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What Makes for Tall Building Innovation?

Abstract

In this paper, the Council on Tall Buildings and Urban Habitat seeks to define "innovation" in terms of the potentially transformative technologies and practices for tall buildings, which have received recognition through its Awards program since the designation was incepted in 2012.

Keywords: Innovation, Technology, Development, Visualization, Seismic, Façade, Structural Engineering

Introduction

As the 50th anniversary of the founding of the CTBUH, this year sees a broad campaign to examine historic achievements in the tall building industry over the last 50 years, and to look forward through the lens of innovations that will drive the next 50 years. The apex of that activity is the 2019 World Congress in Chicago this October on the theme of ***50 Forward | 50 Back.*** In April, the Council holds its newly-expanded Tall + Urban Innovation Conference in Shenzhen, which incorporates the 2019 Awards program.

We've devoted a portion of this issue to commemorating that program, and in this paper, we provide a context of values that shapes how we define "innovation." Given that "Innovation" is in the title of the Conference, and CTBUH has been bestowing a Tall Building Innovation Award since 2012, it seemed prudent to examine select awardees over the years as a way of tracing development in several key sub-disciplines, and as a way of evaluating the criteria itself.

This theme is further explored in the Conference's *Innovation Panel Discussion* Track, which convenes six panels across two days, to discuss questions that span Awards categories as well as disciplines, such as "What Makes for Innovative Tall Building Engineering?" and "What Makes for Innovative Tall Building Façades?" Refer to the Conference Program for details.

Criteria

Although the criteria may be well-known to those who have participated in the program previously, it bears repeating in these pages, for the benefit of the uninitiated, and as a way of understanding the arc of awardees across several areas of practice, over time. The criteria state:

The Tall Building Innovation Award recognizes a specific area of recent innovation in a tall building project that has been realized in a design, implemented during construction/operation, or thoroughly tested and documented for its suitability in a high-rise. This award is focused on one special area of innovation within the design, construction, or operation of the project – not the building overall. These can embrace any discipline, including but not limited to technical breakthroughs, construction methods, design approaches, urban planning, building systems, façades, and interior environment. The Innovation Award can include recognition of a breakthrough that may not yet have been implemented in a specific building, but has been thoroughly tested (CTBUH 2019).

Bear these criteria in mind as you navigate through the highlights of the CTBUH Awards programs, and you will have a good idea of the task of the Awards Jury each year.

Vertical Transportation

Stated simply, there could be no modern tall buildings without elevators. The rise of the skyscraper in the 1880s was coincident with advancements in electrical distribution and lighting, which made the passenger elevator a viable technology. However, it is also true

Figure 1. UltraRope, a carbon-fiber and epoxy-based product, is a fraction of the weight of a traditional steel-cored hoisting rope. © KONE

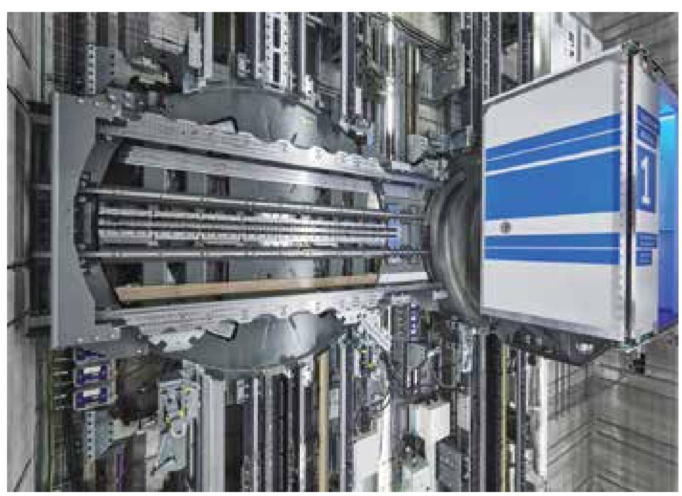

Figure 2. In the MULTI ropeless elevator system, "exchangers" transfer cars from one shaft to the other, or divert their path of travel. © thyssenkrupp

Figure 3. The BSB prefabricated system is assembled at the company's test site in Changsha. © Broad Group

Figure 4. The T30 tower, Changsha, was constructed in 15 days using a custom prefabrication system. © Broad Group

that the basic model of a steel-cable-supported elevator cabin, one to a shaft, went essentially unaltered for more than 120 years. Of course, there have been advancements in speed, comfort, capacity and efficiency, but the central proposition, with its attendant limitations, remained unchallenged. Two CTBUH Award-winning projects stepped up to that challenge, and made it possible to envision a near future of our built environment very different from today's.

