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Case Study: South Beach Towers, Singapore

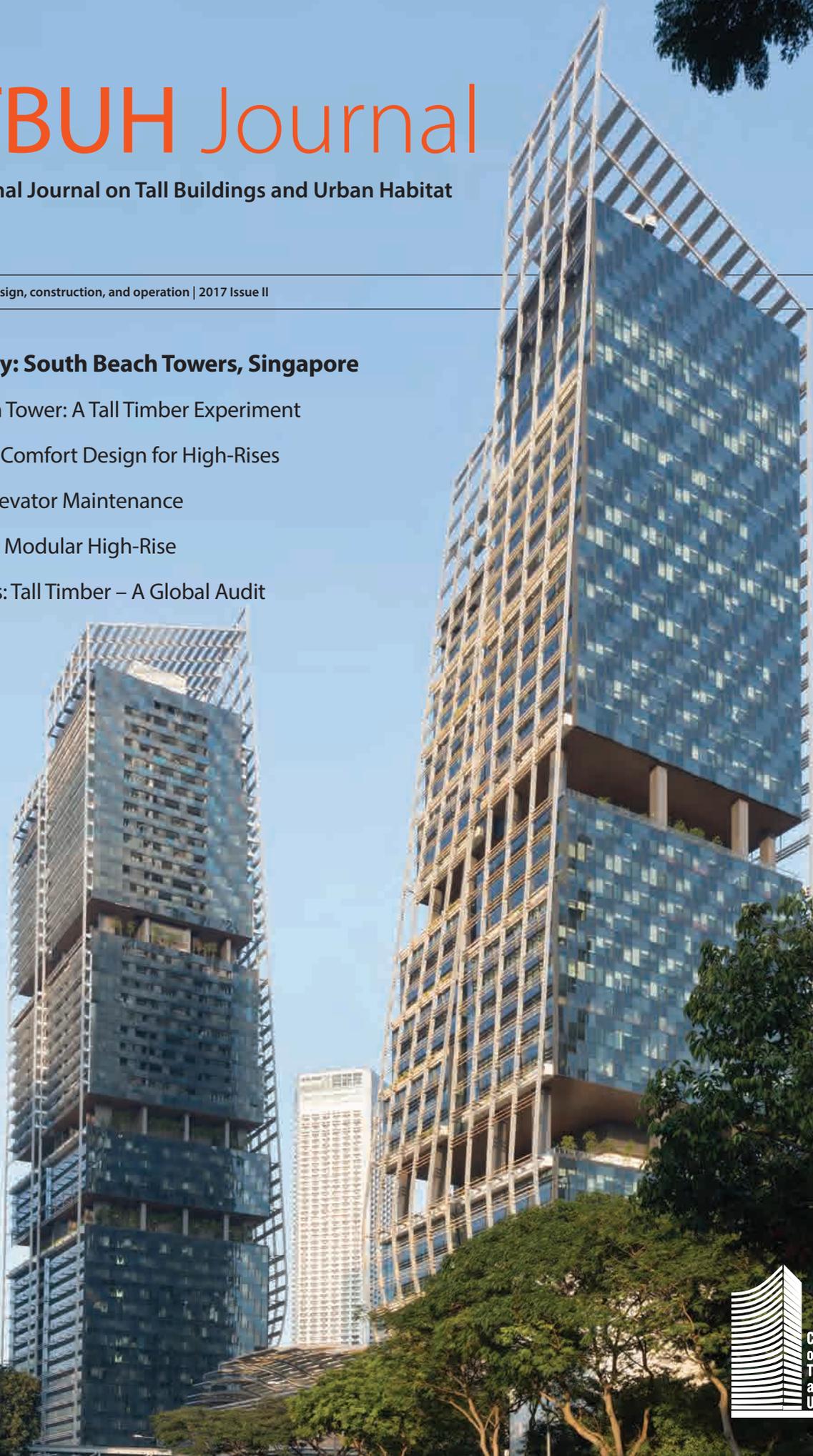
River Beech Tower: A Tall Timber Experiment

Bioclimatic Comfort Design for High-Rises

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MEP
A Bioclimatic Comfort Design Toolkit for High-Rise Buildings



Abstract
Building in an urban environment with high building density on both the ground and upper levels presents an increasingly complex design space. The design process must consider the impact of the building on its context, including the surrounding urban fabric and the building's impact on the urban environment. This paper presents a bioclimatic comfort design toolkit that can be used to assess the impact of a building on its context and to optimize the design process. The toolkit consists of a set of design guidelines, a set of design tools, and a set of design metrics. The design guidelines provide a framework for the design process, the design tools provide a means for assessing the impact of a building on its context, and the design metrics provide a means for quantifying the impact of a building on its context. The toolkit is designed to be used by architects, engineers, and other professionals involved in the design process. The toolkit is available for download at www.ctbuh.org.

Keywords
Bioclimatic comfort, High-rise buildings, Design toolkit, Urban environment, Building density, Design process, Design guidelines, Design tools, Design metrics.

Introduction
Building in an urban environment with high building density on both the ground and upper levels presents an increasingly complex design space. The design process must consider the impact of the building on its context, including the surrounding urban fabric and the building's impact on the urban environment. This paper presents a bioclimatic comfort design toolkit that can be used to assess the impact of a building on its context and to optimize the design process. The toolkit consists of a set of design guidelines, a set of design tools, and a set of design metrics. The design guidelines provide a framework for the design process, the design tools provide a means for assessing the impact of a building on its context, and the design metrics provide a means for quantifying the impact of a building on its context. The toolkit is designed to be used by architects, engineers, and other professionals involved in the design process. The toolkit is available for download at www.ctbuh.org.

Conclusion
The bioclimatic comfort design toolkit is a valuable resource for architects, engineers, and other professionals involved in the design process. The toolkit provides a framework for the design process, a means for assessing the impact of a building on its context, and a means for quantifying the impact of a building on its context. The toolkit is available for download at www.ctbuh.org.

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Vertical Transportation
Elevator Maintenance Considerations for Supertall Buildings



Abstract
The design and construction of supertall buildings presents unique challenges for the design and construction of the vertical transportation system. The design and construction of the vertical transportation system must consider the impact of the building on its context, including the surrounding urban fabric and the building's impact on the urban environment. This paper presents a set of design guidelines for the design and construction of the vertical transportation system for supertall buildings. The design guidelines provide a framework for the design process, a means for assessing the impact of the building on its context, and a means for quantifying the impact of the building on its context. The design guidelines are available for download at www.ctbuh.org.

