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Designing a Data-Driven, Humanistic High-Rise

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Hao Ko
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

ventilation and thermal stack effect ventilation strategies were considered; the latter was chosen as a more controllable option, both at the scale of the entire building and on the individual floors. The strategy intended to introduce negative air pressure at the façade, so fresh air would be drawn into the building, and up through a central shaft. This was validated with extensive computational fluid dynamics (CFD) modeling at the early stages of design.

In wind tunnel testing, the results of applying pressure and suction forces on the façade were plugged into the whole-building CFD model to evaluate whether any wind conditions on the site would override the thermal stack effect.

Building massing and orientation on the site were addressed to achieve the total gross usable area required, with the right solar orientation. In addition, the team assessed the lease depth that would allow natural daylight to fill the entire workspace area, while optimizing furniture layouts and efficiency of the façade-to-floor-area ratio. The result was a 10.7-meter lease depth, shallower than the more common 13.7-meter lease depth for commercial office buildings. This lease depth allowed daylight into 91% of the floor, covering virtually all of the work area, except those inside the building core, such as bathrooms.

Geothermal opportunities were considered as a means to potentially run a radiant heating/cooling system. Since the water table would be accessible from the basement, the team theorized that underground water movement might generate large amounts of heat storage and cooling capacity for radiant conditioning systems. The proximity of the Alleghany and Monongahela Rivers could also potentially lead to underground water flows. Unfortunately, exploratory probes came back showing that the underground water was not flowing, and the heat storage capacity would not create a meaningful offset to the loads from the building. Thus, geothermal was not pursued as an energy source for the project.

Water treatment on-site was evaluated as a means to avoid overloading the city sewer systems, especially during storms, when overflow is allowed by the city to drain directly to the public waterways. There was an opportunity to avoid compounding that problem and to be a good community builder by treating the building's water on the site.

"Community enhancement" also meant thinking about how the building engages with the city around it. To do this, the team focused on providing programmatic functions that could be used by non-tenants, such as an auditorium. Most importantly, a right-sized food venue was designed that would meet the basic needs of the PNC employees onsite, but not be so big that it dissuaded people from going off-site. By encouraging employees to go out of the building and eat in the surrounding neighborhood, PNC is supporting the local community, small businesses, and the nearby farmer's market (Arieff 2013).

Predictive Computer Simulation

Predicting outcomes with certainty by using a scientific approach to variables, while still working at a conceptual design level, is a challenging endeavor. Mapping data inputs to architectural concepts to test an idea requires fast iteration. The scientific method – holding