UltraRope (Innovation Award Category Winner, 2013) is made of carbon fiber and a high-friction epoxy coating, rather than steel (see Figure 1). By developing a product that was only 19% the weight of steel-cored ropes for the same lifting capacity, the industry could move beyond height limitations that had been dictated by the steel rope's weight and its limited ability to bend before secondary looping wheels are required, meaning that the amount of energy required to lift a car increases exponentially with height. The reduced rope weight means a dramatic reduction in elevator moving masses – the weight of everything that moves when an elevator travels up or down, including the hoisting ropes. With this innovation, the energy and space savings now mean that elevators can ascend up to 1,000 meters in a single run. At a time when we are producing more supertall (300-meter-and-higher) buildings than ever before, the implications of lowering the number of required transfers and the number of shafts are enormous, even for shorter buildings and those due for renovations.

The next evolution took only five years to arrive, with the emergence of **MULTI** (Innovation Award Winner, 2018), an elevator technology that dispenses with ropes altogether, using magnetic linear induction to travel along rails. This theoretically eliminates the mechanical limitation on shaft heights – though the limiting factor of people's patience for long elevator rides remains. Combined with an "exchanger" machine that can turn the traveling motor on a horizontal axis, it allows the elevator to move sideways or diagonally while its cabin remains upright (see Figure 2). Intriguingly, the lines between horizontal and vertical transportation begin to blur, opening the door wider to creating 3D cities that efficiently move people not only within, but between buildings. Though the imagination races at the possibilities, here too, there are more mundane but highly valuable applications, such as the ability to run multiple elevators in one shaft, independently of each other, or increase capacity by running cars in a continuous loop.

Construction Materials and Methods

Constructing a tall building has always been a delicate ballet with heavy masses, as the paramount needs of safety, logistics and cost-effectiveness drive innovation ever higher. Add the relatively new considerations of environmental protection, energy and materials conservation, and the challenges become even more pronounced. These CTBUH Award-winning materials and methods shine a light on multiple potential paths forward.

The **Broad Sustainable Building Prefabricated Construction Process** (Innovation Award Category Winner, 2013) is a prefabricated construction process that front-loads fabrication to a factory before assembly on-site, the main module of which is a concrete-filled, profiled steel sheet, which is affixed to a cage of steel beams (see Figures 3 and 4). Only 7% of construction time is on-site; the rest is inside the controlled conditions of a factory. The system's developer, Broad Group, stunned the world with a YouTube video showing a 30-story building being constructed in 15 days, and then went on to build several more, including a 57-story building in 19 days. Though clearly not applicable in all labor markets, for those contemplating rapid construction of projects in the developing world, it was serious food for thought.

"Broad Group stunned the world with a YouTube video showing a 30-story building being constructed in 15 days, and then went on to build several more, including a 57-story building in 19 days."

Figure 5. The Atira La Trobe apartments in Melbourne used prefabrication and nighttime construction to minimize disruption to its city-center neighbors. © Hickory Group

Figure 6. The Atira La Trobe apartments, shortly after completion of construction. © Hickory Group

Figure 8. The Tallwood House at Brock Commons, Vancouver, under construction. © University of British Columbia

Figure 7. The Tallwood House at Brock Commons, Vancouver, shown after completion. © Acton Ostry Architects/ Michael Elkan Photography

Using mainly concrete, the **Hickory Building System** (Innovation Award of Excellence, 2018), was used to construct an apartment tower in central Melbourne. The 133-meter, 44-level apartment building has used an innovative new prefabricated construction method in order to become Australia's tallest prefabricated building. Delivered 30% faster (eight months earlier) than if a conventional approach were used the construction method used prefabricated building elements, including modular bathroom pods, precast concrete slabs and pre-attached windows (see Figures 5 and 6). The basic structural architecture was designed to be scalable with occupancies that can span across multiple modules to generate generous floor spaces, and has no vertical or horizontal extension limits.

