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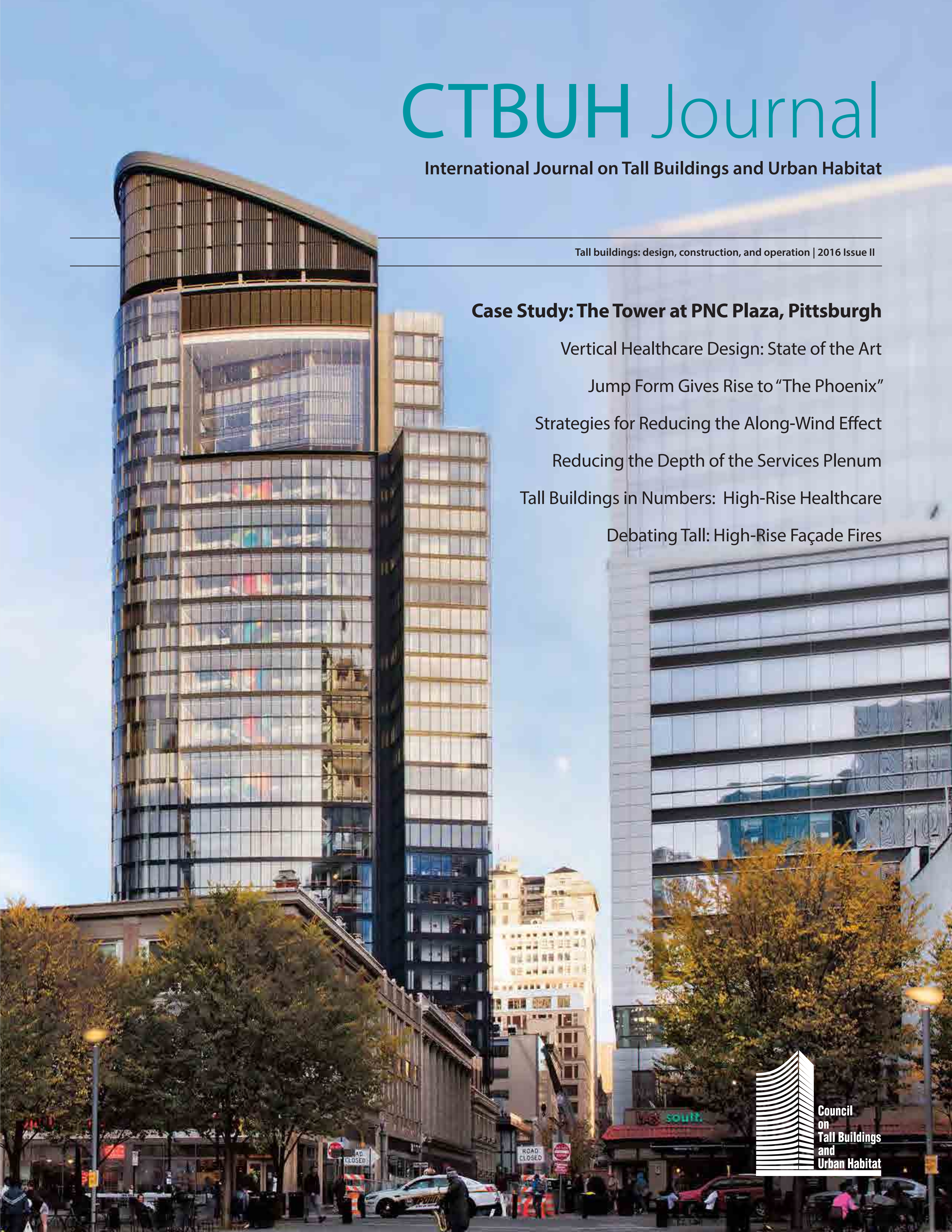

Council on Tall Buildings and Urban Habitat

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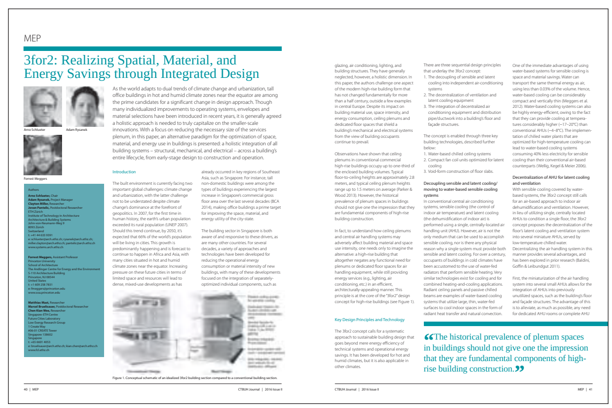
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"Most high-rise buildings…provide maximum rentable area for the least amount of building cost. But we are realizing that the way we work and live has changed radically. Today, social interaction and communication are the drivers of innovation and change."

Martin Henn, page 49

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Americas

A major worldwide milestone was hit when **432 Park Avenue** in **New York City** was officially completed. The 426-meter tower by Rafael Viñoly Architects is the 100th supertall to be completed in the world and the world's tallest all-residential building. Several more supertalls are in the pipeline, including **The Spiral,** whose vegetated terraces are meant to act as an extension of the nearby High Line. Meanwhile, **340 Flatbush,** a proposed SHoP Architects supertall in Brooklyn, would be the first in New York outside Manhattan, and by extension the tallest building in the city off the island.

Outside of New York, a number of significant developments are taking shape across major US cities. In **Chicago,** planning authorities approved the five-hectare **Riverline** complex by Perkins + Will, which will fill in long-vacant lots along the east side of the Chicago River directly south of the Loop. The first phase of the project will include a series of townhouses along with a 19- and 29-story tower. Not to be outdone, conceptual renderings were revealed for **Schuylkill Yards** in **Philadelphia** – a 5.5-hectare "innovation neighborhood" master planned by SHoP Architects and West 8. The long-term development seeks to transform the University City neighborhood by integrating a number of uses into a single environment.

And in **Miami,** a groundbreaking ceremony was held for the **Miami Worldcenter.** The multi-billion dollar project is the second-largest private development in the country behind Hudson Yards. Its first phase of construction includes the 60-story **Paramount Miami Worldcenter.**

432 Park Avenue, New York. © Macklowe Properties

The Spiral, New York. © BIG - Bjarke Ingels Group

Out west, another groundbreaking was held in **Austin** for **The Independent,** designed by Rhode : Partners. When completed, the all-residential tower will be the tallest of its kind west of the Mississippi River. Owners of the Pei Cobb Freed & Partners-designed **US Bank Tower** in **Los Angeles,** the overall tallest West Coast tower, have revealed plans to build a glass-bottomed "skyslide" that will transport viewers from the 70th to the 69th floor as part of an outdoor thrill ride. The planned attraction is part of a general tourist-friendly upgrade to the building's programming.

As plans move forward to update the US Bank Tower, its time as the West Coast's tallest building is quickly coming to an end. A major milestone was reached when the **Wilshire Grand Center**, also in Los Angeles, structurally topped out in March. It will supplant the US Bank Tower as both the tallest building in the city and, as a result, the tallest on the West Coast.

A highly unconventional building project has been proposed for **Toronto.** The unnamed towers, known by their location as **King Street West** and informally called **"Ziggurat Towers"** because of their shape, would cluster up to 500 apartment units in 3.7-square-meter modules, rising up to 17 stories, but twisted at oblique angles to take

The Riverline, Chicago. © Perkins + Will

Schuylkill Yards, Philadelphia. © SHoP Architects

King Street West, Toronto. © BIG - Bjarke Ingels Group

State Courts Towers, Singapore. © Serie + Multiply Consultants

in sunlight and support green terraces. The deep, 140-meter site also contains heritage buildings that would need to be partially demolished and rebuilt as part of the scheme, which proposes to allow pedestrians to walk into the building's courtyard, and possibly through the block.

Asia and Oceania

In **Kuala Lumpur,** the dynamic capital of Malaysia, a 16.2-hectare plot of land is set to be dramatically redeveloped from an enclave of 1,355 small lots owned by more than 5,300 people into a megadevelopment known as the **Kampung Baru City Centre.** At the center of the development the **M101 Skywheel** is perhaps the most notable; the twin 70-story towers are planned to support a gigantic clock between them. Up to four signature towers and 12 iconic buildings comprising 1.5 million square meters of space are planned, connected by a series of pedestrian walkways and pocket parks. Although construction has started on some plots, realizing the entire project will be an outsized task – negotiating with the huge number of owners has confounded previous development attempts since the 1970s.