Keywords
Supertall buildings, Vertical transportation, Design guidelines, Design process, Design metrics.

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Conclusion
The design guidelines for the design and construction of the vertical transportation system for supertall buildings are a valuable resource for architects, engineers, and other professionals involved in the design process. The design guidelines provide a framework for the design process, a means for assessing the impact of the building on its context, and a means for quantifying the impact of the building on its context. The design guidelines are available for download at www.ctbuh.org.

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Architecture/Design
River Beech Tower: A Tall Timber Experiment



Abstract
The design and construction of a tall timber building presents unique challenges for the design and construction of the building. The design and construction of the building must consider the impact of the building on its context, including the surrounding urban fabric and the building's impact on the urban environment. This paper presents a set of design guidelines for the design and construction of a tall timber building. The design guidelines provide a framework for the design process, a means for assessing the impact of the building on its context, and a means for quantifying the impact of the building on its context. The design guidelines are available for download at www.ctbuh.org.

Keywords
Tall timber building, Design guidelines, Design process, Design metrics.

Introduction
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“The volumetric modular process is designed for dense urban areas. The fact is that there are more and more dense, urban areas around the world, where you want to control waste, minimize interruptions, and do as much off-site work as possible.”

Krulak, page 50

Americas

A city not previously known for its skyscrapers, **Quito** has been making headlines, following the ongoing construction of an improved transportation network and subway system that is facilitating transit-oriented development in the Ecuadorian capital. **YOO Quito**, a residential and hotel development designed in-part by Arquitectonica, is an early result of that infrastructure investment. The proposed project is part of a larger master plan aimed at densifying the city. The recently completed **Gaia Building** is another addition to the Quito skyline. The 15,000-square-meter mixed-use tower features retail, office, and residential programming at a prime location near a major intersection and a 67-hectare public park.

In the United States, famously car-centric **Los Angeles** is in the midst of its own development boom, also driven in-part by major regional infrastructure projects and transit-oriented development. Many of the newly proposed projects are located in the fast-densifying South Park neighborhood in downtown LA. There, Gensler has been tapped to design two unique projects at **1300 and 1600 Figueroa Street**. The former is a 1,024-room, 53-story hotel that will rise adjacent to the Los Angeles Convention Center, while the latter is a 52-story dual residential/hotel tower featuring a divided



1300 South Figueroa, Los Angeles. © Gensler

core design and vegetated exteriors. Both are in an early proposal stage, with no specific timetable for development.

Meanwhile, an initial impact study has been released for the **6th & Alameda** complex, located just west of downtown. The US\$2 billion development would rise from a six-hectare site and feature two 58-story towers. The multi-phase project is envisioned to be built over a long timeline, with a final completion date currently set in 2035.

In **New York**, construction recently wrapped up on **50 West**, designed by JAHN. With a certificate of occupancy from the city, residents are expected to begin moving in to the 237-meter luxury high-rise despite ongoing work on the tower's upper floors, a typical arrangement for high-rise buildings. The Financial District building also features a 630-square-meter privately owned public space with an art gallery and café.

In Midtown, KPF's **One Vanderbilt** took a major step forward with the successful completion of its foundation pour. The 427-meter supertall located adjacent to Grand Central Terminal has witnessed a number of preconstruction setbacks, so the concrete foundation pour represents a significant milestone in its development.

As crews were pouring concrete at One Vanderbilt, counterparts in **Chicago** were doing much the same work at **Vista Tower** by Studio Gang Architects, which completed its foundation pour on the same day. The monumental day-long effort required 3,000 cubic meters of concrete brought to the site in 400-plus truckloads. As the tallest building currently under construction in Chicago, the tower has garnered plenty of attention from the city's skyscraper-watchers, who were on-site to document the milestone.

Meanwhile, a proposed tower in **Detroit** is poised to become the tallest building in the



Gaia Building, Quito. © Sebastián Crespo



50 West, New York. © Qualls Benson

THEY SAID

“Livability is about building communities and encouraging interaction among people. You have to create places that bring people together as a community. Public spaces and placemaking become critical if a city is to be livable. At a project level, creative design can encourage interaction and the building of bonds between neighbors.”

Dr. Cheong Koon Huan, Chief Executive Officer of Singapore's Housing & Development Board, the 2016 recipient of the CTBUH Lynn Beedle Award in her interview with Urban Land, February 2017.



Vista Tower, Chicago – under construction. © Shawn Ursini

city. Known as **Hudson's Tower** for the former department store on its site, the project represents a major investment for the once-bankrupt city. It is hoped that it will spur further development in the Motor City, and with a groundbreaking set for December 2017, developers are wasting no time advancing the project.

Asia and Oceania

Major construction updates dominated news in **Beijing**. The Chinese capital has several significant projects underway, including its future tallest building, **China Zun Tower**. Recent photography highlighted construction on the tower, which is expected to complete in 2018. The tower will be the new centerpiece of the Beijing Central Business District, the city's fast-expanding financial hub.

Directly adjacent to China Zun lies the **Samsung China Headquarters** by SMDP, which is also under construction and recently topped out at 260 meters. Cladding has begun to rise up the exterior of the building, while the contours of the building's cube-shaped sky lounge are coming into view. Final completion of this project is also expected in 2018.

Construction is also progressing on the **SOHO Li Ze Tower** by Zaha Hadid Architects, located southwest of the city center in yet another growing business district. Construction of the 207-meter building has reached floor 20, slightly less than half its 46-story height. Topping out is expected in September 2017. Notably, the tower will feature a 190-meter central atrium rising nearly the full height of the structure.

While the relentless pace of construction continues in Beijing, several second- and third-tier Chinese cities are in the spotlight for notable skyscraper proposals. In **Zhengzhou**, a five-tower mixed-use complex has been proposed. The **Cradle Towers** are designed with a nod to the city's ancient history as a cradle of civilization, while looking ahead to its high-tech future. Featuring office, residential, and hotel



China Zun Tower, Beijing.
© Kohn Pedersen Fox Associates



SOHO Li Ze Tower, Beijing. Render by MIR,
© Zaha Hadid Architects.