Though concrete and steel still predominate in tall building construction, the past few years have seen rapid advances in mass timber construction, which has quickly become a serious, environmentally sound building material. **Tallwood House** (Innovation Award of Excellence, 2018), a dormitory on the campus of the University of British Columbia, Vancouver, is comprised of 17 stories of unique timber structure: five-ply cross-laminated timber (CLT) floor panels, point-supported by glued-laminated timber columns, all resting on a concrete transfer slab at level two. Two full-height concrete cores provide lateral stability (see Figures 7 and 8). By utilizing the two-way spanning capabilities of CLT, the beams of a classic post-and-beam system were eliminated, along with labor-intensive connections, which dramatically reduced fabrication and

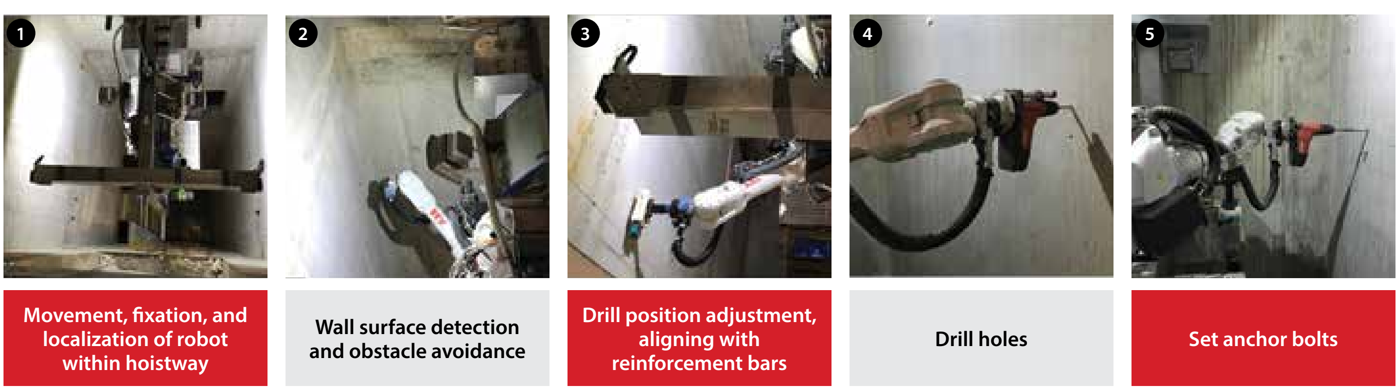

Figure 9. The operating process of R.I.S.E. (Robotic Installation System for Elevators). © Schindler

erection time, and costs. This floor system also significantly reduced the structural depth and created a clean, flat, point-supported surface for unobstructed service distribution.

In some cases, the innovation was automating a process that had previously been entirely manual – and precarious. The Robotic Installation System for Elevators (R.I.S.E.) (Innovation Award of Excellence, 2019) consists of an industrial robot on a platform which is automatically lifted up the elevator shaft and locks itself in place where the work needs to be performed. To do this, the robot digitally maps the shaft, scans for rebar, drills holes into the concrete and mounts anchor bolts with precision. In a second step, (human) fitters can then move into the shaft, mount the rail brackets on the prepared positions, and complete the elevator installation (see Figure 9).

The Self-Climbing Kokoon (SCK) (Innovation Award of Excellence, 2019) is an automated system for high-rise construction. It is equipped with a hydraulic lifting system that allows the assembly to climb up or down façades. No additional equipment or operators are required to run the SCK, and it is able to climb two floors or 8.2 meters in less than 3.5 hours, with a push of a button. Once several floors' worth of steel is in place, the SCK retracts its walkways, activates its hydraulic cylinders and jacks itself up to the next tier. Suspended from the building's columns and driven by its own onboard generator, the SCK can travel between floors without the aid of a crane, or the need to stop work on the site (see Figure 10). In so doing, it improves the safety standard for all workers on the site, eliminates the potential risk of falling objects, and provides safe and easy access to the building envelope.