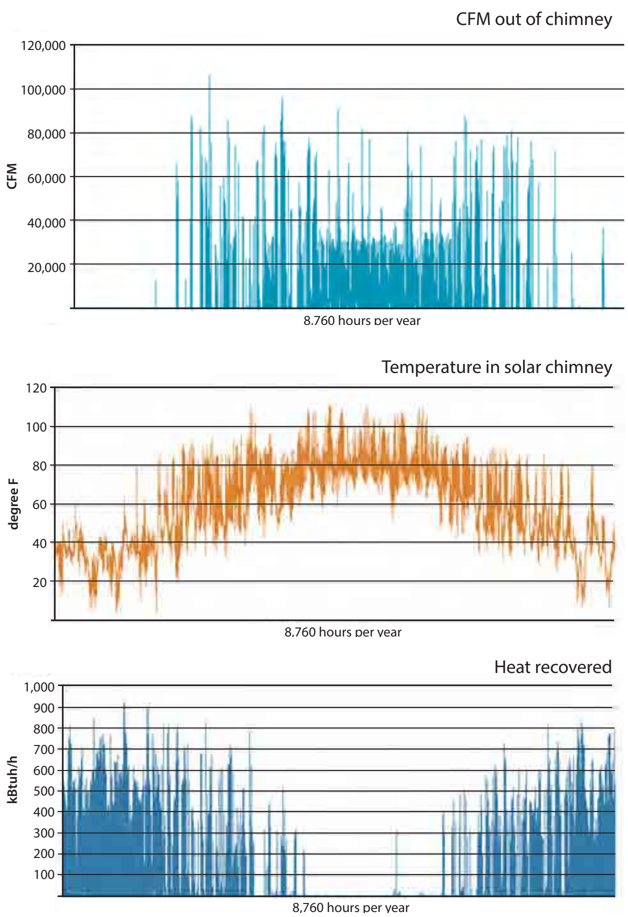

Figure 2. Solar chimney simulation. © Gensler and Buro Happold

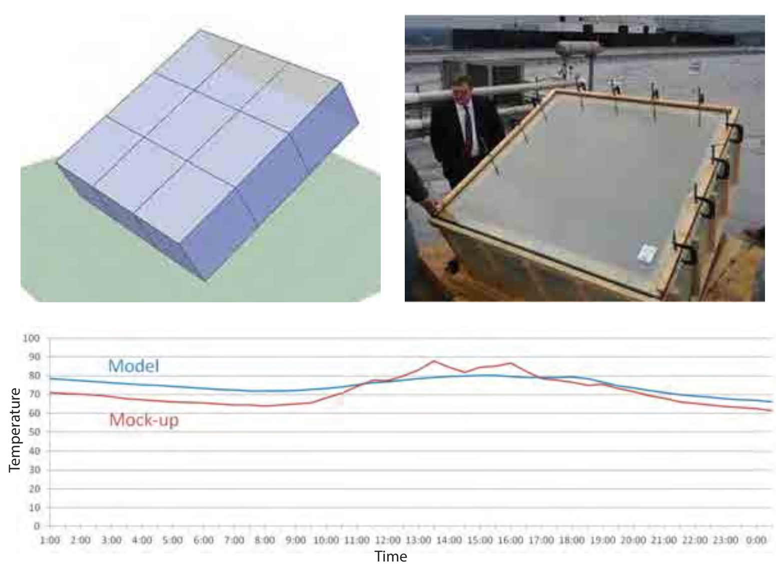

Figure 3. Solar chimney mockup. © Gensler and Buro Happold

certain variables constant while testing hypotheses – was used to evaluate the possibility of natural ventilation as a key way to save energy and provide a comfortable user environment. While it is well-established that vernacular forms of architecture before the air-conditioning era used natural ventilation effectively, the comfort expectations in a modern office require that any conditioning strategy work to a very tight comfort band, typically 22.2–23.8 ºC.

Using data to generate options, such as the possibility of stack-effect ventilation vs. cross ventilation, the team evaluated what would create the best return on investment for both what had to be built and the space it would occupy. Cross-ventilation was tested first. This revealed that external wind patterns created too much uncertainty with interior air flow on each floor level. This ran against the design objective that a system introduces air on every floor in a controlled way. The result of the analysis was to proceed with thermal stack-effect ventilation, using the double wall to allow air into the floors, and using the solar chimney shaft to exhaust that air up through the core of the building.

Extensive evaluation of this scenario took place through computer modeling and simulation. The data showed that the design could generate three times as many air changes per hour as the code-required minimum, creating a workplace filled with much fresher air than a typical office. All of this air movement would be accomplished for free, by using solar heat to create the draw for the thermal stack effect, thus eliminating the requirement for fan power to move the air. As a result, occupant comfort would be higher, energy consumption would be lower, and the total number of heating and cooling hours per year would be reduced.

As a specific design approach was identified, additional computer simulation refined the selected option. Initial simplified analyses were first conducted in isolated small areas, then expanded to evaluate a whole floor of the building, followed by the entire building itself. Once the design was validated at the scale of the whole building, additional permutations of various scenarios were evaluated by changing input criteria. For example, the temperature at which the double wall would work was checked, and this helped identify the range of temperatures at which the design could be predicted to work. Flowvent, CFX, and IES software was used to test façade cavity temperature, run airflow analysis on natural ventilation, and perform full-building energy analysis.

Upon completion of the whole-building simulations, actual weather data for the site was entered to further verify that the building would perform as predicted by the computer simulations. This meant taking into account overcast weather, for example. Most critically, the wind tunnel test results were imported into the CFD whole-building model to evaluate stack effect and operable window feasibility, with specific wind pressures and suctions based on the actual wind tunnel test.

From Theoretical to Actual: Building Mockups

Once the initial design hypothesis was confirmed through computer simulations, the design progressed for verification through physical mockups. The data from the mockups confirmed that the minimum and maximum predicted temperatures for the double-skin façade cavity were close to the computer simulations, but in the mockups, a lag was observed in temperature of the cavity that slightly shifted the timing of the building's natural ventilation mode (Tranel and Snyder 2013).

