was the installation of 10,000 viscoelastic double-layer shear dampers at the World Trade Center in New York City (Mahmoodi 1969). Subsequently, major research studies in the utilization of passive dampers were carried out in New Zealand (Kelly, Skinner & Heine 1972; Robison & Greenbank 1976). However, the key trigger in the development of dampers was the occurrence of several earthquakes in the late 1980s and early 1990s, including Loma Prieta (1989) and Northridge in California, USA (1994), and Kobe, Japan (1995). Parallel development of wind-resistant design occurred in the late 20th century. In 1977, to counter wind forces, tuned mass dampers were installed in New York (601 Lexington, originally the Citicorp Center) and Boston (200 Clarendon, originally the John Hancock Tower). After the Kobe earthquake,base-isolated high-rise buildings started to appear, especially in Japan (Mele & Faiella 2018).

The other major category of dynamic modification, active structural control systems, has a more recent history compared with passive and base-isolation systems (Suhardjo, Spencer & Sain 1990; Inaudi, Kelly & To 1993). The major developments resulted from cooperative efforts between Japan and the US in 1989 (Soong & Spencer 2000).

## Damping Considerations for Tall Buildings

Building dynamic motion is generally triggered by wind and seismic loads. This poses several problems in tall building design, chief among these being occupant comfort, as floor accelerations become prominent for the upper floors as the building height increases. To control the dynamic behavior of a building, a structural engineer can play with three major structural characteristics: mass, stiffness, and damping. It is common practice to work on stiffness and mass, but an alternative solution is to work on damping, or energy dissipation, in a dynamic system.

In a building, the primary source of damping is the so called inherent/intrinsic damping that comes from many different sources: material, structural joints, soil-structure interaction, and non-structural elements. This makes it difficult to reliably estimate its value. Moreover, intrinsic damping exhibits complex behavior due to an amplitude of motion dependency (Jeary 1986) and a building frequency correlation (Smith, Merello & Willford 2010). Given these difficulties, intrinsic damping estimation relationships are frequently based on full-scale measurements. Several databases are available, and one of the most prominent is provided by Satake et al. (2003). However, given the wide frequency spectrum of possible excitation, there is a high variability in damping estimations when different data sets are used (Bernal et al. 2012).

This great uncertainty is reflected in the building code and guideline recommendations, since they do not provide prescriptive theoretical models, but only recommended values for structural analysis (which in most cases are valid only for low-rise buildings) (Tamura 2005).

In addition, for intrinsic damping in a building, there could be other sources of energy dissipation:

- Aerodynamic: due to building movement in a fluid (air).
- Hysteretic: from inelastic behavior of structural members.
- Supplemental/Additional: damping provided by external devices added to the structure.

When a designer decides to control the dynamic behavior through damping, the predominant method is to add an external device. This solution helps in reducing uncertainties in intrinsic damping estimation and meets structural performance criteria, both from a wind and seismic point of view.

## Dynamic Modification Device Types

There are several dynamic modification devices on the market, and they are classified based on the controlling mechanism they utilize. There are three major categories defined as follows (see Table 1):

> “Among 525 buildings of 250 meters or greater height (under construction or to be completed by 2020), 18% (97) are equipped with dynamic modification technologies.”

# World's Tallest Buildings with Dampers

As tall buildings continue to be built in seismically-active and cyclone-prone areas, the need to augment the structures of these buildings with dynamic modification devices (in this case, dampers) to counteract these forces is growing. This data report graphically summarizes the findings of the CTBUH Research project ***Study on Tall Building Damping Technologies***, sponsored by Bouygues Construction (see also Damping Technologies for Tall Buildings, page 42).