Though in terms of sustainability it should be the last resort, sometimes the only option available to a property owner is to tear down a tall building, a process that is typically even more wasteful than that of construction. Yet significant, and eye-catching methods have been deployed to improve this process as well. The Cut & Take Down Demolition process used by Japan's Kajima Corporation on its former headquarters (Innovation Award of Excellence, 2012) inverted the usual practice of placing heavy equipment on the building roof and cutting it down from the top (see Figure 11). The Kajima method alternatively allows the workers to start at the base and work their way up. By starting at the bottom, gutting one floor, and then lowering the entire building down on jacks one floor at a time, all the work can be performed safely at ground level.

Figire 10. The Self-Climbing Kokoon advances up the core of One Manhattan West, New York. © Despe S.p.A

Figure 11. Kajima Cut & Take Down (C&TD) method, used on Kajima's former headquarters in Tokyo. © Kajima

Figure 12. The operable façade of Al Bahar Towers protects the building from harsh sun and blowing sand, while lending it a regionally specific identity. © Aedas

Figure 13. An elevation view of the NBF Osaki Building, with its ceramic perimeter façade. © Harunori Noda

Figure 14. A close-up view of the ceramic transpiration system built into the NBF Osaki façade, known as BioSkin. © Harunori Noda

Façade Systems

From the outside looking in, enclosures establish the physical expression of the built environment, but beyond their aesthetics, they play an immensely complex and multi-dimensional role with respect to contemporary skyscrapers. The evolution of tall building façades is occurring at a rapid pace – more than at any other period in history – resulting in a constant stream of new technologies, systems, and approaches. These innovations, while varied and diverse, speak to the importance of façades, not only for the advancement of the tall building typology, but to the betterment of human habitation in all forms.

> “Through transpiration, the surface temperature of the NBF Osaki Building’s enclosure can be reduced by as much as 12°C, and its microclimate by about 2°C.”

Among the most striking façades of any tall building, the operable, clamshell-like array enclosing the **Al Bahar Towers** in Abu Dhabi (Innovation Award Category Winner, 2012), represents a dramatic approach to resolving the issue of intense solar radiation in the desert climate. The towers themselves are simply-clad curtain-wall buildings, but instead of relying on tinted or highly reflective glazing to mitigate solar effects, they utilize an intricate and dynamic external shading system referred to as the “mashrabiya,” named after a wooden lattice screen used predominantly in Islamic architecture (see Figure 12). The façade’s moveable components are semi-transparent panels, which are combined in arrays much like umbrellas. Each array opens and closes in direct reaction to the sun’s position, allowing indirect sunlight to enter the building while blocking the strongest rays to prevent glare and heat gain. While the system improves the comfort and light in the spaces inside, it also reduces the need for artificial lighting and overall cooling loads.

An even more universal solar issue relates to the urban heat island effect created by the intensive “mineralization” (concrete, asphalt, etc.) of built surfaces. As it has in many other cities, the annual average temperature of metropolitan Tokyo has risen 3°C in the past 100 years. As a response to this, **BioSkin** (Innovation Award Category Winner, 2014), applied at the NBF Osaki Building, is a system of ceramic pipes, affixed to the side of a building, which absorbs heat through rainwater evaporation, mitigating the urban heat island effect by cooling the building as well as its immediate surroundings (see Figures 13 and 14). Through this process, the surface temperature of the building enclosure can be reduced by as much as 12°C and its microclimate by about 2°C. The potential implications of this are substantial: If many buildings in a city used such a system, ambient air temperature could be reduced to the point that cooling loads for many buildings, even those without the system installed, could also be reduced.

One of the best options for mitigating against the ill effects of mineralization is to use a non-mineral material as part of the façade itself: vegetation. This was the insight behind the design of the **Living Walls at One Central Park in Sydney** (Innovation Award of Excellence, 2014; see also Best Tall Building Worldwide, 2014), where more than five kilometers of planters function like permanent shading shelves and reduce thermal impact in its apartments by up to 30%. On the north, east, and west sides, the green takes more continuous veil-like appearances with green walls, continuous planter bands and climbing vegetation (see Figure 15). The plants deliver a message of sustainability, and because their shade reduces energy consumption for cooling and their leaves trap CO_2, they also effectively make the building more sustainable.