The mockups allowed the team to reevaluate certain simulation assumptions and boundary conditions, while it easily confirmed others. This helped determine the location of sensors, along with when and for how long to open operable components. The project mockups not only helped gauge environmental performance, but also underscored another important objective: evaluating the unpredictability of human behavior as test users engaged with the mockups.

A number of mockups were also used to first test individual components of the design, such as whether the solar chimney could collect enough solar heat on the many partly-cloudy days typical of Pittsburgh (see Figures 2 and 3).

Component mockups were conducted for individual elements, such as the operable doors and vents of the double-skin façade. For standard elements like the vents, the regimen included life-cycle testing to validate long-term performance. For elements like the operable doors, the mockups introduced slight enhancements and improvements with each iteration, to achieve the smoothest operation. Most components went through at least one iteration of improvement, and a few went through as many as five or six iterations.

A "beta" mockup was built, which involved constructing an entire section of a typical building floor off-site, bringing together different configurations of blinds, chilled beams, lighting, furniture systems, and raised access flooring (see Figure 4). Although all of these components had a proven track record individually, the beta mockup allowed for evaluation of the interactivity of these components. Curtain-wall mockups with an enhanced performance test regimen were conducted for each wall type. An interesting challenge with testing air infiltration was the 914-millimeter-deep double façade, where both the inner and outer façades were evaluated separately and together. The beta mockup offered the initial human encounter with the project, allowing direct experience to be taken into account alongside simulation.

Figure 4. Beta mockup. © Gensler

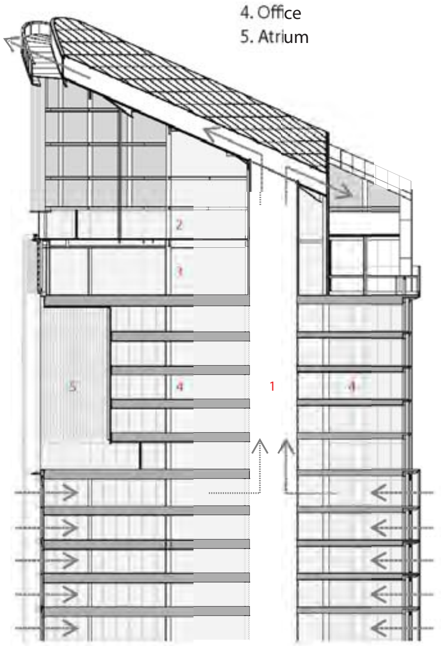

Figure 5. Detailed section of the solar chimney. © Gensler

A Smart Building Needs A Brain

The building operates its own data collection systems, with sensors inside and out that measure air temperature, rain, sun, humidity, air quality, and light. These measurements are processed by the building operations system.

The control systems connect together in a central room that allows the building engineers to monitor what is happening throughout the building and control every single operating component. The client required a transparent view into the automation system's software, so owners could see how the building is actually functioning. A representative cross-section of the design, construction, and ownership team – including the commissioning agent, the client's facilities department, the architect, MEP engineer, façade consultant, and the control systems suppliers – worked together early in the process to think through "what if" scenarios, test them, and develop a response. It was vital to have the entire project team participate in the process to ensure the agreed-upon solution addressed all operational requirements.

Rigorous Analysis of the Final Result

Once a design was fully developed and modeled, the design team brought in an outside panel of experts to peer review the project, resulting in several changes.

The self-imposed peer review was approached with the ruthlessness that had been learned at the outset of the project, and with the pragmatism that an owner might bring to a speculative development. Seeking to avoid the pitfalls often associated with highly aspirational projects and with the headquarters typology, the team used the peer review as a means to evaluate the design against best practices. One of the biggest potential pitfalls was that of creating a solution so highly tailored to a given program that there would be no flexibility to make changes to how the building works in the future.

The peer review led to greater efficiency and flexibility in many systems and created cost savings in general. For example, the weight

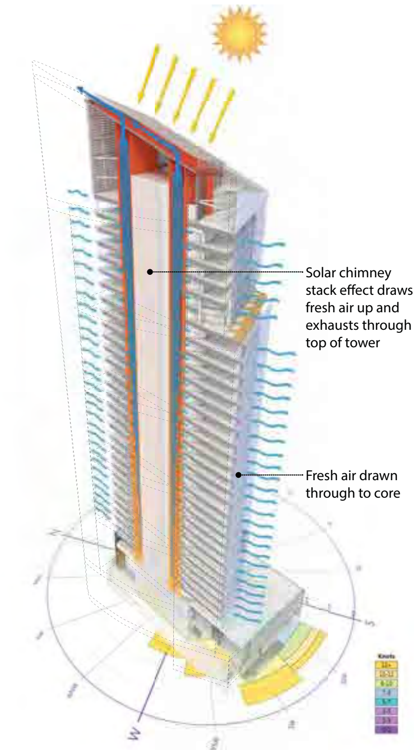

Figure 6. Passive natural ventilation strategy, showing thermally activated solar chimney and shafts connected with user-controlled double façade. © Gensler

of the steel was reduced, and a third chiller was added to optimize the performance of the chilled beams.