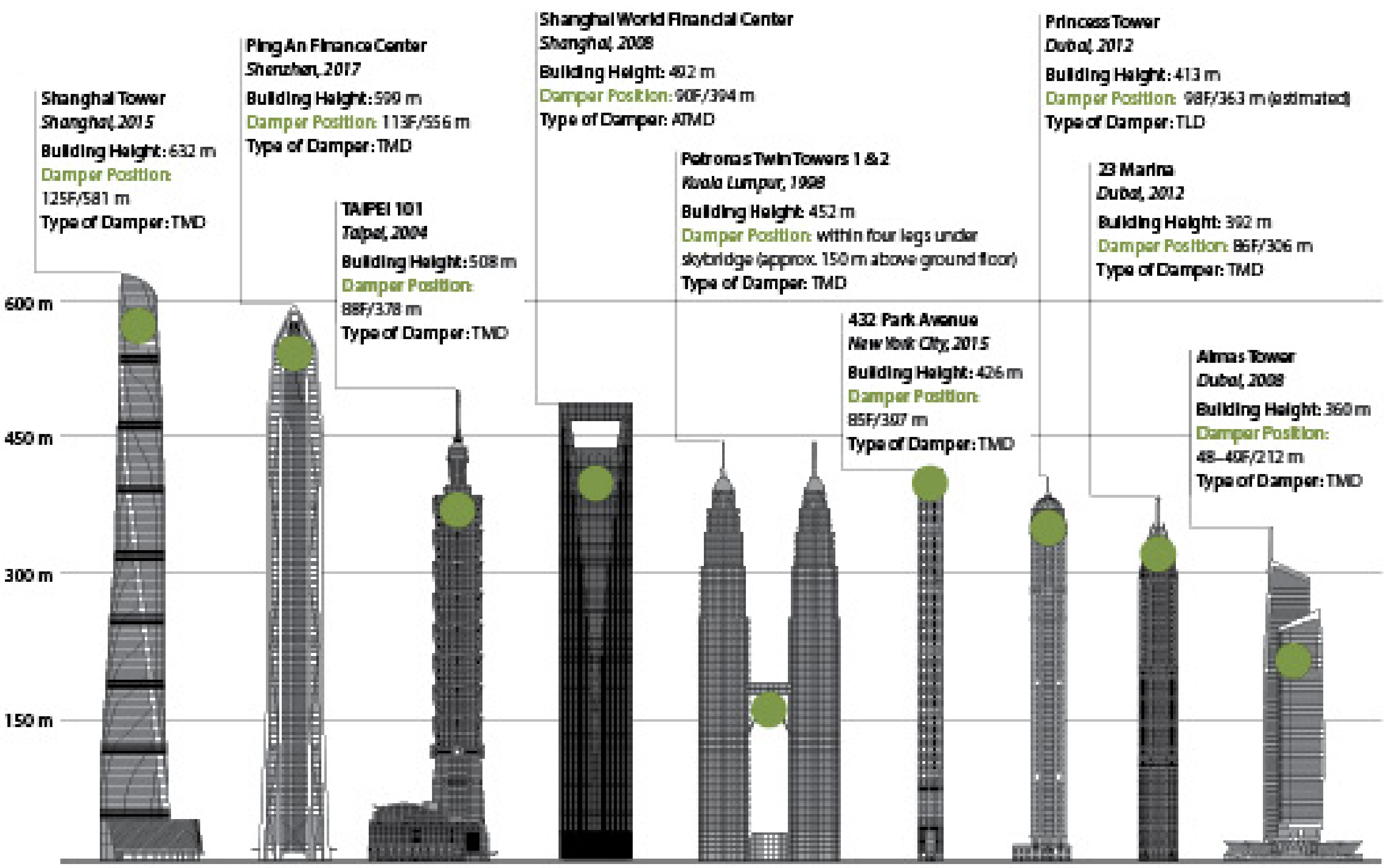
*» See the full list of buildings with dampers at* **ctbuh.org/damping**

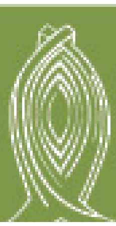
## Types of Dampers

AMD – Active Mass Damper
ATMD – Active Tuned Mass Damper
BRB – Buckling Restrained Brace
HMD – Hybrid Mass Damper
TLCD – Tuned Liquid Column Damper
TLD – Tuned Liquid Damper
TMD – Tuned Mass Damper
VD – Viscous Damper
VED – Viscoelastic Damper

*See the research paper on page 42 for more details about each damper type.*

## Tallest 10 Completed Buildings with Dampers



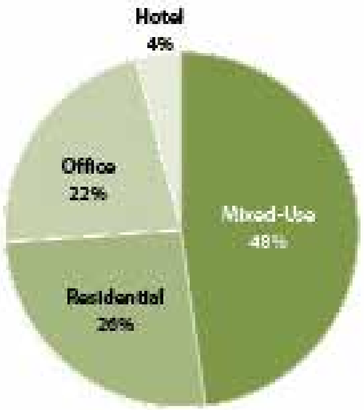
Shanghai Tower's damper is celebrated by a special public "skyspace" with an abstract sculpture atop the damper enclosure.

**30%** Only 30% of the World's 20 Tallest Buildings are equipped with dampers.

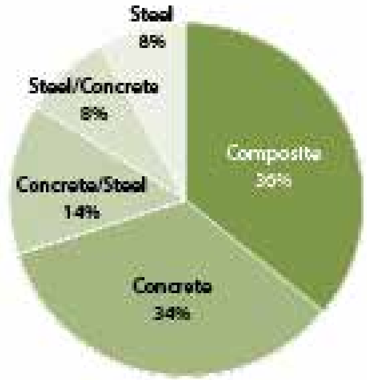
The ball-shaped pendulum damper at **TAIPEI 101** is on public view, and is commemorated with a mascot called "Damper Baby."