Structural, Seismic, and Wind Engineering

The structural engineering of skyscrapers has always been a custom affair, but the challenges of building tall have increased along with advances in technique and technology. Scarcity of buildable land in high-density urban areas and the desire to have residences and offices with sweeping, column-free views and access to usable outdoor space at height – all while resisting sway and damage from wind and earthquakes – have conspired to make performance-based design methods a critical component of high-rise design. Contemporary occupiers won't accept buildings that are fortress-like and costly in order to achieve safety and commercial design objectives, which means engineers must work harder than ever to achieve efficient solutions. Over the years, the CTBUH Awards program has highlighted several exemplary projects where a symphony of structural solutions has been composed to achieve elegant and resilient outcomes.

The **Ark Hills Sengokuyama Mori Tower,** Tokyo (Innovation Award of Excellence, 2012), used an ingenious system of built-in devices to achieve seismic resilience. Two damping devices were installed throughout the building as integral parts of the structure: Viscous Vibration Damping Walls and Brake Dampers (hysteretic dampers) (see Figures 16 and 17). The first type of damper is used to counteract the initial movements due to small and medium-sized earthquakes, while the latter is designed to prevent damage to the building in the event of a large earthquake. The viscous damping walls involve using pairs of steel plates which are attached to an upper and lower beam, but not to each other. These plates are layered in close proximity, but the interstitial spaces are filled with a high-viscosity fluid to absorb vibrational energy between structural elements. The brake damper uses frictional energy of brake pads to absorb vibrations. It requires little to no maintenance, delivering a good return on investment.

Facing similar circumstances in Osaka, the **Nakanoshima Festival Tower** (Innovation Award of Excellence, 2013) had a challenging program calling for a 2,700-seat music hall in the lower portion, topped by offices (see Figures 18 and 19). These sections are seismically isolated from each other in two places – at 45 meters above ground, forming the base of the 13th floor sky lobby, and at 54 meters, at the roof of the sky lobby, by using a system of steel megatrusses, belt trusses and lead rubbing bearings (LRBs) and oil dampers. By virtue of this arrangement, the majority of the force imposed by the

Figure 15. One Central Park, Sydney, used "Living Walls" - vegetation - as a critical part of its façade strategy. © Rob Deutscher

Figure 16. Viscous damping walls use steel plates attached to an upper and lower beam, with a viscoelastic material between them, at Ark Hills Sengokuyama Mori Tower, Tokyo. © Obayashi Corporation

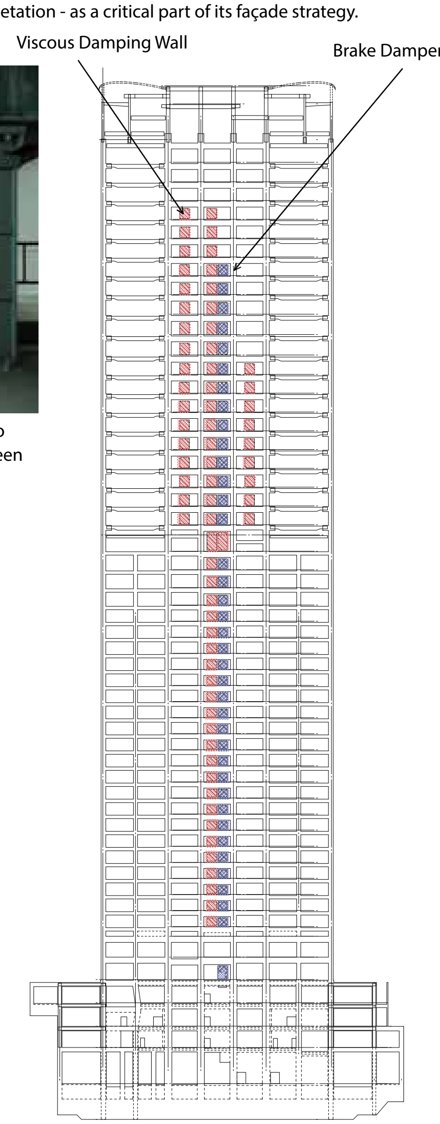

Figure 17. Section showing location of damping equipment at Ark Hills Sengokuyama Mori Tower, Tokyo. © Obayashi Corporation