Lacrosse Apartments, Melbourne, after the fire in 2014.
Source: ABC News

Further down the Malay peninsula in **Singapore,** Samsung C&T has been hired as the contractor to build the twin **State Courts Towers,** which will ultimately contain more than 60 courtrooms and 50 hearing chambers. The 178-meter towers will be linked by skybridges, and one will have an open façade, both to symbolize the transparency of the justice system and to provide access to gardens, daylight, and fresh air.

Down Under, transparency is also the name of the game, after it was revealed that more than half of the 170 residential high-rise buildings inspected by the Victorian Building Authority (VBA) in **Melbourne** were found to be using non-compliant external wall cladding materials that failed to meet combustibility requirements. Authorities undertook the audit after a November 2014 fire at the **Lacrosse Apartments** in the Docklands was pinned to use of aluminum composite paneling. Seeking to calm nerves, the VBA stressed that "non-compliant" doesn't necessarily mean "unsafe;" only one building was required to be immediately retrofitted due to fire-safety concerns.

THEY SAID

"If concrete high-rise towers and an enclosed layout breed crime, why is London's listed Barbican estate not a notorious slum ripe for demolition? The answer is (costly) management and maintenance, not the architecture."

Hugh Pearman, Editor of RIBA Journal, discussing the relationship between the concrete high-rise and crime. From "Fault Lines," RIBA Journal, February2016.

Designing a Data-Driven, Humanistic High-Rise

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Grounded by the belief that the fundamental role of architecture is to elevate the human spirit, Ko strives to design beautiful places – ones that are inspirational for life and work and that impact people for the better. He carries this design-first, people-centric approach into his leadership roles as both a Design Director and Studio Director in Gensler's San Francisco office. Always pursuing a high level of both craft and performance in his buildings, Hao was recognized by the American Institute of Architects in 2012 with the Young Architects Award. Additionally, he's a contributor to organizations such as SPUR and Greenbuild and to publications such as Fast Company.

Ben Tranel
Ben Tranel views his role as architect in the broadest sense, as a steward of the built environment. He aspires to an artistry of building, where craftsmanship and a love of detail inform every aspect of the design concept. Being from a large family made Tranel part of a community from day one, so it's no surprise that he is known as a consensus builder and strong team leader. Tranel's spirit of creative problem solving has earned him global leadership roles within Gensler's Commercial Office Buildings Practice Area. Tranel regularly participates in design reviews at local schools, and presents frequently at conferences. He has been honored twice with "40 Under 40" awards.

Much attention has been given to how data and "the cloud" will revolutionize the workplace. Indeed, the way we work is rapidly changing, though many of the demands and challenges we must address are still very much physical. The case of the Tower at PNC Plaza (see Figure 1), an office building in Pittsburgh, Pennsylvania, demonstrates how extensive research, data collection and field-testing lead to a more sustainable tall building and a happier, healthier, more productive workforce.

From Data to Meaning

"The goal is to build the greenest high-rise in the world." When Gary Saulson, then director of real estate for PNC Bank, stated this aspiration for PNC's headquarters, he immediately followed his statement by asking what that would mean.

To design an ambitious building such as this is a journey that involves parsing continuous streams of data. But this data is irrelevant if it cannot be given meaning that in turn impacts the human experience of the built environment.

In the increasingly complex universe of architectural design, data has the power to inform how and what we design to achieve vast improvements in the result. The challenge with the Tower at PNC Plaza lay in collecting, and then turning this data into meaningful, actionable information for the architects, the owners, and ultimately the building occupants.

A Shared Purpose: Open-Source Design

The Tower at PNC Plaza's aspirations stemmed from a fundamental belief that waste is the inefficient use of resources, whether financial, environmental, or human. Thus the metrics for success coalesced into three categories: community, environment, and workplace. The project team set out to establish a new benchmark in performance, both in the building itself, and for the people who use it.

The team recognized they weren't the first to state this ambition for a project, and so they evaluated other projects first. This included case study research and numerous visits to precedent buildings around the world to learn what worked and what didn't. The fact-finding mission took an "open-source" approach, which depended upon the willingness of others to share their results, whether positive or not. For those attempting to achieve the vision of this type of project, there is a greater purpose beyond the individual building. Thus, community building becomes a key goal, not only for this building, but for those working elsewhere to create high-performance environments.

Precedent analysis delivered a few key lessons. First was the imperative to "keep it simple," so that the end users could understand how the building works and operate it with ease. Second, if human performance, not just building performance, was the objective, the design team would need to rethink the entire "chassis" of the high-rise. Other successful projects relied on teamwork among a diverse group of experts to achieve the desired outcome. For a project of this scale to realized, a certain "ruthlessness" would also be required (Simon 2009).

> "The use of natural ventilation became central to the design, not only as a potential energy strategy, but also as a way to provide the most comfortable work environment for people."

Site Analysis

The team began the project with a series of questions and ideas. One of the initial questions, "How do we get the most that Mother Nature has to offer?" led directly to a foundational design idea: orient the building on the site to harvest as much daylight as possible and capitalize on natural ventilation to provide fresh air.

It wasn't possible to simply muscle through with technology alone; rather, a combination of passive and active strategies would be needed. Since passive strategies are essentially free, the design team adopted an approach of "passive first," which became a guiding principle of the project. The designers ranked strategies based on cost, payback and energy savings. This list showed that passive moves, such as solar orientation, are the cheapest and most effective. Once all of the passive approaches have been taken, the efficacy of active technology and renewables is much greater.

The solar orientation of the building was one of the first massing moves. Orienting the building façade to true south, diverging from the urban grid in downtown Pittsburgh, allowed for passive performance that increases daylight, reduces glare, and controls solar heat gain.

Weather information for Pittsburgh betrayed the stereotype of a gritty steel town that is hot and humid in summer and cold in winter. In fact, through 42% of the year, the temperature and humidity in Pittsburgh are well-suited to passive natural ventilation. And at those times, the air quality, pollen counts, etc., are all acceptable for natural ventilation. Thus the use of natural ventilation became central to the design, not only as a potential energy strategy, but also as a way to provide the most comfortable work environment for people.

To make natural ventilation work, the team needed to understand the wind environment around the site and how that air flow might impact an operable façade. Both cross

Figure 1. The Tower at PNC Plaza, Pittsburgh. © Connie Zhou Photography

Challenges and Opportunities In Vertical Healthcare Design

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Douglas King
A principal with the design firm VOA Associates, Douglas King is an instrumental leader in VOA's global healthcare practice, with a particular emphasis on the design of large-scale mixed-use healthcare projects. Mr. King was the technical director for the iconic US$732 million Feinberg/Galter Pavilion and for the US$500 million Prentice Women's Hospital at Northwestern Memorial Hospital in Chicago.

Mr. King serves as the lead peer review planner for several of the largest Veterans Affairs (VA) projects currently under construction in the United States. He has peer-reviewed large scale, private high-rise healthcare projects including the recently completed NMH Outpatient Care Pavilion.

In recognition of Mr. King's expertise on large-scale high-rise healthcare projects, the Chicago Committee of High-Rise Buildings (CCHRB) elected him to membership. Mr. King is active with the CCHRB in the promotion of research and education on the unique challenges of high-rise design. Mr. King supports the education and mentorship of architects, has served on advisory committees for two architecture schools offering Master's concentrations in healthcare design, and regularly serves as guest critic for the University of Illinois' healthcare design studios.

Vertical healthcare design is an emerging field with its own particular set of benefits and challenges. This building type will become more desirable and popular, particularly in North America, due to the location of healthcare facilities in urban centers, escalating land values, and demand for reimbursable healthcare services, but also because of numerous, little-explored advantages that the high-rise building type offers to healthcare providers. These advantages can include planning flexibility, security, and efficiency, as well as improved air quality and reduced noise, which can benefit healing.

However, vertical healthcare buildings, with their caregivers and vulnerable patient populations, require special sensitivity to the challenging aspects in healthcare design – noise/vibration control, air quality, temperature and airflow, vertical transportation, planning, and life safety and security among them. It's clear the high-rise healthcare typology is due for more detailed study and investigation.

Healthcare Grows Up

Where healthcare lives

Major urban medical centers in North America are typically located on the edge of, but rarely in the middle of, downtown, where land would be prohibitively expensive. Healthcare campus settings typically grew horizontally, with additional buildings connected by bridges and tunnels as healthcare organizations focused on maximizing outpatient service.