Canting Towers and a Cooling Canopy

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Abstract

After more than 100 years, an area of Singapore formerly off-limits to the public has been transformed into a new mixed-use development that combines two landmark towers, historic preservation of colonial military buildings, and a flowing canopy at the ground level. The result, called South Beach, is an integrated and vibrant space in central Singapore, maximizing the critical assets of innovative design, warm weather, connectivity, and history. Highlighting three key aspects of the project, this case study unpacks the design team's integrated approach, illustrating the complexity of the design process, and exemplifying how a tall building may make a positive contribution to its surrounding urban realm.

Keywords: Redevelopment, Sky Garden, Vertical Urbanism, Parametric Design

Introduction

The South Beach development covers an entire city block between the Marina and Civic District in the heart of downtown Singapore. Combining new construction with the restoration of existing buildings, the new mixed-use, energy efficient urban quarter brings together places to live and work with shops, cafes, restaurants, a hotel, and public spaces.

Rising up towards the north and south of the site are two inclined towers – 35 and 45 stories respectively – the South Tower is divided between a hotel and apartments, while the North Tower contains offices. A wide landscaped pedestrian avenue – a green spine – weaves through the site,

connecting the towers, retail areas, and the MRT station, and is protected by a large innovative canopy, which shelters the light-filled public spaces beneath from the extremes of the tropical climate (see Figure 1).

From the outset, the design team's vision included the public spaces as well – the undulating canopy covering the green spine forms a key part of the sustainability strategy for South Beach. Due to its tropical climate, the use of outdoor spaces in Singapore is limited to certain times of day. The creation of the green spine and the canopy was an attempt to introduce a new kind of public space that would provide a comfortable microclimate even during the hottest hours of the day.



Figure 1. The innovative canopy shades the walkways and public spaces below.

The two towers are also defined by an environmental screen that rises out of the canopy to mitigate the harsh Singaporean sun. These eastern and western façades contain cascading sky gardens and balconies, while the north and south façades provide solar shading from oblique sun angles (see Figure 2).

The structural approach complemented and augmented the environmental features of the project, with the design team using parametric modeling to integrate all design aspects. This was particularly pertinent in the design of the canopy, where changes in the structural system impacted the environmental performance of the structure and vice versa. What followed was an iterative process of design, in which a single parametric model was fed with multi-layered information to simulate the performance of the canopy and refine the form of its components. In addition, the two towers – with inclined columns in opposing directions – also presented a significant structural challenge.

South Beach is significant in urban terms as well, with the restoration of four historic buildings on the site forming an integral part of the mixed-use development. As a former military site, the entire city block was largely inaccessible to the public until redevelopment began in 2007. As such, one of the key success stories of the project is the transformation of this site into a public space, with a ground plane that is now entirely open, accessible and largely pedestrianized. For the first time since 1907, the links between the historic district and the Marina Bay area have been re-established, revitalizing an important connection in the city that had been lost over time.

Environmental Design Strategy

South Beach's design aimed for the highest environmental rating – BCA Green Mark Platinum – for both residential and commercial components by introducing holistic approaches to environmental design. The



Figure 2. South Beach Towers, Singapore – rising up from the green spine.

“Rather than attempting to achieve integration through a totalizing approach to parametric modeling on a single software platform, the project exposed different interfaces and outputs based on the team members involved and their immediate goals: visualization, physical modeling, and construction documentation.”

A Bioclimatic Comfort Design Toolkit For High-Rise Buildings



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Abstract

Building in an ever more urbanized world, with high-rise buildings increasing in both height and number, makes it essential to ensure we create comfortable urban spaces, as the urban microclimate in and around towers is affected dramatically. This paper proposes a new method of computational design that creates a continuous workflow, one that synthesizes the interaction of dynamic structural behavior, climate, and thermal comfort directly into the digital design process. The author's team has developed a custom software interface that connects different aspects of the design (geometry, BIM, structural analysis, and computational fluid dynamics) in one workflow, allowing different members of the design team to interact simultaneously and inform the design in real time.

Keywords: MEP Engineering, Thermal Comfort, Environmental Engineering, Computational Fluid Dynamics (CFD)

Introduction

The essence of architectural design comes down to the question of providing shelter and well-being for the occupants of a space. It follows that we should be able to ask ourselves the simple question of whether we are comfortable in a space, whether it is inside or outside. But the answers to this seemingly simple question are difficult to quantify. We need tools and measurements

to assess and decide if the design is successful for the intended use of a space.

The efficacy of the toolkit developed by the author's team can be shown through the example of three real-world projects in London (see Figures 1, 2, and 3). An initial speculative test case around the Centre Point Tower will illustrate the use of an hour-by-hour thermal simulation and show how this can be utilized to assess and mitigate



Figure 1. Centre Point Tower, London.
© (cc-by-sa) Paul Farmer.



Figure 2. Millbank Tower, London.
Source: Millbank Tower Proposal.



Figure 3. South Bank Tower, London. © John Parkin

potential urban heat island effects. The redevelopment of the Millbank Tower will be presented as a second case study of how the toolkit has been used to determine pedestrian wind comfort levels around the complex and its influence on the design. A third test case shows how the toolkit determined load patterns on the façade of the South Bank Tower and established a direct link to the dynamic structural analysis software. The toolkit allows the design engineer to utilize these advanced computational tools to inform the design in the earliest stages of the process and therefore enable a new generation of high-rise buildings in the megacities of the future.

Design Challenges

Current design practice shows a myriad of ways to deal with the problems ahead. Where some designers use rules of thumb and define the impacts of the built environment to the microclimate in a very generic way, others might use sophisticated digital tools to model and simulate the environment in great detail. In basic conditions, these rules of thumb might be sufficient and serve the design quite well. However, urban environments are becoming ever more complex, influencing the effects of natural forces on buildings, and amplifying buildings' effects on their surroundings. The current language of architectural design is taking on more complex shapes, while at the same time public awareness of the environment is growing together with the desire (and increasingly the ability) to control or change it. These rules of thumb might then prove not elaborate enough, and therefore a detailed simulation is required.

Modeling and simulating climatic phenomena, and subsequently wind or thermal comfort assessments, is still considered state-of-the-art technology that can only be dealt with by a specific field of experts within practice and academia. These models are not only highly complex and extremely time-consuming to set up, but are also data-hungry, requiring extensive

computational power to execute the simulations and subsequently read out and understand the results.

