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Ping An Finance Center: Pioneering China's Tallest – Efficiencies of Form and Structures

平安财富中心：中国最高大厦——形态、结构双效能

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Zhizhe Yu has over 10 years of experience and has been a key member of the Ping An Finance Center project team from concept design through the present; she is currently Project Manager for the project.

虞稚哲拥有超过10年经验。她作为平安金融中心团队核心成员自概念设计阶段参与至今，目前担任项目的项目经理。

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Torsten Gottlebe has more than 12 years of experience in structural analysis and design of both concrete and steel structures for a wide variety of buildings.

Torsten Gottlebe 在包括混凝土与钢结构两种结构类型的结构分析与设计领域拥有超过12年的经验。

Abstract

Upon completion in 2015, the Ping An Finance Center - set to become the second tallest structure in the world and the tallest in China - will join an elite group of megatall buildings. As today's super tall buildings become taller and more complex, finding the "right" form of the tower plays an increasing role in the architectural and structural design of a project. This presentation will discuss using the Ping An Finance Center and other buildings as examples of how the optimization of building shape impacts architectural and structural design, showing how these processes work in tandem to achieve both sustainable and efficient design.

Keywords: Megatall, Aerodynamic, Sustainable, Form, Structure, China

摘要

计划于2015年完工，平安金融中心将成为世界第二高结构以及中国第一高- 成为巨型高层建筑精英团队的一员。当今的超高层建筑越来越高，越来越复杂，因而为塔楼寻求‘正确’的造型成为项目建筑与结构设计中越来越重要的环节。本文籍平安金融中心与其它建筑为例对优先建筑造型对建筑与结构设计的影响一题进行了讨论，诠释了这些过程如何环环相扣从而实现即可持续又高效的设计。

关键词：巨型高层、空气动力学、可持续、造型、结构、中国

Pioneering China's Tallest

Four years ago at the CTBUH World Congress in Dubai, the Shanghai World Financial Center was presented as a sustainable model by virtue of its minimal form and structure. SWFC, completed in 2008 and still the tallest in China at 492-meters, targets the reduction of embodied energy by minimizing construction materials and time. Its compact shape--as if the unnecessary areas were simply chiseled away--is tailored to suit the functions housed within. Transforming from nearly-square floor profiles suited for the lower office levels, to rectilinear floor profiles at the hotel levels, and finally to a linear configuration at the topmost observation levels, SWFC's tapering silhouette and iconic aperture contribute to its aerodynamic performance, and subsequently, structural efficiency. A lightweight and modular structure fits neatly within its minimal glass sheath (see Figure 1).

Since then, a number of supertall and now "megatall" projects are underway in the Chinese cities of Shanghai, Shenzhen, and Wuhan. Nowhere is it more necessary to meet the demand for density by building vertically.

领先中国之巅

四年前在迪拜举行的世界高层都市建筑学会全球会议中，上海环球金融中心以其简约的造型与结构作为可持续发展典范得到了展示。492米高的上海环球金融中心于2008年竣工，迄今仍然是中国最高建筑，其旨在借助尽可能节省施工材料消耗及缩短施工时间达到减少隐含能耗的目的。其紧凑的外形为内部功能量身打造 – 好似轻而易举得凿去了所有不需要的面积。低区为适用于办公的近正方平面，逐渐向上在高区转变为长方形平面的酒店区，最后在顶部形成了长条状的观光区。上海环球金融中心的收分轮廓及顶部的标志性开口均改善了建筑的空气动力学性能，及其相应的结构效率。轻盈的模数化结构与建筑的简约外壳结合得天衣无缝（图1）。

之后，一批超高层及今天所称的‘巨型高层’在中国城市，如上海、深圳以及武汉出现。毫无疑问，若要满足密度要求，竖向发展是必需的。然而，如要成为中国城市基础设施的永久部分，所规划的超高层建筑必是可持续的。因此，寻求造型与结构的‘正确’结合成为迈向可持续、高性能设计的关键第一步。造型的紧凑度，对风反应以及隐含能耗是对性能进行衡量的

Yet for the supertall building to become a permanent part of China's urban infrastructure, it must be a sustainable proposition. Finding the "right" combination of form and structure is the critical first step towards sustainable, high-performance design. A form's compactness, wind response, and embodied energy are examples of performative measures which can now be evaluated early in the design process with advanced parametric and analytical tools.