As cities grew, many medical centers found themselves surrounded by dense urban development. Leading examples include Northwestern Memorial Hospital in Chicago's Streeterville, as well as Barnes-Jewish Hospital in St. Louis and Texas Medical Center in Houston. Skyrocketing land prices made it impossibly expensive to expand by acquiring nearby lots; urban medical centers became "landlocked" (see Figures 1 and 2).

A new mandate

In the United States, the desired program for medical centers has changed in recent decades. In the past, inpatient care had accounted for the lion's share of hospital space. Patient bed floors with diagnostic and treatment support space were the key components in hospitals; doctor's offices might be scattered across adjacent facilities.

Advancements in less-invasive medical treatment, combined with limitations in insurance reimbursement, have fueled the growth in outpatient services and ambulatory care, which have lower overhead costs and generally shorter wait times. This has driven demand for spaces similar to an office building, in which a high level of medical treatment are performed. The National Fire Protection Association (NFPA) introduced an entirely new chapter to NFPA 101 (Life Safety Code) in 1992 to address these hybrid "ambulatory care" environments.

For many hospitals today, the ambulatory care component is now equal to, or larger than, the inpatient component. One example is the 25-story, 122-meter, 92,903-square-meter Northwestern Memorial Hospital (NMH) Outpatient Care Pavilion (OCP), which houses outpatient functions and support such as laboratory and research components. A primary driver for the growth in separate outpatient

> "The structural grid or module in a healthcare facility varies by medical modality. Exam spaces in an ambulatory care setting prefer grids of roughly 9-by-9 meters, to around 9.75-by-9.75 meters."

functions is the simple fact that it is cheaper to build an office building than a hospital.

Group practice

At the same time medical centers took on ambulatory care requirements, physicians began to develop larger practices, too. The 41,800-square-meter Northwestern Medical Faculty Foundation project, a group practice comprising a dozen floors in the Galter/Feinberg Pavilion at NMH is one example, as is Houston's Texas Medical Center. As these group practices became the norm, their program evolved from the traditional groupings of doctor's offices (each with their own waiting, reception, and infrastructure) in a shared office building, to shared waiting and reception functions and other common infrastructure, surrounded by scattered, modularized exam and office functions, all appearing as one branded environment.

Medical education and research

Today, academic medical centers embrace three roles – clinical services, education, and research – and their requirements include simulation centers as well as spaces for informal out-of-class learning and research. In 2015, Northwestern University broke ground

Figure 3. Simpson Querrey Biomedical Research Center. © Perkins+Will

Figure 1. Barnes-Jewish Hospital, St. Louis. © Washington University School of Medicine

Figure 2. Texas Medical Center, Houston. © University of Texas Health

on the new 55,741-square-meter Simpson Querrey Biomedical Research Center, which will rise 12 stories in Phase One, but is planned to comprise 45 stories in total in Phase Two, with an eventual buildout of close to 111,000 square meters (see Figure 3).

Stacking

In designing the Feinberg Galter Pavilion at Northwestern Memorial Hospital in the 1990s, the author and design team pioneered the idea of a mega-healthcare structure by stacking the outpatient component on top of the inpatient component and leveraging common vertical transportation capabilities to co-locate the healthcare staff working in the hospital with their accompanying offices in their group practices. This "stacking" of inpatients and outpatients has taken hold in some denser urban environments.

Today, stacking has a natural ally in the trend towards minimal movement of patients within the hospital. In the new "patient-centered care model," clinical staff, nurses, specialists, and physicians come to the patient.

Conferencing and research

Twenty years ago when hospitals realized they were spending a lot of money on outside conferences, they began to construct larger conferencing capabilities within their facilities, which not only saved money, but actually became a profit center for some. Everything from grand rounds (lectures to doctors), to community health education, to vendor-sponsored PR events could be accommodated in this environment.

Additionally, the research element has expanded in buildings such as The Rehabilitation Institute of Chicago (RIC) pavilion, under construction as of the time of this publication. Within two individual floor modules, the RIC will contain space for inpatient treatment, research and development of prosthetics, and other rehabilitative modalities, as well as patient observation and education. The RIC embodies a growing trend in healthcare clinical research towards a "bench-to-bed" regime, in which the practitioner is also the educator and the researcher (see Figure 4).

What does this all mean for the high-rise hospital? As the programmatic uses within the

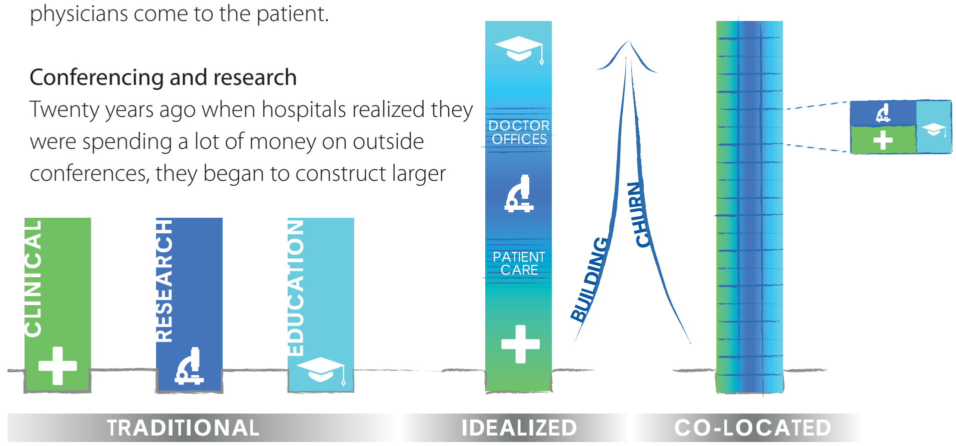

Figure 4. Idealized, bench-to-bed regime.

The Logic of Rapid Extrusion Produces the "Jumping" Phoenix

Giorgio Marfella

Steven Richardson

Paulo Vaz-Serra

In inner cities worldwide, there is limited availability of large land parcels apt for high-rise development. Yet, given the seemingly global trend of "superslim" architecture, this limitation does not preclude building skyscrapers on smaller sites in city centers. Considering the Phoenix Apartments, a superslender tall building completed in Melbourne in 2013, this paper reviews how slenderness can impact technological innovation from a perspective of construction management.

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Steven Richardson is a senior construction manager with four decades of experience in Australia, New Zealand, and the Middle East. For many years, he has collaborated with Grocon and Equiset, and he is now an independent expert advisor on constructability, engaged internationally at different stages of large projects for Grocon and Equiset. He is also a part-time lecturer in the Master of Construction Management at the Melbourne School of Design.

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Introduction

Built on a block of land with the dimensions of 6.7 by 24.5 meters, the Phoenix required an integrated approach to resolve site access, structural engineering, cost control, labor productivity and risk management. At the end of the construction process, an innovative methodology of vertical construction emerged; the result was an unconventional development driven by technological result, rather than by economic return. In the context of the Australian building industry, the Phoenix was a prototypical exercise of superslender tall building technology. The experience of this single project defined a model of construction management that fed into other local developments with an innovative approach that pursues rapidity in construction. A qualitative review of technologies, means and methods of construction of this project calls for an integrated approach of slim vertical construction, which, in the future, could be characterized by an almost simultaneous extrusion of structure and building enclosure.

A Construction Standpoint on Slenderness

There is considerable interest in superslim residential towers. This building type can be defined, summarily, as towers of unusual slenderness ratio, in excess of 1 to 10. Often they exceed 1 to 15, which is considered suitable in extremis for a service core (Sarkisian 2012). These buildings attract interest for their architecture, and the socioaesthetic aspects of the phenomenon have been debated widely in the media,

Figure 1. Phoenix Apartments, Melbourne.

particularly in connection with the production of niche upmarket apartment buildings (Goldberger 2014; Hansen 2016). This typology has been analyzed by the CTBUH, where research and industry contributions came from two prevalent standpoints: structural engineering and socioeconomics of development, with the latter focusing particularly on New York City (Barr 2015; Willis 2015). Reports on slender towers by Australian newspapers suggest that the phenomenon may be diffused globally. There are signs that similar patterns of development – at lower heights than New York – are emerging in Melbourne particularly, as indicated by the frequency, location and type of recent residential projects in the inner city (Rollo 2013; Pallisco 2013; Green 2014; Lucas & Dow 2014; Marfella 2014).