The author's team, consisting of AKT II, together with Tyréns UK and Gas Dynamics, took on the challenge to inform and shape architectural design by using the urban microclimate as a design input. In order to do this, the researchers needed to gain an understanding of the full aspects and influences that go into modeling and simulating the microclimate. The objective, then, was to find bioclimatic design solutions and develop a toolbox of repeatable methods for designing with them. These methods would then be assessed and compared through classified and well-known comfort criteria in order to make a valuable contribution to the early design phases.

Currently, there is a fragmented array of tools and a patchwork of software on the market that serves to answer questions regarding climatic comfort. Many of these work in isolation on one aspect, be it solar radiation, wind flow, or humidity. Other climatic inputs, and the summary results of their interaction, are not intrinsically taken into account. Furthermore, most of these tools are geared to the *internal* comfort of built spaces, whereas the aim of this research is to develop the potential for influencing pedestrian comfort in the *external* urban realm.

In order to accurately model the full range of urban climatic response, the team felt the need to combine these aspects together into one comprehensive toolkit, which not only allows for a full year-round simulation, but also provides an efficient link to the urban geometry and a user-friendly interface.

What is Comfort?

Before continuing to the technical aspects of the simulation, the design space needed to be defined. What do we mean by pedestrian thermal and wind comfort?

Thermal comfort is described as "the condition of mind that expresses satisfaction with the

“The team’s goal was to develop a novel digital design toolkit that could simulate and assess the external thermal comfort of pedestrians in an urban space.”

thermal environment and is assessed by subjective evaluation." Standards for internal thermal comfort are well defined within local building regulations (ASHRAE 2013). Maintaining this standard of thermal comfort for occupants of spaces is one of the important goals for design engineers.

Internal thermal comfort is a well-established field of practice for the services engineer. The team's goal was to develop a novel digital design toolkit that could simulate and assess the external thermal comfort of pedestrians in an urban space. This toolkit would allow creating a well-informed design for the microclimate of external spaces in complex climatic conditions. With this toolkit, the role that the proposed geometry and material properties will play to influence the perceived comfort of a space can easily be assessed.

Within the research community, there is strong interest in the quality of open urban spaces and a continuing search for methods to design with climatic effects. A number of research projects have been undertaken to determine comfort indices to meaningfully assess and compare external spaces. One of the most extensive works of research evaluates people in an urban space in any climatic region according to its Actual Sensation Vote (ASV) (Nikolopoulou, Lykoudis & Kikira 2004). The ASV finds an empirical comfort assessment of a space, corrected for different climatic zones, largely based on field surveys with nearly 10,000 interviews across

Elevator Maintenance Considerations For Supertall Buildings



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Rony joined D2E in 2010. For the first five years at D2E, Rony was involved in account management for several prestigious tall buildings in London, namely Heron Tower, 20 Fenchurch Street (the Walkie Talkie building), and 122 Leadenhall Street (the Cheesegrater). During this time, he has gained valuable experience on building operations and their interaction with elevators and escalators. He has carried this into his role within the design team, where he can identify potential operational issues during the feasibility of new building developments. At D2E, Rony's experience lies within high-rise building maintenance and post-construction mobilization of major projects.

Abstract

The type and quality of elevator maintenance should be considered at the design stage to ensure the longevity and reliability of the elevators proposed. The implications of getting this wrong will have a disproportionately adverse effect on the functioning of supertall buildings (compared to those of a lesser height). This paper addresses how that risk can be minimized. The long-term reliability of vertical transportation has an impact on design and building users, and early awareness of this in the design process can greatly assist the operation of a tall building throughout its lifecycle.

Keywords: Vertical Transportation, Building Management, Virtual Reality

Introduction

At present, there are 1,184 buildings over 200 meters tall around the world. Of these, 114 are 300 meters or higher, classified as "supertalls." Additionally, there are 327 supertall buildings either under construction or proposed for construction in the next six years (CTBUH Skyscraper Center 2017 – see Figure 1). The race to build tall is continuing, and, as the technology for building tall improves, design teams will likely try to go even higher.

Traditionally, the travel range of elevators, and the necessity to include several shafts to house elevators serving several functions (local, express, hotel, residence, office, etc.), have been among the primary limiters of height. In reaction to this demand, elevator manufacturers have developed products that travel faster, use fewer or lighter materials, manage journeys more efficiently, and are proportionally more power-efficient than in the past. Despite the obvious improvements, the introduction of these technologies nevertheless poses several questions regarding the approach to the after-care of the installed product.

Namely, how does one undertake the maintenance of these super high-tech elevators? Does the local maintenance provider have the relevant technical skills to efficiently maintain the elevator in a supertall building? Does the local supply chain have sufficient spare parts if there are only a limited number of supertall buildings in the region that utilize or share similar elevator technology? What is the replacement or modernization strategy at the end of the elevator's serviceable life? It is an interesting fact that, apart from the World Trade Center in 2001, no building over 200 meters has ever been demolished (CTBUH Skyscraper Center 2017). The cost of getting an elevator design wrong could be catastrophic.

Let us consider a scenario: If a train line has a breakdown, inevitably there will be people

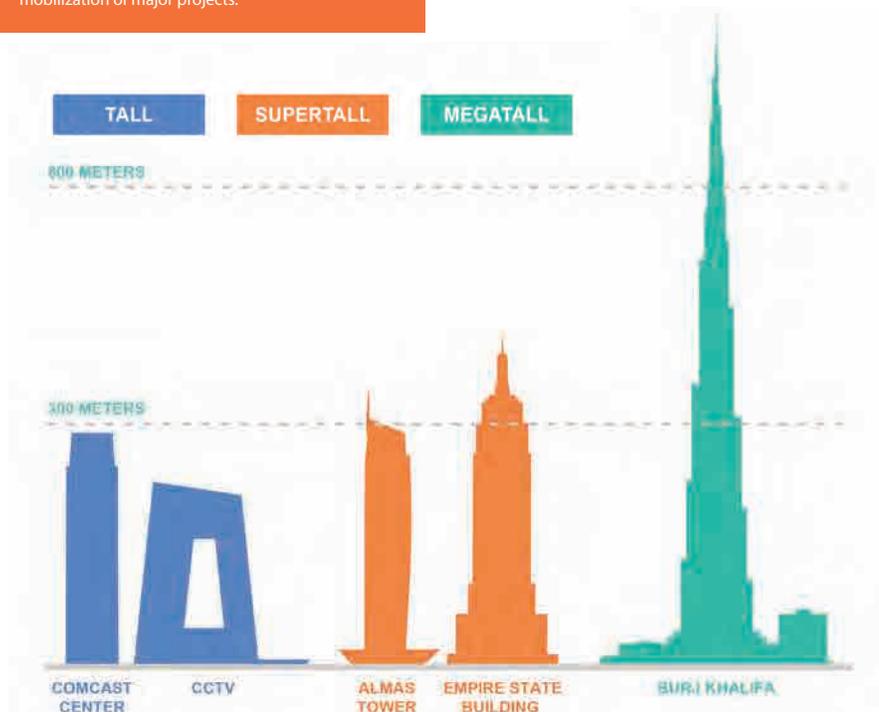


Figure 1. CTBUH's classification of supertall and megatall buildings. Source: CTBUH