One example is KPF's design for the 530-meter CTF Guangzhou (f.k.a. Guangzhou East Tower), currently under construction to be completed in 2017. As with SWFC, the form of CTF Guangzhou is chiseled away to suit its program: office, apartments, and hotel floors. The form steps back at the transition between programmatic zones, with each setback approximately aligned with the services core below to avoid column transfers. The incremental reduction in the floor plate size, in tandem with a reduction in the services core, eliminates the need for large internal atriums at the apartment and hotel levels. The compacting of the form at these upper levels reduces the sail area subject to high winds, and varies the cross-sectional profile along its height to improve aerodynamic performance. Similar strategies are employed in KPF's designs for the mixed-use Chongqing ITCC (456-meters) and Seoul Lotte World Tower (555-meters), both under construction.

The proposed design of the Wuhan Greenland Center (606-meters), designed by AS+GG with Thornton Tomasetti, brings aerodynamic shaping of the supertall to the forefront. According to the architect, the project "features a uniquely streamlined form that combines three key shaping concepts–a tapered body, softly rounded corners and a domed top–to reduce wind resistance and vortex action that builds up around supertall towers. The building's extremely efficient aerodynamic performance will allow it to minimize the amount of structural material (and the associated embodied carbon) needed for construction" (AS+GG, 2012).

Amongst completed projects, KPF's 486-meter tall Hong Kong International Commerce Center (ICC) is perhaps the most prototypical model for the Asian Supertall: mixed-used, high-density, and seamlessly integrated to mass transit. The development brief for ICC called for highly efficient square floor plates with an equally efficient structural system. Preliminary wind tunnel investigations indicated that a square with notched, or "re-entrant," corners would perform suitably in the wind while providing regular internal layouts required by financial services tenants. The form was refined by gradually widening the re-entrant corners towards the top and inclining the upper third of the main facades to reduce the dimensions at the hotel levels. The form and structure splay out for a wider stance at the base to significantly reduce the tower's overturning moment. The tower's angular surfaces give way to gently sloped curves which lift off at its base to create sheltering canopies (see Figure 2).

The form of ICC re-asserted a set of principles which guided the subsequent design of the Ping An Finance Center:

- Widening the base to improve structural stance
- Tapering the tower to reduce seismic and wind loads
- Shaping the corners to improve aerodynamic performance
- Providing large canopies and/or low-rise podiums to mitigate downdraft

It should also be noted that ICC's core and vertical transportation systems formed the basis for adaption to the increased scale and height of PAFC.

Figure 1. The compact tapering form of SWFC suits internal functions. (Source: KPF. Photography: Tim Griffiths)
图1. 上海环球金融中心紧凑的收分造型呼应内部功能（来源：KPF 摄影：Tim Griffiths）

几个方面，而这些方面在设计初期即可通过先进的参数与分析工具进行检验。

正在施工中并计划于2017年完工的KPF所设计530米高广州周大福中心（前称广州东塔）便是一个样例。与上海环球金融中心类似，广州周大福中心的造型被凿刻渐变以适用不同功能：办公、公寓以及酒店平面。建筑造型在不同功能区转换之际进行退台，而每次退台均与下部的核心筒基本对齐以避免结构柱转换。而楼层面积的减少幅度亦与核心筒面积的减少成比例，从而避免了在公寓与酒店楼层设置大型室内中庭。而高区楼层的紧凑造型减少了高空迎风面积，并沿高度变化形成不同剖面形式以改善空气动力学性能。正在施工中的KPF所设计重庆国际交易与贸易中心（456米高）以及汉城乐天塔（555米高）也采用了类似的策略。

由AS+GG与Thomton Tomasetti设计的武汉绿地中心（606米高）方案将超高层的风气动力学造型引领到了最前沿。据建筑师所言，项目‘特色为独特的流线造型结合了三个关键的造型理念 – 收分体量、柔化圆角以及穹型顶部 – 减少了超高层周围所形成的风阻与漩涡作用。建筑的高效风气动力学性能将最大程度减少使用所需结构材料的消耗量（以及所产生的隐含碳）’(AS+GG,2012) 。