This article considers factors of technological innovation in the process of superslim construction. Qualitative building case-study research – in this case focused on the construction of the Phoenix Apartments, a small superslim residential tower in Melbourne – was used as a methodology of investigation. Using a range of sources, which included project documents, site-based observations of the construction process, and access to project records, the building was analyzed, considering the technological decision-making of the head contractor. In synthesis: what was the effect of slenderness on the management of the construction process?

Notwithstanding the limitations of a single case study, this project signals a path of relevance for further research – at least at the level of regional significance. The project was built – and its results used by the head contractor – as part of a deliberate business plan to establish a methodology of development and construction management suitable for other projects of similar use, scale and site conditions. In 2010, Equiset, a development and construction firm, commissioned a study to seek a business strategy for the implementation of "rapid vertical construction" in Australian high-rises. The strategy was designed to unfold in three steps with three superslim projects, and started in Melbourne with the Phoenix Apartments.

The Skinny Challenge

The Phoenix Apartments is a 29-story tower built on a small parcel of land at 82 Flinders Street, in the inner city grid of Melbourne (see Figure 1). The tower sits on a narrow rectangular site of 6.9 by 24.5 meters, which is comparable in size to that of a Victorian terrace house. The first concept of the building, as submitted for town planning approval in 2010, envisaged a 143-meter-high tower with slenderness ratio of 1 to 22. Following mediation with the City of Melbourne, the initial scheme was shortened to 102.5 meters, and the slenderness ratio to 1 to 16 (see Figures 2 and 3).

The challenge to transform such a small footprint into a feasible tall building concept, both at an economic and technical level, was unprecedented – at least in Australia. Evidence of previous projects that could demonstrate technology and profitability of a tower of such "skinny" proportions was not easily obtainable. The initial superslim scheme posed challenges of structural engineering to control rotational sway. The shortened scheme simplified the task of controlling wind-induced accelerations, for example, by avoiding the need for a tuned liquid damper, and reducing the entity of side-sway, which could have caused encroachment on adjoining properties (see Figure 2). A shorter building, however, exacerbated economic challenges, as the loss of revenue from cutting the top floors was such that profit outcomes became more uncertain.

The reduction in height impacted the construction budget, which had to be reduced to the point that standard labor and equipment-hire rates would not suffice. Due to the entrepreneurial determination of the property owner, who was eager to own and occupy the penthouse of the building, the project proceeded with less-than-ideal fundamentals of development. It was equally vital that the head contractor took interest in the project by foreseeing an opportunity to test a new typology of residential development.

Figure 2. Early scheme showing slenderness ratio of 1 to 22. © Fender Katsalidis Architects

Figure 3. Phoenix Apartments final scheme showing slenderness ratio of 1 to 16. © Fender Katsalidis Architects

Modifying Tall Building Form To Reduce the Along-Wind Effect

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In order to reduce undesirable wind effects and structural responses in tall buildings, there are two main solutions: architectural and structural. Architects can mitigate the wind effect on tall buildings by designing the form aerodynamically, or at least by using tapering and setbacks. Structural engineers can reduce wind effects by choosing and designing efficient structural systems, such as the tube and diagrid systems. This research introduces an alternate design method, by creating an innovative computational workbench to design efficient tall buildings to withstand and adapt to the along-wind effect. An architectural parametric design procedure in AutoLisp (AutoCAD) generates the models, and is connected with a Computational Fluid Dynamics (CFD) program (ANSYS) and a structural analysis program (SAP2000).

Introduction

One of the most influential parameters in the structural design of tall buildings, in addition to gravity loads, is the lateral load resulting from wind, and to some extent, earthquakes. Tall buildings have to be designed for a larger base shear from wind forces than from seismic forces; however, ductile detailing is used when needed to account for seismic demands. The wind effect occurs primarily in two main modes of action: across-wind and along-wind. For a rectangular building, the two faces along the mean wind direction are considered the along-wind direction and the two perpendicular faces to the mean flow are considered across-wind (Alaghmandan & Elnimeiri 2013).

The architectural strategies (such as macro- and micro-aerodynamic modifications) are basically considered as precautionary ways to reduce the impact of wind, and subsequently to mitigate the weight of the structure and the cost of the construction. Micro-level modifications tend to involve corner cuts and rounding; macro modifications are geometric and at the whole-building scale, such as tapering and setbacks. The shape and the geometry of tall buildings and aerodynamic modifications can reduce the wind effect (Irwin 2009; Ilgin & Gunel 2007; Irwin, Kilpatrick & Frisque 2008; Amin & Ahujab 2010; Kareem, Kijewski & Tamura 1999; Sevalia, Desai & Vasanwala 2012).

Determining the effect of the type of structural system, based on the form and the shape of tall buildings, is another main objective of this research. Regarding the architectural characteristic of tall buildings, lateral-load-based structural systems, such as tube and outrigger systems, can be designed to reduce the dynamic response of the structure of tall buildings, and consequently to reduce the weight of the structure (Ali & Moon 2007; Moon 2009, 2011).

This research, using architectural and structural strategies to reduce wind effect, introduces a new design method in the realm of tall buildings to achieve minimum structural weight. These kinds of considerations depend on the collaboration of architects and engineers through the design process.

To achieve more efficient buildings, it is necessary to design a common workbench of architectural, structural, and CFD programs

> “Considering the estimated weight of the diagrid system with beams, this solution can be the most efficient system for models with less than three degrees of tapering.”

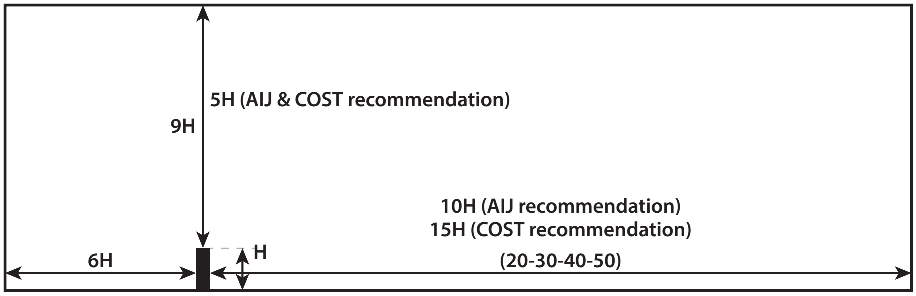

Figure 1. Determining the domain size.

to work together. This method facilitates a comprehensive integration of architectural, structural, and wind aspects to gain the most efficient geometry and form with the minimum wind impact and minimum structural weight, while still achieving the formal functional intents of the building. In this paper, the computing workbench and a test on a building with tapering modifications will be briefly illustrated.

Computational Process

In this proposed design method, there are three main steps to determine the final results and achievements. Based on the CFD results, the lateral force of wind on the windward and leeward sides of the parametric models is obtained for use in the structural analysis and design (Alaghmandan et al. 2014).

CFD simulation

The first step of CFD simulation is to determine the goals and identify the domain of the model. This includes creating a solid model to represent the domain and designing and creating the mesh. In the next step, the preprocessing and solver execution has to be run.

The AIJ (Architectural Institute of Japan) and COST (European Cooperation in Science and Technology) guidelines are used in implementing the ANSYS CFD program.

Determining boundary and meshing size

The models are simulated full-scale in a vertical section 64 meters wide and 360 meters tall. For the size of the computational domain, representing a single tall building model, the lateral and the top boundaries are set at a point least at least five times the height (5H) of the building, and the outflow boundary is set at least 10H and 15H behind the building. The buildings included in the computational domain should not exceed the recommended blockage ratio (3%), where H is the height of the target building (Tominaga et al. 2008; Franke et al. 2004). In this example, the goal is to find the optimal size of the downwind distance from the obstacle, so the basic model is simulated and checked with four sizes (see Figure 1).

For verifying the size, the force pressure is shown in Figure 2. This shows that after 30H, the differences among the results are negligible; thus, 30H is set for the downwind distance for this research. In general, the outflow boundary needs to be far enough from the building to achieve negligible influence by the target building on the wind pattern.

The mesh size before the obstacle divided into 720 segments, with a bias factor of 40. The mesh size after the obstacle is divided into 120 segments, with a ratio of six as the bias factor. For determining the optimal size of the meshing, the basic model is simulated with six different sizes of mesh. The effect of the meshing size on the obstacle and the force pressure is shown in Figure 3. Here it is shown that after 0.3 meters' meshing size, the differences among the results are negligible, so it is set for the basic meshing size in this research.