queuing and overcrowding at the local hub or station platform. This can be an unpleasant and chaotic passenger experience. Likewise, in an elevator lobby, when one of the elevators breaks down, or if elevators are mis-timed due to poor design, queuing and overcrowding happen quickly (see Figure 2). Practitioners already accept that if careful design consideration is not given to the elevator core design, this would be disastrous for a supertall building, as it is virtually impossible to retroactively fix any potential shortcomings. But there should also be equal emphasis on maintenance in the early design stage of a supertall building, with input from all relevant specialist stakeholders. An optimized maintenance strategy needs to be incorporated into the elevator design strategy, as the impact of getting the strategy wrong will cause an adverse effect in the operation of the supertall building at a later stage. It should be noted that component quality is also a key factor in poor elevator design and future maintainability; however, for the sake of brevity, this article does not elaborate on the subject, as it is worthy of its own separate analysis.

Background

The key stakeholders who have direct influence over the elevator design at an early stage are the developer, the architects, the elevator consultant, and the elevator manufacturers (see Figure 3). From observing discussions between

architects, developers, and various design consultants, it is apparent that discussion of elevator maintenance is often limited to passing comments in early meetings. The author's research with developers indicates this group of people believes it is the responsibility of the elevator consultant and the elevator specialist to ensure that a robust elevator maintenance strategy is considered at the design stage. A developer is interested in the capital sum and the return on investment, with minimum impact to the core. An architect is like a director of a film, who does not need to know every detail of special equipment, but does need to be aware of how to bring these different elements together and coordinate them, to ensure that an efficient core is the result. Thus, the elevator consultant and elevator specialist are typically the parties who consider the elevator maintenance strategy. However, in the author's research, these stakeholders have admitted there is little discussion and sharing of information at the design stage of the process. For more than a decade, elevator manufacturers have invested their research and development budgets mainly in the development of faster elevators, the use of lighter materials to travel higher, and on specialized dispatching algorithms that speed lobby-to-destination travel times. However, these technology advancements are based on an ideal scenario with 100% elevator availability. If elevator availability drops, these technologies become ineffective, thus emphasizing the need to maintain the elevator system with a robust maintenance strategy.

To further understand the necessity of a good supertall building elevator maintenance strategy, it is important to understand how it differs from maintenance in a more typical building.

What is Supertall Elevator Maintenance?

Elevator maintenance is the process of ensuring that the elevator is preserved to last in line with the Original Equipment Manufacturer's (OEM's) recommendation, typically 20–25 years, and to ensure that high standards of safety are maintained for both the users and the maintenance team.

In a typical multi-story building, the standard maintenance regime would feature an assigned technician covering the route and call-out schedule. However, in a supertall building, the requirement is complex, as the technology involved is more advanced. Double-deck elevators, two independent elevators operating in a single shaft, complex dispatching techniques, high-speed motor



Figure 2. Elevator lobby overcrowding. © Ian Smith

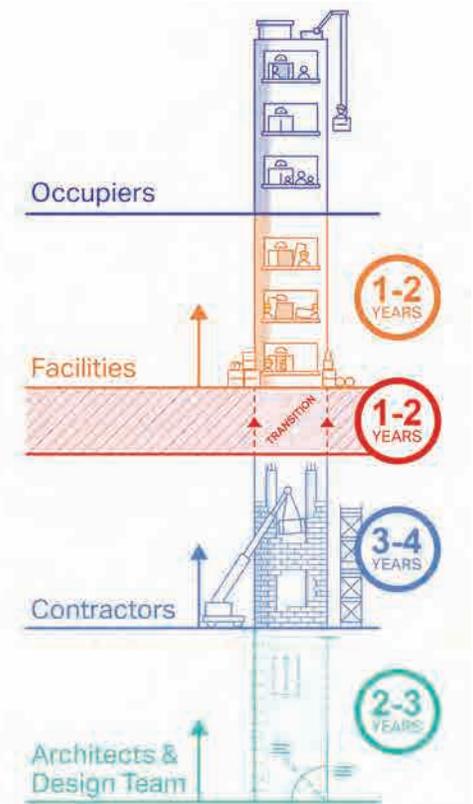


Figure 3. Stakeholders of a supertall building.

Closing Gaps in Commercial Software To Solve Structural Engineering Issues



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Alfonso Oliva is the Director of LERA+, LERA's in-house computational research arm. Through LERA+, he collaborates with design teams on a variety of complex projects and provides instructional seminars to other firms. As a structural engineer, he has led the structural design of sculptural art installations, sports arenas, and supertall towers.

Richard B. Garlock has over 20 years of experience designing efficient structural solutions to facilitate architectural visions. His expertise ranges from university lab buildings to high-rise towers. Garlock was the Project Director for 4 World Trade Center, he was also a member of the WTC Recovery team following 9/11. In addition, Garlock has worked on a number of supertall mixed-use projects internationally, including the BDN Center in Indonesia.

Nidhi Sekhar focuses her efforts on developing and optimizing software that solves problems arising from the structural design workflow, for which she creates complex parametric models and simulations and devises solutions for automating various parts of the design process. She is the cocreator of Cuttlefish, an interoperability platform developed by LERA+.

Mia Tsiamis is a BIM Specialist at LERA. Having first joined LERA on a temporary basis to lead a research collaboration on architectural origami with Sapienza University, Mia Tsiamis rejoined LERA in 2016 and focuses on interoperability and various research endeavors.