A Newly Engineered Building Chassis

The final chassis combined a solar chimney at the core with a double façade around the entire building (see Figure 5). The solar chimney is powered by the sun's heat, which is amplified by the glass enclosure at the top of the tower, to create a thermal draw up through the building (see Figure 6). The double façade wrapping the building

Passive Mode – A Net-Zero Day

Heating Flushing Mode – Summer

Thermal Buffer Mode – Winter

Figure 7. The double façade's different modes throughout the year. © Gensler

Figure 8. Operable doors in the double façade. © Connie Zhou Photography

> “One of the biggest potential pitfalls was that of creating a solution so highly tailored to a given program that there would be no flexibility to make changes to how the building works in the future.”

provides an insulating layer in winter, shade in summer, and operability the rest of the timeto allow fresh air to enter the building and rise up through the solar chimney (see Figure 7). Thus the application of “on-site renewable energy” in this case consists of using free solar energy to replace the energy associated with heating and running fans to move air.

While there are other buildings that provide fresh air to occupants, often through a raised floor or cross ventilation, the Tower at PNC Plaza is unique in connecting the double façade to the solar chimney, which creates natural ventilation on every floor, drawing fresh air directly from the outside into the workspace. The quantitative efficiency gains for the building are complemented by the qualitative enhancements to the human experience.

By providing operable doors in the double façade, the design invites users to engage with the building in a way that transcends common expectations for an office setting (see Figures 8 and 9). This direct user engagement provides people with control over their environment, which has been demonstrated to generate higher satisfaction with temperature and air quality (ASHRAE 2009). Occupants are engaged in the building's use and operations, which saves energy, and in the process, they become happier and more comfortable.

The “neighborhoods” located on the west side of the building are double-height interconnected areas between floors, providing a social, collaborative workspace accessible to two floors at a time, without creating a code-defined “atrium” and the associated costs and complexities (see Figure 10). These neighborhoods are positioned to have great views to the west, and they also provide a low-energy buffer to strong western solar exposure. Because the spaces are used for transitory functions, they can be conditioned to a wider temperature band than the typical office space with workstations. The neighborhoods offer people a choice in their workplace environment, by providing variety in the types of spaces available.

A roof terrace on the 28th floor offers outdoor space with panoramic views of downtown Pittsburgh (see Figure 11). On the same floor, but just inside, is a sky garden

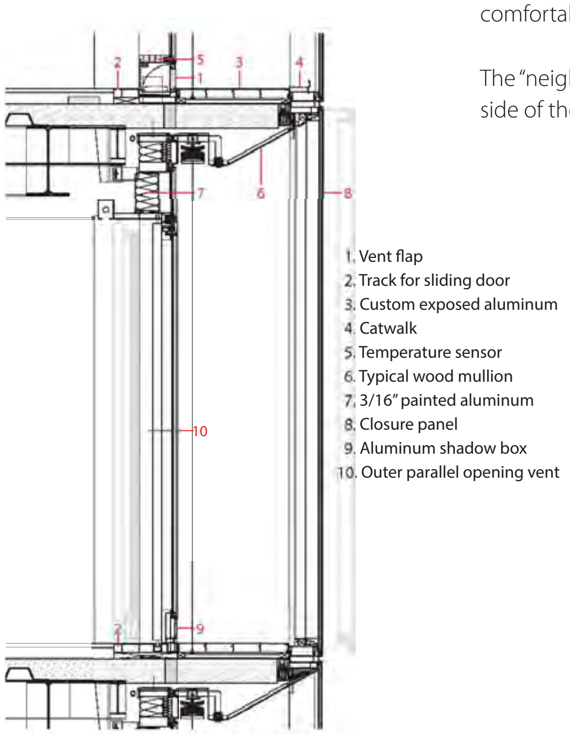

Figure 9. Double façade detail. © Gensler

Figure 10. The two-story “neighborhoods.” © Connie Zhou Photography

Figure 11. Roof terrace on 28th floor. © Connie Zhou Photography

Figure 12. Sky garden on 28th floor. © Connie Zhou Photography

that provides workers and guests a weather-protected enclosure that is allowed to swing in temperature range (see Figure 12). This creates a seasonal experience indoors and the feeling of stepping outside for a breath of fresh air, without having to endure rain and extreme temperatures.