Based on the aforementioned illustrations, all of the model's iterations are linked in to the ANSYS meshing module for accuracy. The parameters of the ANSYS meshing procedure and its FLUENT CFD simulation must be carefully adjusted to yield enough results to be meaningful.

The main goal in testing gridding and meshing is certifying that the prediction result does not change significantly as the grid systems are changed. In this case, the meshing is good enough to do the final CFD simulation. It is also necessary to ensure that the aspect ratios of the grid shapes do not become excessive on regions adjacent to coarse grids or near the surfaces of the obstacle. It is also best to arrange the prismatic cells parallel to the walls or the ground surfaces for the unstructured grid system (Tominaga et al. 2008; Franke et al. 2004).

After determining the domain and meshing considerations and creating the name section for each wall of the model in the FLUENT procedure, the material properties are defined as fluid, solid, or mixture. Then, solver settings such as numerical schemes and convergence controls have to be set and computed. Basically, the discredited conservation equations are solved until convergence is achieved.

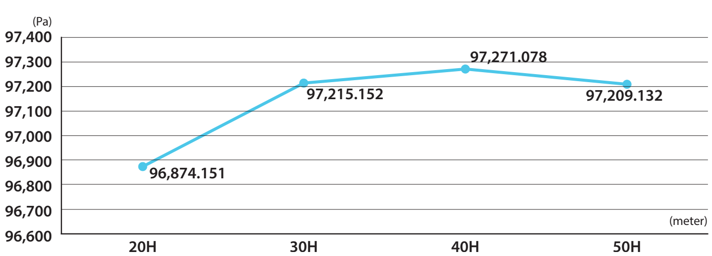

Figure 2. Total force report regarding different domain (outflow) sizes.

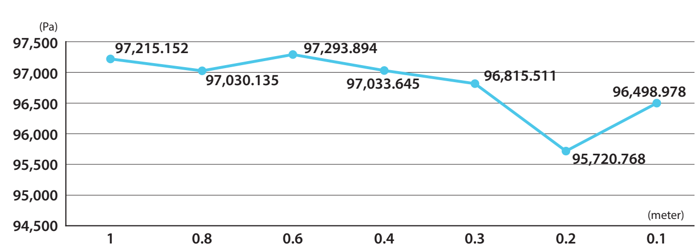

Figure 3. The total force report regarding meshing size.

3for2: Realizing Spatial, Material, and Energy Savings through Integrated Design

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As the world adapts to dual trends of climate change and urbanization, tall office buildings in hot and humid climate zones near the equator are among the prime candidates for a significant change in design approach. Though many individualized improvements to operating systems, envelopes and material selections have been introduced in recent years, it is generally agreed a holistic approach is needed to truly capitalize on the smaller-scale innovations. With a focus on reducing the necessary size of the services plenum, in this paper, an alternative paradigm for the optimization of space, material, and energy use in buildings is presented: a holistic integration of all building systems – structural, mechanical, and electrical – across a building's entire lifecycle, from early-stage design to construction and operation.

Introduction

The built environment is currently facing two important global challenges: climate change and urbanization, with the latter challenge not to be understated despite climate change's dominance at the forefront of geopolitics. In 2007, for the first time in human history, the earth's urban population exceeded its rural population (UNEP 2007). Should this trend continue, by 2050, it's expected that 66% of the world's population will be living in cities. This growth is predominantly happening and is forecast to continue to happen in Africa and Asia, with many cities situated in hot and humid climate zones near the equator. Increasing pressure on these future cities in terms of limited space and resources will lead to dense, mixed-use developments as has already occurred in key regions of Southeast Asia, such as Singapore. For instance, tall non-domestic buildings were among the types of buildings experiencing the largest increase in Singapore's commercial gross floor area over the last several decades (BCA 2014), making office buildings a prime target for improving the space, material, and energy utility of the city-state.

The building sector in Singapore is both aware of and responsive to these drivers, as are many other countries. For several decades, a variety of approaches and technologies have been developed for reducing the operational energy consumption or material intensity of new buildings, with many of these developments focused on the integration of separately-optimized individual components, such as

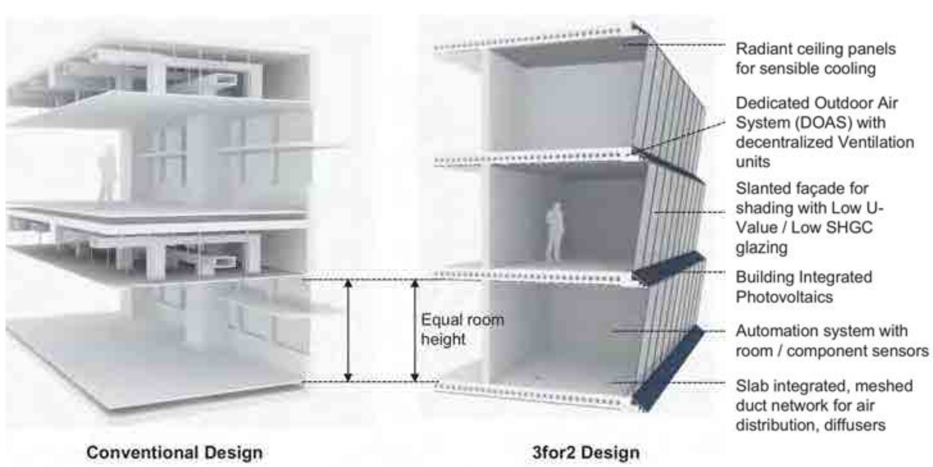


Figure 1. Conceptual schematic of an idealized 3for2 building section compared to a conventional building section.

glazing, air conditioning, lighting, and building structures. They have generally neglected, however, a holistic dimension. In this paper, the authors challenge one aspect of the modern high-rise building form that has not changed fundamentally for more than a half century, outside a few examples in central Europe. Despite its impact on building material use, space intensity, and energy consumption, ceiling plenums and dedicated floor spaces that shield a building's mechanical and electrical systems from the view of building occupants continue to prevail.

Observations have shown that ceiling plenums in conventional commercial high-rise buildings occupy up to one-third of the enclosed building volumes. Typical floor-to-ceiling heights are approximately 2.8 meters, and typical ceiling plenum heights range up to 1.5 meters on average (Parker & Wood 2013). However, the historical prevalence of plenum spaces in buildings should not give one the impression that they are fundamental components of high-rise building construction.

In fact, to understand how ceiling plenums and central air handling systems may adversely affect building material and space use intensity, one needs only to imagine the alternative: a high-rise building that altogether negates any functional need for plenums or dedicated floor spaces for air handling equipment, while still providing energy services (e.g., lighting, air conditioning, etc.) in an efficient, architecturally-appealing manner. This principle is at the core of the "3for2" design concept for high-rise buildings (see Figure 1).

Key Design Principles and Technology

The 3for2 concept calls for a systematic approach to sustainable building design that goes beyond mere energy efficiency of technical systems and operational energy savings. It has been developed for hot and humid climates, but it is also applicable in other climates.

There are three sequential design principles that underlay the 3for2 concept:

1. The decoupling of sensible and latent cooling into independent air-conditioning systems
2. The decentralization of ventilation and latent cooling equipment
3. The integration of decentralized air conditioning equipment and distribution pipe/ductwork into a building's floor and façade structures.

The concept is enabled through three key building technologies, described further below:

1. Water-based chilled ceiling systems
2. Compact fan coil units optimized for latent cooling
3. Void-form construction of floor slabs.

Decoupling sensible and latent cooling/moving to water-based sensible cooling systems

In conventional central air conditioning systems, sensible cooling (the control of indoor air temperature) and latent cooling (the dehumidification of indoor air) is performed using a single, centrally-located air handling unit (AHU). However, air is not the only medium that can be used to accomplish sensible cooling, nor is there any physical reason why a single system must provide both sensible and latent cooling. For over a century, occupants of buildings in cold climates have been accustomed to the use of water-fed radiators that perform sensible heating. Very similar technologies exist for cooling and for combined heating-and-cooling applications. Radiant ceiling panels and passive chilled beams are examples of water-based cooling systems that utilize large, thin, water-fed surfaces to cool indoor spaces in the form of radiant heat transfer and natural convection.