Abstract

The ability of architectural graphical software to generate infinitely complex geometrical solutions for building design calls for an equally concerted effort to provide rational structural solutions. This paper presents the example of the design of a tower located in a dense urban environment to show how the evolution of modeling technologies is changing best practices in high-rise design. By engaging in the demonstrated workflow, designers and engineers can better respond to the needs of their clients and project sites, using research and development geared towards bridging the gap between incompatible software platforms and shortening the time between architectural vision and structural reality.

Keywords: BIM, Design Process, Integrated Design, Parametric Design, Structural Engineering, Virtual Reality

Introduction

As technology advances in both design and construction, so has our ability to build more monumental and unconventional structures. The realization of such structures necessitates a more modern, technological approach to the design and coordination process.

In the following pages, we will present a case study of the design of a 130-story tower in Southeast Asia, heretofore referred to as "the Tower," whose main structure is composed of steel-framed floors supported by a central concrete core and composite perimeter columns (eight megacolumns and eight secondary columns). The building's façade tapers at various degrees depending on the plan location and elevation, and the columns, in turn, slope in parallel (see Figure 1)

An algorithm-driven design approach, paired with a custom-developed interoperability platform, allowed for the rapid adjustment of complex geometries in the structural models and gave the architectural team the latitude to macro- and micro-adjust the geometry as needed.



Although the details of the design are not the focus of this paper, three design components are listed below to introduce the reader to the concepts of algorithmic-driven design and the necessity for and utility of an interoperability platform.

A parametric design is a design directed by an algorithm. The main advantage of this approach is that the user can build a dynamic 3D model, as opposed to the typical static 3D model. A dynamic model is capable of reacting to certain inputs in real time. A 3D model created through the algorithmic approach is controlled by input parameters that allow for real-time changes to its geometry.

In the specific case of the Tower, a study conducted on the column/façade interaction of the structure required the development of an ad-hoc algorithm to optimize column locations based on the building façade's slope rate. This algorithmic approach, implemented throughout the course of the project, proved useful for design and coordination purposes amongst the multiple disciplines of the design team.

Figure 1. "The Tower," a confidential project in Southeast Asia, is the example subject.

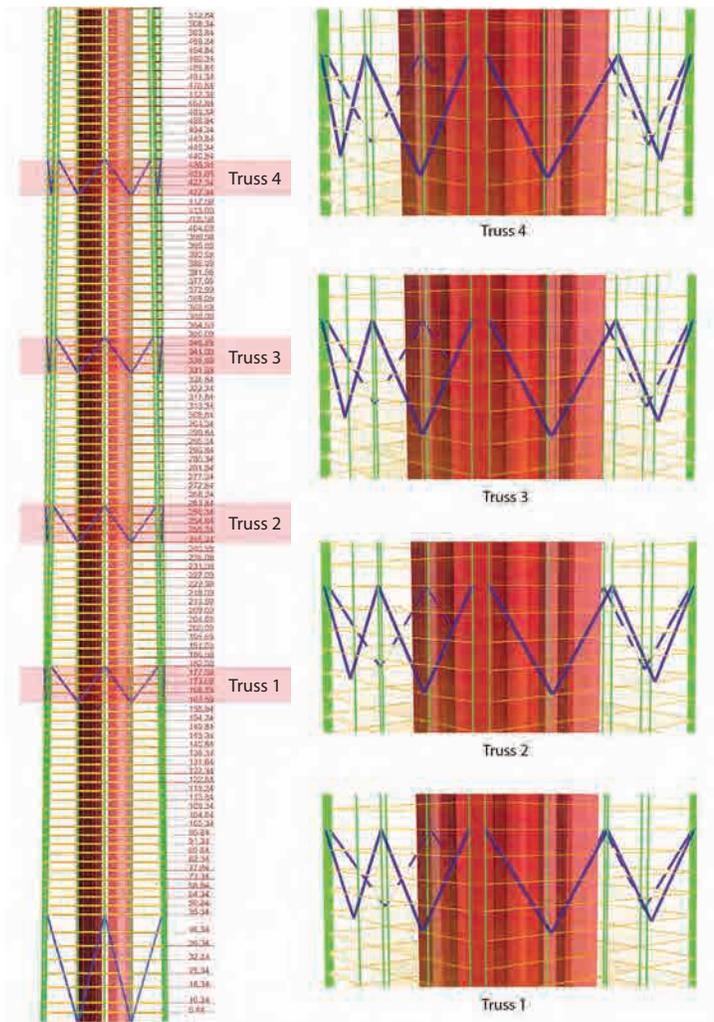


Figure 2. Outriggers optimization study.

Three different algorithms were developed to optimize the number and location of outriggers, their height, and their relative position in the building. This was achieved by linking the parametric definition to a Finite Element Analysis (FEA) software to measure the contribution of the above-mentioned elements in reducing lateral displacements of the Tower. This was studied at different stages of the project. For the algorithm to study approximately 10,000 unique configurations, the run time was about three minutes in each case.

Figure 2 shows screen captures of a typical iteration of the optimization algorithm at an early stage of design.

geometrical and analytical information between these platforms. As was the case for the sloping columns, the crown model was driven by an algorithmic definition in order to quickly readapt to architectural changes. Leveraging the power of algorithms and computation helped to streamline the overall process, as well as to aid exploration of different design options, all within a short period of time (see Figure 3).

Although the workflow presented herein was customized for this particular project, the fundamental framework can be extracted and applied to any high-rise design. The workflow incorporated several tools commonly used in architecture and engineering offices today.

“By reading the data stored in the cloud, the interoperability platform creates a corresponding set of points in the software and generates frames, rigid links, surfaces, and/or volumes based on those points and their associated information.”

The complexity of the crown structure of the Tower necessitated numerous detailed geometrical and analytical studies across different software platforms. The interoperability platform used in the design workflow, described in more depth in subsequent sections of this paper, allowed for the transfer of

- **Rhino 3D** is a freeform software modeler that allows the user to accurately create designs for a variety of purposes, such as engineering, drafting, analysis, and rendering.
- **Grasshopper**, a plugin for Rhino, is widely used by architects, engineers, product designers, and other industry professionals to define parametric control over models. The plugin also enables design exploration by giving the user a graphical interface with which to develop generative design.
- **Autodesk Revit** is a BIM modeling tool widely used in the architectural, engineering, and construction industry for documentation and coordination purposes.
- **Dynamo**, a plugin for Revit, enables parametric control through its graphical interface.
- **SAP2000** and **ETABS** are FEA software used by engineers to study the effect of loads on structures.
- **Cuttlefish** is a custom-developed interoperability platform – composed of a Grasshopper and Dynamo component and a standalone desktop application – that links all of the above-mentioned software and directs the exchange of both geometrical and analytical data between them.