## Tallest 50 Buildings with Dampers

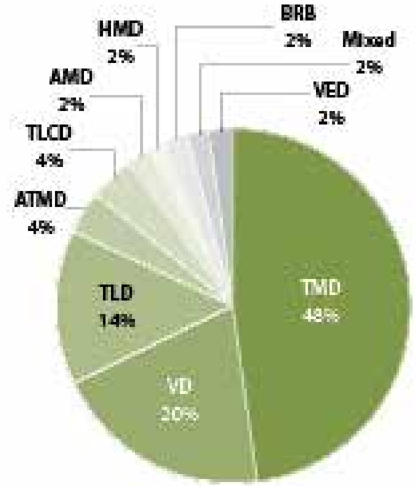
*Includes buildings under construction*




**By Function**

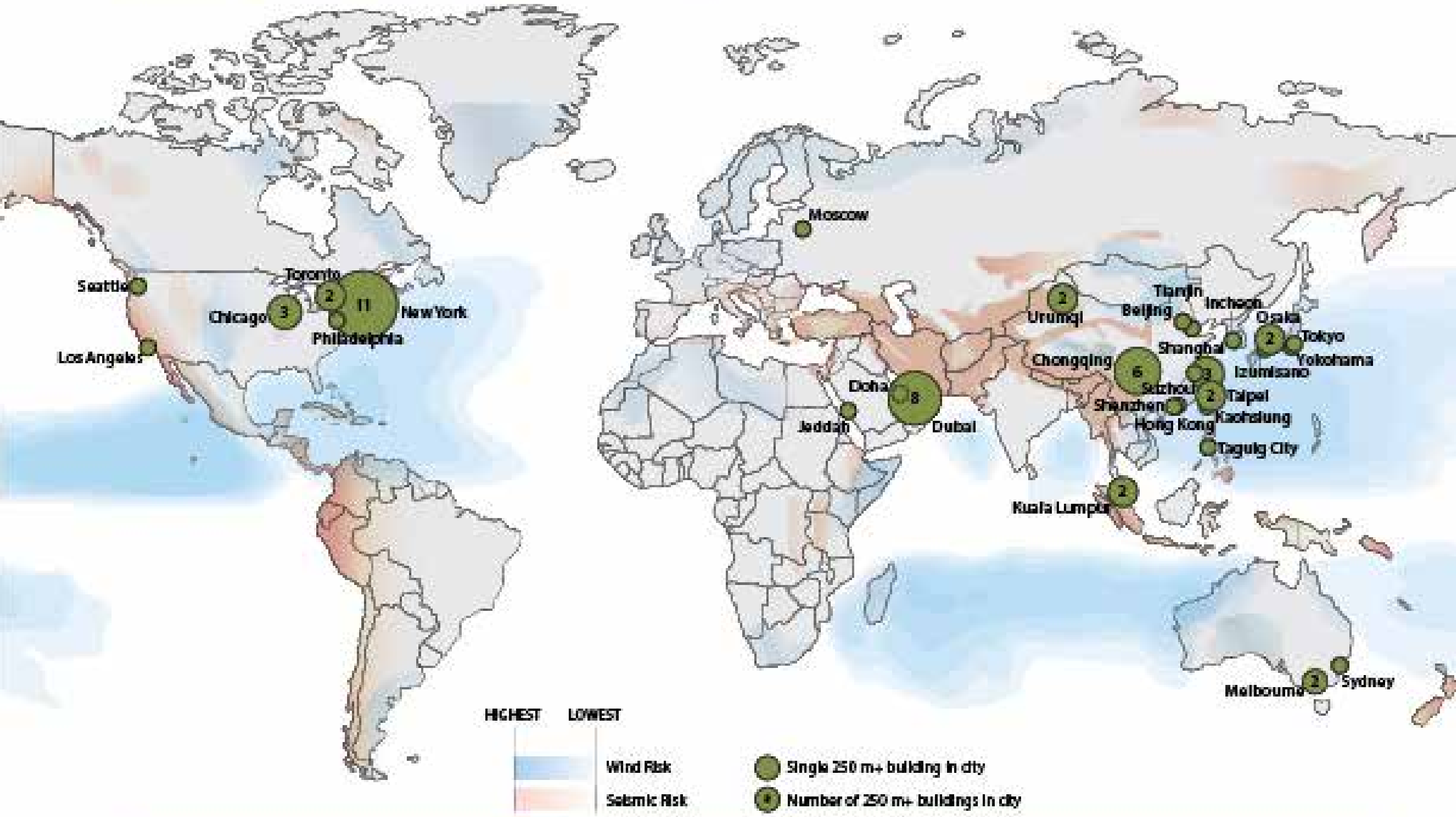



**By Primary Structural Material**




**By Damper Type**

## All 250 m+ Buildings with Dampers, by Location




**288**

The Shinjuku Center Tower, Tokyo (1979) was retrofitted with 288 distributed oil dampers in 2009, which reduced movement by 20% during the 2011 Tohuku earthquake.

The damper at 111 West 57th Street, New York City, will weigh 726 metric tons – more than 3.5 Statues of Liberty.

# Engineering a Better Future

Aine Brazil

Interviewee

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**Aine Brazil** is a leading structural engineer who has been instrumental in shaping the skylines of cities across the globe. In her 40-plus year career, she has been responsible for the design and construction of some of the most significant high-rise buildings in the United States and internationally. Brazil's prominent work and significant contributions to the built environment have earned her numerous accolades and titles. She has always been, and continues to be, passionate about encouraging women to join the engineering profession. Brazil established a discussion and mentorship program at her firm to help female employees grow their careers, and founded a scholarship program at her alma mater to provide financial support for young women pursuing an engineering degree.

*Aine Brazil, Vice Chairman, Thornton Tomasetti, is the recipient of the 2018 CTBUH Fazlur R. Khan Medal. Through a 40-plus-year career, she has been responsible for the design and construction of some of the most significant high-rise buildings in the United States, and globally. She also started a mentorship program at her firm to help women grow their careers, and founded a scholarship program at her alma mater, the National University of Ireland, to provide financial support to young women pursuing engineering degrees. CTBUH Editor Daniel Safarik interviewed Brazil on the occasion of receiving her award at the* ***2018 CTBUH Tall + Urban Innovation Conference.***

**Have you always been interested in tall buildings? When you started your education, did you imagine that you'd be designing them?**

When I started pursuing a civil engineering degree, I knew that buildings were my main interest, but being from the west of Ireland, I didn't see a lot of tall buildings around me. When I was in college, the tallest building in Ireland was 17 stories. So, it wasn't something I saw all the time.

But my first job in London was designing towers in Kowloon Bay, Hong Kong, and I was kind of smitten immediately. From the structural analysis and detailing standpoints, I enjoyed the challenges, which always seemed to me a little bit more extreme, because there are so many design issues to be considered, beyond that of a typical shorter building.