Water savings in the project is achieved through what was dubbed the "Blue Water" plant in the basement, reducing potable water consumption by 77%, and using potable water only as required by code (Cirrani 2015).

Net-zero waste in operations was another goal, which was achieved by separating recycling and compost from trash on each floor, and providing individual users with the ability to sort trash themselves as they dispose. The project takes an important step forward by using composting, which is not yet a widespread mandatory requirement.

The building chassis creates an entirely new user experience, one that makes the office environment exhilarating and enables high-performance work. With the benefit of a chassis that has been engineered completely from scratch, the building works holistically and efficiently, realizing not just incremental gains with layers of technology, but also reducing energy and water demand, and offsetting carbon, all while creating a great user experience.

Figure 13. The double façade as it appears from street level. © Connie Zhou Photography

Material Selections

Material selection is an integral part of both performance and supporting the qualitative aspects of user experience. The use of highly transparent glass over an entire façade would seem to compete directly with the overall sustainability aspirations (see Figure 13). Yet the benefits of providing users with access to daylight and views, and reducing energy demand by using daylight to offset electric lighting, both support the rationale for using large expanses of glass. Introducing blinds in the cavity of the double façade provides solar control while maximizing the transparency of the glass for daylight and views out (see Figure 14). The final glazing assembly is entirely low-iron glass, with a heat-insulating coating only applied to the number-3 surface of the inner façade.

A wood curtain wall offsets embodied carbon content, while supporting the community with locally sourced materials and providing users with a unique and enhanced experience. About 122,000 metric tons of CO_2 was calculated as the difference between a conventional aluminum façade and a wood façade. In addition, powder-coat paint finishes were specified for all metal components in order to provide a product with complete recycling potential during the manufacturing process.

Initial Operation and Ongoing Monitoring

The commissioning team was involved early-on in the design phases, so as to be aware of the decision-making process and how the building was intended to operate. As an advanced commissioning tool, the beta mockup provided an early opportunity to test the interface of different technological systems, such as daylight controls and various sensors. Commissioning of the building itself began in advance of occupancy, and is intended to continue for a full year of initial operation for data-gathering purposes.

Occupancy of the tower officially took place on October 1, 2015, with the first office floors being turned over, and continued throughout the end of 2015 as more occupants moved in.

The first full year of performance data will be taken from January 1, 2016 to December 31, 2016. This will provide a full calendar year of data without construction activity. Initial data sets validate that the design is working as intended, but all systems were not fully commissioned for those initial measurements. It is anticipated that the first full year of operation will include anomalies in the performance results, as systems are still being optimized. From the beginning, the team envisioned this commissioning regimen, with the idea that the building would reach optimal operational performance in the second or third full year of occupancy.

A Shared Purpose

We all benefit from a better environment, where buildings are more efficient, resources are not wasted, and people have a joyful experience that elevates the human spirit.

Figure 14. Wooden mullions provide embodied energy savings and a unique, enhanced aesthetic. © Connie Zhou Photography

This is a vision that is bigger than one project, and just as the team started by learning from others, the hope is that others will be inspired by and learn from this project. The design is "open-source code," and as more data are collected on actual performance, it will be converted to meaningful information, allowing others to learn from The Tower at PNC Plaza. ■

Unless otherwise noted, all photography credits in this paper are to the authors.

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Project Data

Completion Date: October 2015
Height: 172 m
Stories: 33
Area: 56,485 sq m
Primary Function: Office
Owner: PNC Bank
Developer: PNC Realty Services
Architect: Gensler (design)
Structural Engineer: Buro Happold (design)
MEP Engineer: Buro Happold (design)
Main Contractor: P J Dick Inc.
Other CTBUH Member Consultant: Langan (geotechnical)
Other CTBUH Member Supplier: Sematic S.r.l. (elevator)

"As an advanced commissioning tool, the beta mockup provided an early opportunity to test the interface of different technological systems, such as daylight controls and various sensors."