One of the immediate advantages of using water-based systems for sensible cooling is space and material savings. Water can transport the same thermal energy as air, using less than 0.03% of the volume. Hence, water-based cooling can be considerably compact and vertically thin (Meggers et al. 2012). Water-based cooling systems can also be highly energy-efficient, owing to the fact that they can provide cooling at temperatures considerably higher (~17–20°C) than conventional AHUs (~4–8°C). The implementation of chilled water plants that are optimized for high-temperature cooling can lead to water-based cooling systems consuming 40% less electricity for sensible cooling than their conventional air-based counterparts (Wellig, Kegel & Meier 2006).

Decentralization of AHU for latent cooling and ventilation

With sensible cooling covered by water-based systems, the 3for2 concept still calls for an air-based approach to indoor air dehumidification and ventilation. However, in lieu of utilizing single, centrally located AHUs to condition a single floor, the 3for2 concept proposes the decentralization of the floor's latent cooling and ventilation system into several miniature AHUs, served by low-temperature chilled water. Decentralizing the air handling system in this manner provides several advantages, and has been explored in prior research (Baldini, Goffin & Leibundgut 2011).

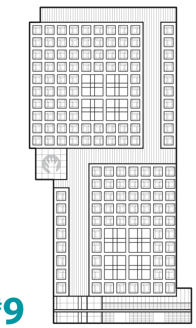
First, the miniaturization of the air handling system into several small AHUs allows for the integration of AHUs into previously unutilized spaces, such as the building's floor and façade structures. The advantage of this is to alleviate, as much as possible, any need for dedicated AHU rooms or complete AHU

> "The historical prevalence of plenum spaces in buildings should not give one the impression that they are fundamental components of high-rise building construction."

The World's 75 Tallest Hospitals

No	Building	City	Country	Architectural Height (m)	Completion
1	Memorial Hermann Tower	Houston	USA	152	2009
2	Guy's Tower	London	UK	149	2015
3	Hong Kong Sanitorium & Hospital - Li Shu Pui Block	Hong Kong	China	149	2008
4	The O'Quinn Medical Tower at St. Luke's	Houston	USA	145	1990
5	Wuhan Xiehe Hospital Tower	Wuhan	China	145	2006
6	Texas Children`s Hospital Expansion	Houston	USA	139	2018
7	David H. Koch Center for Cancer Care	New York City	USA	137	2019
8	Queen Mary Hospital Block K	Hong Kong	China	137	1991
9	Ann & Robert H. Lurie Children's Hospital of Chicago	Chicago	USA	136	2012
10	Hospital Sírio-Libanês	Sao Paulo	Brazil	134	2015
11	Methodist Outpatient Care Center	Houston	USA	133	2010
12	Ability Institute of RIC	Chicago	USA	131	2016
13	Memorial Hermann Medical Plaza	Houston	USA	131	2007
14	Elegance Medical Tower	Riyadh	Saudi Arabia	130	2016
15	Mortimer B. Zuckerman Research Center	New York City	USA	129	2008
16	M&D Tower	Tokyo	Japan	129	2009
17	Instituto do Câncer de São Paulo Octavio Frias de Oliveira	Sao Paulo	Brazil	125	2007
18	Galter Pavilion	Chicago	USA	123	1999
19	Methodist Inpatient Hospital	Houston	USA	120	2017
20	Herlev Hospital	Herlev	Denmark	120	1976
21	Imperial Medical Center	Tehran	Iran	120	2003
22	Southwest Hospital Surgery Tower	Chongqing	China	120	2003
23	Tungs Taichung Metroharbor Hospital	Taichung	Taiwan, China	120	2008
24	Queen Sirikit National Institute of Child Health	Bangkok	Thailand	120	2014
25	Nieuwbouw Erasmus MC	Rotterdam	Netherlands	120	2012
26	Centuria Medical Makati	Makati	Philippines	118	2015
27	MRCCC Siloam Semanggi	Jakarta	Indonesia	118	2011
28	Northwestern Medicine – Lavin Pavilion	Chicago	USA	117	2014
29	Zincirlikuyu Hospital	Istanbul	Turkey	116	2016
30	Smith Tower at Methodist Hospital	Houston	USA	115	1988
31	New York Hospital Cornell Medical Center	New York City	USA	115	1932
32	Children`s Hospital @ 700 Schuylkill Phase 1	Philadelphia	USA	114	2017
33	Bhumisirimangkhlanusorn Building	Bangkok	Thailand	113	2015
34	New City Medical Plaza	Tijuana	Mexico	113	2019
35	MD Anderson Cancer Center	Houston	USA	113	2009
36	CHUM	Montreal	Canada	112	2020
37	Taipei Veterans General Hospital Chung-Cheng Building	Taipei	Taiwan, China	112	1989
38	Hospital Clinico Quirurgico Hermanos Ameijeiras	Havana	Cuba	112	1980
39	Guangdong Provincial Outpatient Hospital	Guangzhou	China	112	2003
40	Bellevue Hospital Center	New York City	USA	111	1974
41	Mellain Center	Tuzla	Bosnia and Herzegovina	110	2015
42	Centro Medico Puerta de Hierro	Zapopan	Mexico	110	2005
43	National Cancer Center Chuo Hospital	Tokyo	Japan	110	1999
44	National Taiwan University Hospital Child Medical Treatment Building	Taipei	Taiwan, China	108	2007
45	Indriati Hospital	Surakarta	Indonesia	107	2017
46	Yonsei Medical Center Severance Hospital	Seoul	South Korea	107	2004
47	Cityplex West Tower	Tulsa	USA	106	1981
48	UT Health Center	Houston	USA	105	1974
49	Ellison Building	Boston	USA	104	1992
50	Rajavithi Hospital	Bangkok	Thailand	102	2016
51	Lingnan Building of Sun Yat-sen Memorial Hospital	Guangzhou	China	102	1997
52	Arkes Family Pavilion	Chicago	USA	101	1979
53	Charite	Berlin	Germany	100	1982
54	Outpatient Diagnostic Building of Ruijin Hospital	Shanghai	China	100	2006
55	Juntendo University Hospital Building B	Tokyo	Japan	100	2014
56	Cleveland Clinic Abu Dhabi Hospital	Abu Dhabi	UAE	100	2015
57	Jikei University Hospital	Tokyo	Japan	99	1999
58	St. Luke`s Episcopal Hospital	Houston	USA	98	1970
59	Princess Margaret Hospital	Toronto	Canada	98	1995
60	Hospital das Clinicas	Curitiba	Brazil	97	1973
61	Prentice Women's Hospital	Chicago	USA	96	2007
62	Feigin Center	Houston	USA	96	2008
63	Feigin Center West Tower	Houston	USA	96	2001
64	Shijiazhuang No.1 Hospital Medical Technique Building	Shijiazhuang	China	95	2002
65	Lanzhou No. 1 Hospital Building	Lanzhou	China	95	2005
66	Por Por Ror Building	Bangkok	Thailand	94	1989
67	Center for the Mentally and Physically Handicapped	Tokyo	Japan	94	1998
68	Skirball Institute	New York City	USA	93	1993
69	Gonda Building	Rochester	USA	93	2001
70	Daping Hospital Complex Ward Building	Chongqing	China	93	2008
71	Kaohsiung Medical University Hospital – Frank C. Chen Memorial Building	Kaohsiung	Taiwan, China	92	2002
72	Tokyo Medical and Dental University Building 3	Tokyo	Japan	91	2004
73	Nassau University Medical Center	Hempstead	USA	91	1974
74	Jim Pattison Pavilion	Vancouver	Canada	91	1995
75	Plummer Building	Rochester	USA	91	1928

While hospitals are not frequently featured among tall building studies, the buildings highlighted below have uniquely shaped the world of hospital architecture and perhaps lead the way for future tall hospitals. Ranked by architectural height, the table to the left lists the location and height of the current 75 tallest hospitals in the world that are either complete (unshaded) or are currently under construction (shaded).



#9

Ann & Robert H. Lurie Children's Hospital of Chicago

Height: 136 m / 447 ft
Location: Chicago
Completion date: 2012
Floor Count: 22

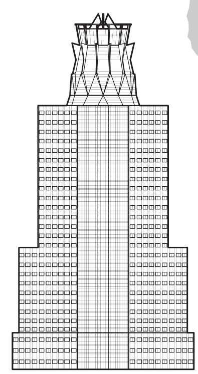
This building was the first free-standing children's hospital in the US and was realized through the collaboration of more than 20 design, art, cultural and civic institutions.