Figure 18. Nakanoshima Festival Tower, Osaka. © Nikken Sekkei

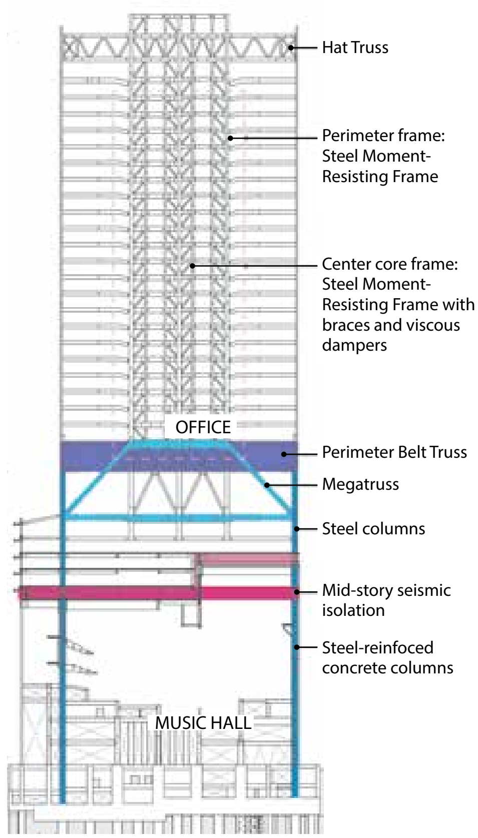

Figure 19. Diagram of seismic isolation strategy used for Nakanoshima Festival Tower, Osaka. © Nikken Sekkei

Figure 20. Close-up view of the Pin-Fuse structural solution under testing. © Skidmore, Owings & Merrill LLP

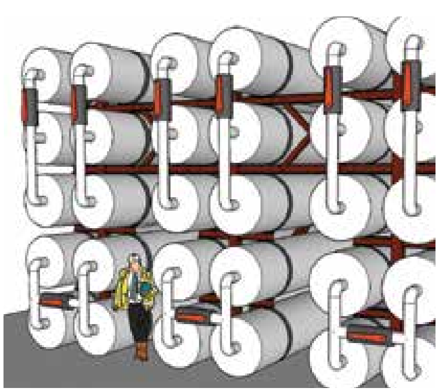

Figure 21. The Hummingbird is a tuned liquid-column gas damper, which can be easily distributed throughout a building. © Hummingbird Kinetics

peripheral columns is sent to the isolation devices, delivering very high performance as a seismically-isolated building.

A simplified approach to seismic engineering for steel buildings was introduced with the **Pin-Fuse** (Innovation Award Category Winner, 2016), a dual-element structural solution, composed of joints and frames, which slip at pre-set loads to dissipate energy and achieve ductility during seismic events (see Figure 20). With Pin-Fuse, material yielding and frictional slip allow base structural materials to remain undamaged, thereby reducing associated repairs, offering the potential for increased resilience, lower costs, and enhanced sustainability.

Seismic resilience and spatial freedom tend to be at odds, but two recently-introduced devices set out to change the calculus. The **Hummingbird** (Innovation Award of Excellence, 2018) is a tuned liquid-column gas damper that uses a system of water pipes and independently tuned air springs to mitigate wind motion in tall buildings (see Figure 21). Unlike traditional tuned liquid dampers, 100% of the water mass in the Hummingbird is active, which allows it to provide equivalent damping with a lighter and smaller footprint. Further, the Hummingbird's modular design is highly flexible and configurable. This flexibility allows the Hummingbird to be distributed throughout a building, and lends itself to retrofit opportunities for buildings requiring damping late in construction, or even after construction is complete. The Hummingbird is easily re-tuned in hours instead of weeks, and it is built from basic parts that can be sourced globally.

The **Viscoelastic Coupling Damper (VCD)** (Innovation Award of Excellence, 2019) protects tall buildings against both wind storms and strong earthquakes. Because of its range of effectiveness from very small to large displacements, it offers the unprecedented ability to simultaneously control all dynamic loads, within a single system. This improves human comfort, decreases structure costs, improves resiliency, increases safety and protects the owner's assets. The VCD consists of two modular panels, with viscoelastic high-damping material sandwiched between steel plates, bolted to steel beams and then anchored to concrete walls in coupling-beam or outrigger configurations (see Figure 22). Because VCDs replace structural members, they do not impact the architectural use of the building in any way, and therefore building owners do not need to allocate significant space at the top of the building for vibration absorbers, commonly used for mitigating wind-vibration perception problems. In addition, the damper offers reliability, as its performance does not require any maintenance or tuning to ensure efficiency.