The first project I worked on in the United States, in Chicago, was then called the Northwestern Atrium Center [now Citigroup Center] – which was over a railway station [Ogilvie Transportation Center]. It is interesting that so early in my career I was working on tall buildings over railway tracks, and now at this stage I am doing so much work over the tracks at Hudson Yards in New York. It's sort of bookended, you know?

> "I want to make this industry more inclusive and innovative. I've had the most amazing fun doing tall buildings. I want the 10-year old girl in the frilly dress, jumping up and down to ask a question, to have the same or better opportunity that I did."

**It must be interesting to approach the problem of building over railways from a civil engineer's perspective. Are you drawn to the interdisciplinary nature of this field?**

Yes, certainly. Understanding the interface between structure and the functionality of the building has always been my passion. I don't want to design "the best structure." I want to design "the solution that results in the best building." Obviously for tall and supertall buildings, the structure has to be excellent for the building to work properly. More than for other types of buildings, with tall buildings, the "best structure" and "best building" often go hand-in-hand.

**Some buildings are famous for their structures because they are expressed on the outside. It must be particularly gratifying for a structural engineer to work on those types of buildings.**

That's true. It can be exciting to see the structure exposed. But there are far more where the decision has been made to hide the structure. If it really serves the purpose, I can justify exposing the structure. But it really has to serve the purpose.

**Looking back, what has been the most challenging project you have worked on, and why?**

In many ways, the most challenging has been the most recent project I have been working on, 30 Hudson Yards, and not for its height - it's around 390 meters - and certainly not for its slenderness (see Figure 1). But it is challenging because of its base and its interface with tracks and infrastructure. There are a lot of things happening within it that have rendered it "softer" and less efficient, that cause torsion, etc. There are lot of things that a structural engineer would not do if given the choice! You have to thread everything down between the Long Island Rail Road tracks, which are not in a straight run – they are coming together in a mesh to get into the throat of Penn Station. So there is this narrow 24-meter wide range, and more than 20 tracks to bridge over. And of course it had to achieve high levels of resilience and redundancy, so it was challenging to take all of that work and still develop a building that made sense from a functional standpoint. It doesn't look like the kind of building that might need a tuned mass damper (TMD), but because of all that softness, it ended up having a considerable need for one. There are buildings that are challenging structurally, and those that can be challenging in other ways, and this one combined a little bit of everything.