#18

Northwestern Memorial Hospital Feinberg & Galter Pavilion

Height: 123 m / 402 ft
Location: Chicago
Completion date: 1999
Floor Count: 22

This innovative 2.1-million-square-foot facility recently won the 2016 Legacy Project Award, bestowed by the American College of Healthcare Architects (ACHA).

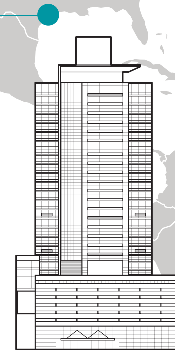


#1

Memorial Hermann Tower

Height: 152 m / 500 ft
Location: Houston
Completion date: 2009
Floor Count: 35

The glass feature atop the tower – sometimes referred to as *the crown* or *the robot head* – has become an icon in the city and currently makes the building the tallest hospital in the world.



#10

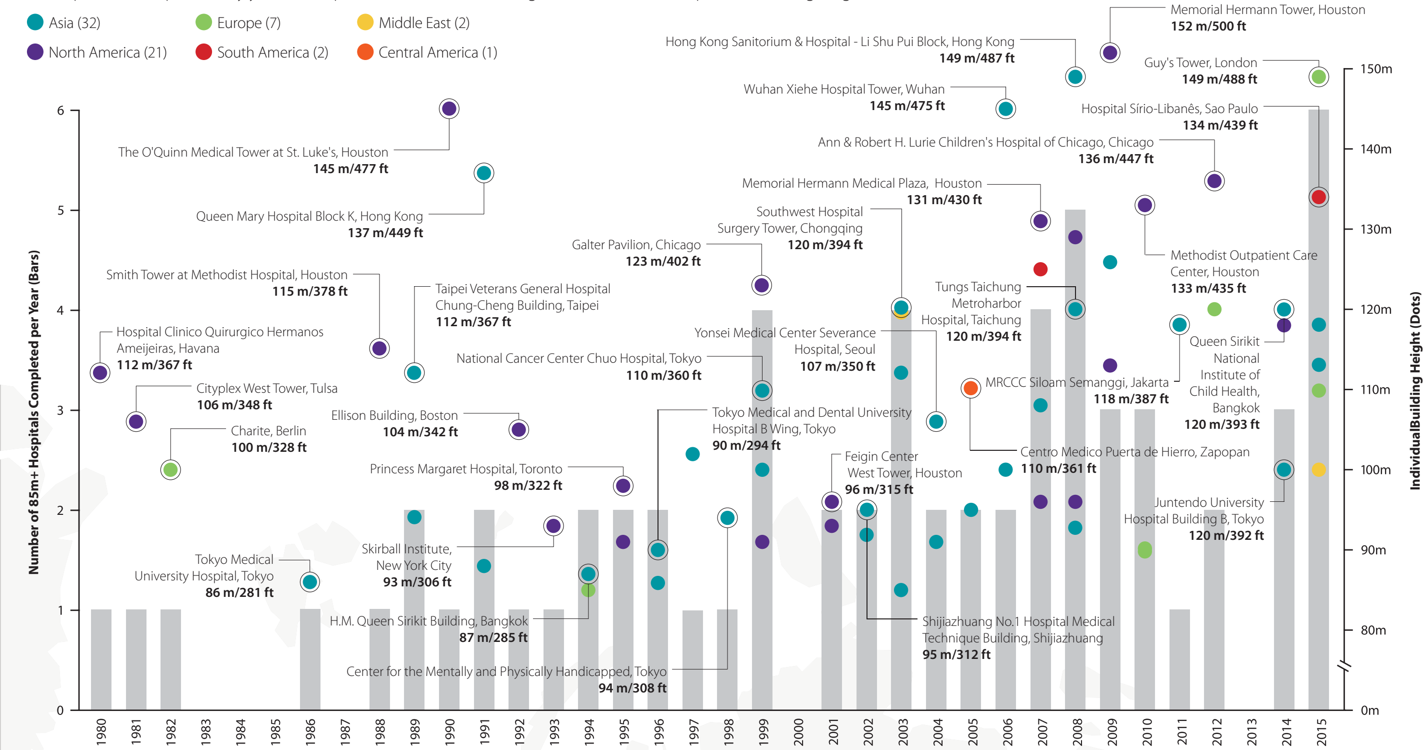
Hospital Sírio-Libanês

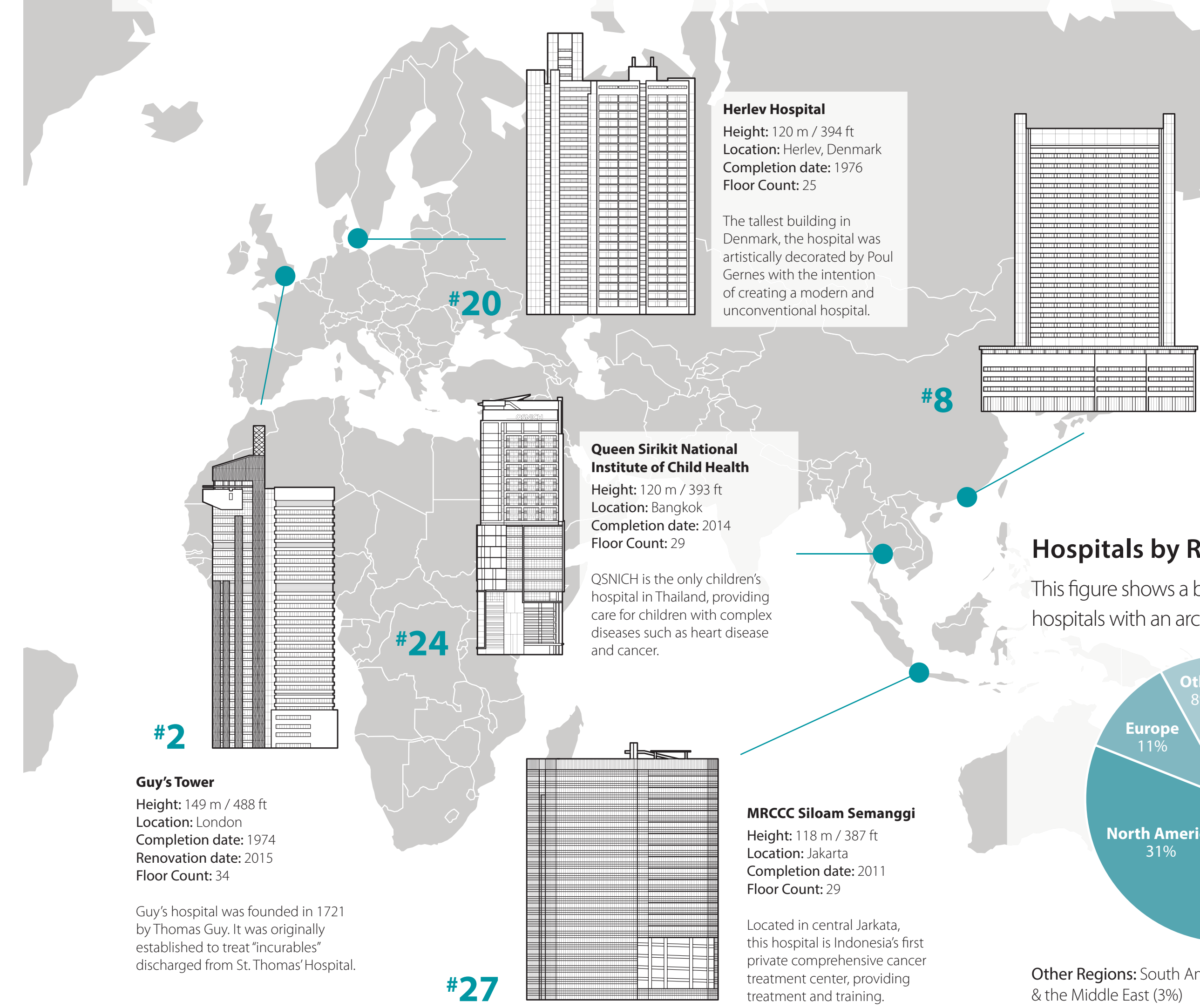
Height: 134 m / 439 ft
Location: São Paulo
Completion date: 2015
Floor Count: 27

One of the most important and well-known health facilities in Brazil due to the high quality of care, it was founded by the large Syrian and Lebanese community of São Paulo.

Timeline of Tallest Hospital Completions, since 1980

Bars represent completions by year for hospitals over 85 meters in height, since 1980. Dots represent building height and location.