River Beech Tower: A Tall Timber Experiment

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Jeff Sanner is an architect and building performance leader at Perkins+Will. Jeff's focus is the relationship between building design and resource conservation, delivering innovative concepts based on shared targets, research and analysis. His current work explores net-positive energy, net-positive water, and experimental building materials.

Todd Snapp brings versatile expertise and dynamic knowledge as a practice leader and design principal at Perkins+Will. His work spans from mixed-use master planning of high-rise residential and office developments to cultural and higher education facilities. Todd was recently selected as one of *Fifty Under Fifty: Innovators of the 21st Century*.

Alejandro Fernandez is a structural engineer in Thornton Tomasetti's Chicago office. Alejandro brings a holistic approach to the design of tall buildings with master's degrees in both architecture and engineering from the Illinois Institute of Technology and the Ecole Nationale des Ponts et Chaussées in Paris.

Dave Weihing is a principal and office director in Thornton Tomasetti's Chicago office. He has over 20 years of experience in the development and management of structural design. In 2010, he was named one of ENR Midwest's "Top 20 under 40" professionals. Dave has worked on projects in six continents including tall and long-span structures.

Robert Foster is a researcher at the University of Cambridge. His current research explores the potential of engineered timber as a material for tall building design. He holds an MEng in Civil & Architectural Engineering and a PhD in structural engineering.

Michael Ramage leads the Centre for Natural Material Innovation at University of Cambridge. He is also a senior lecturer in the Dept. of Architecture and a founding partner of Light Earth Designs. His current research focuses on creating better housing in the developing world and improved engineered timber and bamboo through natural material innovation.

Abstract

The Chicago River Beech Tower is a collaborative research effort with the goal of identifying challenges and opportunities associated with designing increasingly tall mass timber structures. This paper represents the team's findings to date on these topics, their implications for tall building design, and suggests possible pathways that may inform and engage the design community. A key objective of the project is to explore new design potential with timber buildings, rather than substituting timber in the familiar forms of conventional construction in steel and concrete. Refer also to Tall Buildings in Numbers on page 47.

Keywords: Timber, Construction, Low Carbon, Code Compliance, Prefabrication

Introduction

While the reasons for considering mass timber will vary by project, client, and region, the building industry is experiencing an increase in the use of mass timber products for tall buildings. In 2008 there was one mass timber building over eight stories tall; by 2014, a survey of tall wood buildings identified nearly 30 buildings over eight stories that were either complete, under construction, or in late-phase design (Perkins+Will 2014).

This research began with acknowledging how wood behaves as a material. Its properties were compared to steel and concrete in terms of structural behavior, fire resistance, construction methods, environmental impact, and architectural expression. This fundamental understanding was then applied to the challenge of designing a building with real world design constraints.

Designed by the Chicago offices of Perkins+Will and Thornton Tomasetti in collaboration with researchers at the University of Cambridge's Centre for Natural Material Innovation, the River Beech Tower follows the program of an 80-story, 244-meter-tall timber residential tower situated along the South Branch of the Chicago River (see Figure 1). Exposed mass timber would offer a unique experience within the residential market by connecting occupants with natural materials. The program includes 300 units, a development density in keeping with current

construction along the Chicago River (see Figure 2). The 80-story program of the tower forces the design team to consider many of the issues typical to designing tall buildings, while staying within the established 70- to 80-story height range for tall residential towers in Chicago.

Design Strategies

The overarching goal of this study is to identify areas of mass timber research that could help advance the use of timber in tall building structures. Approaching this from a practitioner's perspective, the team placed focus on developing an all-timber superstructure and allowed the planning and architecture to adapt in response. Using a residential floor plate as a planning framework, the team set out to examine how design professionals could use current timber technology to make the design of a tall timber tower feasible.

The material properties of mass timber drive the design of a tall tower in unique ways. Timber's elastic stiffness and material density vary notably from those of structural steel and reinforced concrete. Both natural and engineered timber have lower strength than steel and concrete, with steel supporting up to 460 MPa (fy), concrete up to 95 MPa (f'c), and timber around 25 MPa (Axial ADS); new engineered hybrid materials record higher strengths. However, it is the softer elastic stiffness that will most directly influence the design of tall towers, which must resist large lateral loads. In this case, steel comes in at

200 GPa, concrete at 25–44 GPa, and timber at 7–17 GPa (see Figure 3). Using this data, the team developed several strategies to guide the design when using mass timber.

Proportion the tower footprint to make a timber superstructure feasible.

The design of River Beech Tower interconnects two separate towers, with each tower having a narrow profile. This slenderness is ideal for residential planning, but too narrow for each tower to be stable when subjected to lateral loading. Separating the two towers on each side of a multi-story atrium creates a wider combined footprint and increases stability by performing as a single, larger superstructure. The two individual towers are structurally connected across the atrium using glued laminated timber (GLT) cross-bracing (see Figures 4 and 5). This connection couples the structure together to act as one, maximizing the superstructure’s performance and minimizing member stresses.

Maximize the participation of all vertical members of the tower’s lateral system.

River Beech Tower’s lateral system connects all the vertical structural members together. Cross-laminated timber (CLT) shear walls, GLT bracing, and laminated veneer lumber (LVL) diaphragms effectively engage the vertical elements for resisting the tower’s lateral loads, making full use of gravity-carrying members (see Figure 6).

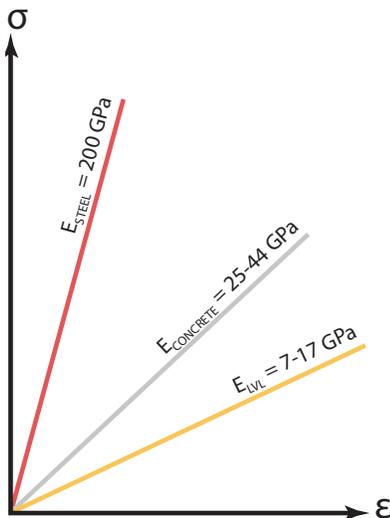


Figure 3. Relative elasticity of steel, concrete, and LVL timber. © Thornton Tomasetti



Figure 1. River Beech Tower, Chicago. © Perkins+Will



Figure 2. The proposed tower in context of its site at the southwest edge of the Chicago Loop CBD. © Perkins+Will

“Establishing timber as ‘non-combustible’ is a challenge. A wood sample would need to be genetically modified, treated, or engineered as a composite material to pass the ASTM E136 test for combustibility.”