Figure 1. 30 Hudson Yards, New York (the tallest building under construction at the rear), with its neighbors in Hudson Yards. The project is being built partly over an active rail yard, presenting a structural engineering challenge. © Related Oxford

### Is there a region in which you have not yet worked, but you would like to?

I have enjoyed working in the Northeast of the United States, and where my clients have taken me, including Istanbul, Miami, and Milan. The challenges are different with every project. I've never felt I was missing out by not doing the world's tallest building or some of the crazy things my partners are doing in the Far East. The goal has been to learn from what we're all doing in the office, and bring the best innovations from all the projects to the table. I have enjoyed learning from all of them. But I don't feel like there is a need to be in a specific region. Definitely, supertall buildings are a different challenge. I think we, as a structural community and at Thornton Tomasetti, have been learning consistently. Every day, there is another thing we can learn from, about how to better design tall buildings and improve their performance.

### What technology has you excited right now?

We have been involved in developing the Hummingbird harmonic damper, which I think will revolutionize the field. I'm not the lead developer of that project, but I am proud to be involved. I rely on the super-smart people all around me to make me smarter, and thankfully, I have a good few of those. Hummingbird, to me, is probably something that will change the way we all do damping systems in buildings. In the near furture, you'll see them everywhere, because they will reduce the cost of damping to a third or a quarter of what it is now. It is such a simple mechanism that eliminates a lot of the complexities inherent to the big mass and sloshing dampers. This is something that is so easy to bring to site. It has tremendous potential to take dampers out of the realm of being really difficult and costly, and something to be avoided if you can!

### How does this compare to distributed dampers that go in-line with structure?

Hummingbird goes into horizontal planes as opposed to vertical planes. So it can be hung in ceilings, sit on a roof, and be located around all the ancillary items that go in a roof or underfloor system. You don't need to assign a giant room at the top of your building to accommodate something like this. Because it comes in pieces it is very easy to install, and to replace parts if necessary. And in general, it would be lighter.

Dampers traditionally cost anywhere from US$3 million to US$5 million. If you figure out how much more you could spend on structure – some owners will conclude, "I can do the 'dumb' structure thing and increase the thickness of the members." That's sometimes cheaper than a damper system. But if you can achieve a damper system that is cheaper and just as effective, then you can reduce the amount of material going into the building, reduce cost, and give back floor space. If you're an owner, and you are given the choice of spending US$2 million for massive structure and US$4 million for a TMD, most will go for the structure if they have the space. That's a lot of material going into the building, which if it could be reduced, could really help the sustainability of the project. I can think of a lot of buildings I have done where Hummingbird would have been applicable, and hopefully this is one of the things that we'll see more of soon.

### Is there something the industry does that you look at today and say, "I can't believe we're still doing this"?

To be honest, that to me is more a question of process than materials or technology. In the 40 years I have been designing buildings, I cannot believe that we are still using drawings. It is only in the past few years that we have begun to accept that we can design as well as construct in 3D. You don't have to take a 3D concept and "dumb it down" to get it on a 2D piece of paper and get it through the building department, and then have people use that 2D drawing and try to recreate what you thought the 3D should have been!

# About the Council

The Council on Tall Buildings and Urban Habitat (CTBUH) is the world's leading resource for professionals focused on the inception, design, construction, and operation of tall buildings and future cities. Founded in 1969 and headquartered at Chicago's historic Monroe Building, the CTBUH is a not-for-profit organization with an Asia Headquaters office at Tongji University, Shanghai, a Research Office at Iuav University, Venice, Italy, and an Academic Office at the Illinois Institute of Technology, Chicago. CTBUH facilitates the exchange of the latest knowledge available on tall buildings around the world through publications, research, events, working groups, web resources, and its extensive network of international representatives. The Council's research department is spearheading the investigation of the next generation of tall buildings by aiding original research on sustainability and key development issues. The Council's free database on tall buildings, The Skyscraper Center, is updated daily with detailed information, images, data, and news. The CTBUH also developed the international standards for measuring tall building height and is recognized as the arbiter for bestowing such designations as "The World's Tallest Building."

Council on Tall Buildings and Urban Habitat

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