Herlev Hospital
Height: 120 m / 394 ft
Location: Herlev, Denmark
Completion date: 1976
Floor Count: 25

The tallest building in Denmark, the hospital was artistically decorated by Poul Gernes with the intention of creating a modern and unconventional hospital.

Queen Mary Hospital Block K
Height: 137 m / 449 ft
Location: Hong Kong
Completion date: 1991
Floor Count: 27

Queen Mary Hospital is the flagship teaching hospital for two major medical schools; the main block of this hospital complex (Wing A – E) is a Grade III historic building.

Queen Sirikit National Institute of Child Health
Height: 120 m / 393 ft
Location: Bangkok
Completion date: 2014
Floor Count: 29

QSNICH is the only children's hospital in Thailand, providing care for children with complex diseases such as heart disease and cancer.

Guy's Tower
Height: 149 m / 488 ft
Location: London
Completion date: 1974
Renovation date: 2015
Floor Count: 34

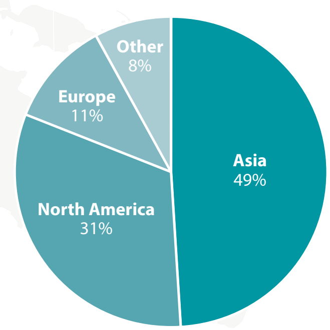
Guy's hospital was founded in 1721 by Thomas Guy. It was originally established to treat "incurables" discharged from St. Thomas' Hospital.

MRCCC Siloam Semanggi
Height: 118 m / 387 ft
Location: Jakarta
Completion date: 2011
Floor Count: 29

Located in central Jarkata, this hospital is Indonesia's first private comprehensive cancer treatment center, providing treatment and training.

Hospitals by Region

This figure shows a breakdown of the location of hospitals with an architectural height over 85m.



Other Regions: South America (3%), Central America (2%) & the Middle East (3%)

Local Context and Global Workflows: Designing Tall for Today and Beyond

Martin Henn

Interviewee

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Martin Henn studied architecture at the University of Stuttgart and at the ETH, Zurich. He received his Master's Degree in Architecture from the ETH, Zurich in 2006, and his Post-Professional Master of Advanced Architectural Design from Columbia University, New York in 2008. Prior to HENN, he has worked for Zaha Hadid Architects in London and Asymptote Architecture in New York. Martin Henn is Design Director of HENN. In 2012 he was made partner.

The work of HENN Architects is reflective of the themes of both the previous CTBUH Conference ***Global Interchanges*** (New York, 2015) and the upcoming ***Cities to Megacities*** (Shenzhen, 2016). The Berlin-based firm is perhaps best known for its AutoTurme 1 & 2, glass-enclosed car elevators at the Volkswagen factory in Wolfsburg, Germany completed in 2000. But the firm has steadily found tall building work around the world, in the burgeoning megacities of China and in more unusual places, such as Ethiopia. CTBUH Journal Editor Daniel Safarik spoke with Martin Henn, Design Director and Partner, HENN Architects, for an insight into how individual originality, economic imperatives, and local relevance can all be maintained in the contemporary global high-rise.

As skyscraper technology and design are global phenomena, and the process of designing and building spans across boundaries, how do you maintain a valid connection to the local social, cultural, architectural, and environmental conditions? What makes your designs uniquely localized?

Understanding of the cultural and social context of the place is key. For example, in our 428-meter Haikou Tower project (in Haikou, China) we felt that the Buddhist faith was an important influencing factor (see Figure 1). While avoiding any direct iconography, we did reflect upon principles such as harmony, balance, flow and continuity. But these are architecturally abstracted and find their references in the geometric language and the spatial articulation of the building. Projects often happen at such great speed and scale that we are confronted with a noncontext. In China, entire CBDs often mark the starting point of new urban developments. The challenge is to bridge the gap between rich, ancient, local cultures and the new, contemporary identities of the place and the people.

Therefore, we also feel strongly about making tall buildings friendly urban neighbors that allow the "urban tissue" to continue. Especially, the podium should be an animated part of the cityscape and streetscape; not isolated, solitary, and one-dimensional, as was traditionally the case with many towers. But the context is not only a cultural one: the Haikou Tower also reacts sensitively to its tropical climate with a smart façade design that reacts to differing sun and wind conditions.

Figure 1. Haikou Tower, Haikou.

Many sites in China do not have a relevant urban context, so with our design we help create an identity. But since a context can also turn into a restriction, the absence of a strong urban context can feel liberating!

The workflow for the Haikou Tower was an interesting experience of intercontinental collaboration: the façade was engineered in New York, the building was designed in Berlin, the structure in London, and the details in Beijing!

How did you become involved in designing skyscrapers in the first place, and how did this expand outside of Germany?

We got involved through our work in China, a place of unprecedented urban growth, with a need for much higher building density than we are used to in Europe. The vertical expansion is an imminent need and tall buildings are a very common and far more accepted building typology.

One of the first high-rise competitions we won was for Haikou Tower, which is now under construction. Through our experience in China, we are now involved in multiple high-rise projects around the world.

Clearly, German design expertise has been, and still is very well respected in China in many industries, including tall buildings. What do you think you have brought back, or will bring back, to Germany from your experience designing for China?

A more semantic dimension of "architecture." The Chinese culture, language, and writing have a stronger emphasis on "the image." We discovered that a powerful narrative is absolutely key to sell your project. This goes hand in hand with a strong idea.

German design stands for a rather rational and efficient approach, with a great focus on the detail and the proper execution of the project. We aim to combine both strengths in all of our projects and to mutual benefit.

How do you find the approach and end results differ when the project is solicited via competition instead of a bilateral client-architect arrangement? Do you prefer one over the other?

We really appreciate participating in architectural competitions. Several of our high-rise designs in East Asia, such as the towers in Taiyuan, Shenzhen, and Haikou are the result of an architectural competition.

The great thing about competitions is that they force you to distill a clear architectural vision and let you benchmark your design concepts against other contenders. That is why competitions are important to ensure a high level of quality. In Germany, competitions are steered by an expert jury that makes the decision making very transparent and comprehensible. The (only) upside of hierarchical decision-making is: Once something has been decided upon, you are good to go!

However, we also receive many direct commissions. Here we have the chance to build a stronger dialogue with the client at an earlier stage. We like to use "Architectural Programming" as a tested tool to shape the design process in a more nonlinear, communicative fashion. Understanding the needs of the client and the ccontext better often leads us to unexpected conclusions and design solutions.

"Contemporary skyscrapers should no longer resemble mere 'stacks of pancakes,' because our societies are no longer based on Taylorism, but instead on multi-directional networks – advanced architecture can become a spatial equivalent for that."

In your research paper for the CTBUH 2015 Conference, "Novel High-Rise Typologies," you speak of the usefulness of "voids" as a design canvas. As some of the most heavily programmed and highly secured building typologies on earth, how do you foresee adaptability taking shape in tall buildings in the future?

Most high-rise buildings are singularly programmed entities, which provide maximum rentable area for the least amount of building cost. But we are realizing that the way we work and live has changed radically over the past decades. Today, social interaction and communication are the drivers of innovation and change. Voids free up space for the unexpected. They set the stage for a more vibrant and urban experience. Largely undetermined spaces can stipulate a dynamic and create at least semi-public realms with some visual exchange across floors, when easy accessibility is provided. Contemporary skyscrapers should no longer resemble mere "stacks of pancakes," because our societies are no longer based on Taylorism, but instead on multi-directional networks – advanced architecture can become a spatial equivalent for that.

Speaking of "voids," can you talk about how you were able to engineer the overall performance of the Haikou Tower, a supertall building with several atria in the middle, to occupant comfort?

In the case of the Haikou Tower our main aim was to integrate structure, program and circulation into a consistent whole and therefore ensure the maximum user experience. The engineering of the void spaces in the upper part of the tower was a big challenge due to extreme seismic and wind forces. The hotel lobby on the 72nd floor has a 360-degree panoramic view and opens up to a central void above (see Figure 2). In an area that is prone to earthquakes as well as typhoons, the structure of a supertall tower has to be rigid and flexible at the same time. The structure is based on eight

Figure 2. Haikou Tower 72nd floor sky lobby offering 360 degree panoramic view.

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 Headquarters office at Tongji University, Shanghai; a Research Office at Iuav University, Venice, Italy; and a Chicago Research & Academic Office at the Illinois Institute of Technology. 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."

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