Modular High-Rise: The Next Chapter



Roger Krulak

Interviewee

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Full Stack Modular's CEO and founder, Roger Krulak, was formerly Senior Vice President of Modular Construction at Forest City Ratner Companies (FCRC), where he was a leading member of the team that built the modular business supporting foundation of FCRC's flagship project, 461 Dean Street, the tallest volumetric modular building in the world. An internationally recognized expert in modular construction and innovation, Roger Krulak was the recipient of the 2014 Popular Mechanics "Breakthrough Award" for his work on the creation of the high-rise modular process, has been appointed to the Building Innovation Panel for Singapore, and regularly speaks all over the world.

“There is no question that there will be demand for this type of technology in the near future. In the next five years, China needs to build 44 million apartments for the elderly. That's manufacturing nirvana!”

In 2016, 461 Dean Street, the world's tallest volumetric modular building, was completed in New York City (see Figure 1). As few such projects had ever been attempted, let alone in a construction market with New York's constraints, the project's developer, Forest City, and contractor, Skanska, formed a joint modular manufacturing venture to assure the predictable delivery of the 930 modular units that make up the building. Full Stack Modular is a new company that has taken the assets and lessons from that project and plans to scale it up into a global business. Full Stack's CEO, Roger Krulak, outlined his plans in an interview with CTBUH Editor Daniel Safarik.

What has held the industry back from fully embracing modular?

There are two major answers. One is a technology answer. There are two problems with construction technology. One is that we're at the bottom of the barrel of 50 industries, spending like 2–3% of gross revenue on IT. It's a ridiculous number. What that means is, technology advances in relation to construction have been really slow. That is a major driver, because, in order to be a manufacturer of a reliable product, you need to have a process by which you build that product. And then you need to have something that drives that process.

If you are making pencils, that's not a hard thing to do. But if you are making buildings with 12 trades, it's a whole different ball game. The convergence of that process is complicated.

The technology has almost caught up. Using an integrated model from a manufacturing perspective, or AutoCAD and its respective plug-ins and pieces and CATiA from the building design world, you can create a federated process that allows you to manufacture things in one place and install them in another place.

The other reason is that the way that our industry is organized currently is broken. There are basically three siloes in any construction project. There is development and financing in one silo. There is architecture, engineering, and design in another silo. And then there is construction management in the third silo.

Thanks to the insurance companies, they have made it so that no one wants to bridge the information gaps from one silo to the other, because no one wants to be responsible. I mean, look at the sinking [Millennium] tower in San Francisco – who wants liability for that? It's a huge problem.

The way the industry has tried to address it is through processes like Integrated Project Delivery (IPD), which is really fascinating theoretically. But at the end of the day, somebody has to own the model. One entity has to put all the pieces together, in the drawings, before you build it in the factory or on-site.

Historically, the means and methods of the processes are decided by the trades that get the contracts. Apart from the structure, literally, the trades usually end up doing whatever they want so long as it meets the performance specifications of the designer. Then, they take the end product back to whoever owns the model, and then they fight about all the clashes that resulted because everyone was still designing in their own bubble.

The reason modular has not happened is not because it is illogical, but because the requirement to get it done is to change the way you do business. The way we do business is to flip everything on its head. We're the design-builders of the building. We can work with an architect or we can provide our own architecture. We are really agnostic about that. We can work with contractors big or small. What we offer to the developer, our customer, is one turnkey solution. You give

us the program, the requirements, and we'll fit it into land that you have. We will do it in a way that you think is appropriately marketed to the customer, and we take it from there. In our factory we do labor and materials, electrical, mechanical, and structural. We assemble it, bolt it up together, and connect all the systems, and we're done.

To me, the innovation of volumetric modular construction is that we are changing the process by which you create buildings.

We research and report on new methodologies all the time, and it's pretty rare that someone can make a claim that their methodology is that innovative. The fundamental process of construction remains the same.

Here's my favorite story. Josef Shafran, my great-grandfather, was a carpenter. He was born in Russia, he moved to Detroit, and had a very successful career in carpentry. My grandfather was a carpenter, ran a lumber yard, became an executive. If you took my great-grandfather Josef and put him on a construction site today, he would be ridiculously comfortable. Nothing would surprise him. He would not know how to use a cell phone, computer, car, or ride on an airplane. But on a construction site, he would be completely comfortable. That is sad.

The conditions you have described certainly apply in the United States, and the genesis of your solution and your company had a lot to do with the peculiarities of the New York labor market. There are other prefabrication-oriented builders out there with similar goals of efficiency and predictability, such as the Broad Group of China. Do you think Full Stack is a US-centric model, and/or can this be exported?

Full Stack is finishing, to the largest extent possible, as much of the work as we can in the factory, so that the work on-site is *de minimus* – 15–20%, closer to 20% when you include the foundation.

So that is very different from what Broad Group does. Even though the chairman [Zhang Yue] is a charming man – and I think

he is a real innovator, a disruptor, who is trying to think out of the box – they use a ridiculous amount of labor on-site. That works in China. And to some extent, it would be hard for us to do what we do if Broad Group had not put forth their idea first.

When I started this thing eight years ago, and we did our first R&D project, we produced a 600-page book, in which we talked about what we thought about the potential of volumetric modular, the systems of analysis we used, etc. I gave this to Bruce Ratner at Forest City, and he put it on his

desk with the 500 other things that were on his desk. I heard nothing about it.

And then, I was on vacation and I got an e-mail at 3:00 a.m. It was from Bruce. He said, "Look at this video! How did they do a hotel in 15 days?" It was of course the famous Broad Group video of T-30. I said, "If you're willing to get 15 cranes and 300 laborers, we can build in 15 days too, as long as you are willing to also spend about a year and a half manufacturing." But that video is really what kicked off the whole initiative of building 461 Dean Street.



Figure 1. 461 Dean Street, New York. © SHoP Architects

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 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."



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