Digital Design

The design and construction of tall buildings is unquestionably a three-dimensional process (perhaps even four-dimensional, as time is obviously a critical component), but historically, it has been largely a case of interpreting 2D drawings into built reality. Nevertheless, it is also unquestionable that digital design has allowed the creation of shapes that would not have been achievable without it. The level of sophistication of design, engineering and testing software grows exponentially each year. It is not a question of whether the construction industry will fully exploit these solutions; it is simply a question of when.

Once the design process is ready to move to the building scale, finite challenges persist. The **Morpheus Hotel** (Innovation Award of Excellence, 2019; see also Best Tall Building Award of Excellence, 2019) required a highly sophisticated digital strategy that integrated the project's complex design and construction logistics. The main challenges were the complexity of its freeform geometry and irregular diagrid exoskeleton, the sheer quantity of construction elements and their interconnections (see Figure 23). The digital strategy was thoroughly parametric, precise, and above all, highly automated and fast. It also facilitated backtracking, enabling previously explored options and geometry to be revisited. Morpheus required a very specific form of building information modeling (BIM) rather than a centralized single platform model straight out of the box. Instead, it used a network of interlinked Rhinoceros models enhanced by the Grasshopper algorithmic plug-in. The entire digital edifice, with its dynamic network of models and geometry, was built from scratch.

Alongside directing construction, importantly, digital design has also answered the call for predicting destruction. A series of high-profile high-rise fires intensified the sense of urgency to create an appropriate predictive regimen for the built inventory. The fires shared a disturbing characteristic: they were too fast for the fire department to control before they had spread extensively along the façade. The cause for this rapid flame spread is linked to the increased use of combustible materials in façades and exterior walls during this period. **EFFECT: External Façade Fire Evaluation and Comparison Tool** (Innovation Award of Excellence, 2019) was devised based on global fire engineering principles, independent of any codes. The scope of the tool is to assess the likelihood and consequence (risk) of a fire spreading over the exterior façade system of a building, for existing buildings over 18 meters high with a business or residential occupancy, including hotels. At a time when many countries are scrutinizing codes and questioning fire testing approaches to façade materials and assemblies, the tool provides a much-needed baseline for risk assessment of existing buildings for owners, government authorities, and the industry. ■

To see all of this year's, and all previous awardees, visit awards.ctbuh.org.

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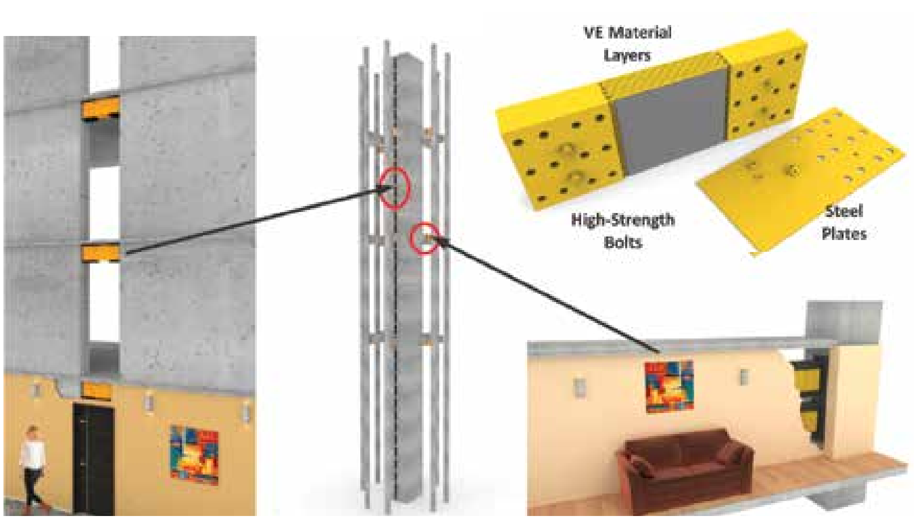

Figure 22. The Viscoelastic Coupling Damper (VCD) can be inserted into party walls, so as to avoid obstructing leasable space. © Kinetica

Figure 23. Morpheus, Macau, was realized using parametric design software. © Leigh Orange