在所有的建成项目中，KPF设计的486米高香港国际贸易中心（ICC）可能是亚洲超高层的最典型样例：多功能、高密度、与体量转变的无缝结合。ICC设计任务书要求高效的方形平面以及同样高效的结构系统。初步风洞试验显示有缺角或‘凹’角的正方形在风环境中表现良好，同时也可满足金融服务业租户的规则室内布局需求。在此基础上进一步优化建筑造型，顶部的凹角渐宽，主立面的顶部1/3段向内倾侧以减小酒店层的尺度。建筑形体与结构在底部向外伸展，从而大大减小了塔楼的倾覆力矩。塔楼各个表面均是直线转角形式，在塔楼底部升起转换为曲面形成了雨篷 （图2）。

ICC的造型印证了一套设计原则，并指引了之后的平安金融中心设计：

- 加宽底部改善结构姿态
- 收分塔楼减少地震与风荷载
- 塑造角部形式改善风气动力学性能
- 提供较大雨篷或低层裙房缓和倒灌风

Figure 2. ICC's re-entrant corners improve aerodynamic performance. (Source: KPF. Photography: Tim Griffiths)
图2. ICC凹角处理改善了风气动力学性能（来源：KPF 摄影：Tim Griffiths）

Figure 3. Ping An Finance Center on the Shenzhen skyline. (Source: KPF)
图3. 深圳天际线上的平安金融中心（来源：KPF）

Ping An Finance Center

Project Introduction

The Ping An Finance Center (PAFC) occupies a site of 18,932 m2 centrally located in the Futian Central Business District of Shenzhen, China. With a total construction area approximately 460,000 m2, PAFC will be amongst the largest commercial projects to be LEED Gold Certified (the project is LEED Gold Pre-Certified). The 115-story tower features 86 floors of Class-A office with the top three floors serving as an observatory and restaurant, coupled with a ten-story retail podium and five-stories below grade. The office area is comprised of seven elevator zones at approximately 14 floors per zone, serviced by double-deck local and shuttle elevators between the ground floor lobby and two double-height sky lobbies, with a total of ten refuge/mechanical floors between zones. The tower is crowned by a domed atrium which, at 550-meters above street level, will be amongst the highest public spaces in the world.

PAFC features a number of above and below grade pedestrian connections. The XRL high-speed rail link connecting Hong Kong, Shenzhen, and Guangzhou, to be completed the same year as PAFC in 2015, is to the immediate northeast of the site and connected via an underground arcade to the project and adjacent subway interchange. The project is also linked to the surrounding developments via pedestrian bridges, with a planned 3-storey retail bridge connecting to future developments to the south.

Architectural Form

The Ping An Finance Center is an office tower stretched upwards to its logical extreme. Ductile lines define a form anchored by gravity and pulled skywards to a point. Eight mega-columns, firmly earthed at the tower's base, converge in a spire rising to 660-meters. The main facades drape over the form and part at the edges to reveal transparent corners stitched together by a structural lattice. Vertical strands of stainless steel, drawn tightly across the facade as if pulled through a loom, complete a structure poised in equilibrium between opposing elements of earth and sky (Figure 3).

In commissioning KPF and Thornton Tomasetti, Ping An Life Insurance Company of China requested a tower whose form and structure would emphasize long-term stability and safety, befitting the company's business and title (in Chinese, ping an literally means "peace and safety"), while evoking the "pioneering spirit" of Shenzhen. The client's requirement for an efficient and functional design led to a

应当指出的是ICC的核心筒与竖向交通系统成为平安金融中心对其增加的尺度与高度所进行调整的基础。

平安金融中心

项目简述

平安金融中心(PAFC)占地18932平方米，位于中国深圳福田中心商务区的核心位置。平安金融中心总建筑面积达460000平方米，建成后将跻身于获LEED金奖认证的最大商业项目行列（项目已获LEED金奖预认证）。建筑共115层，由包括86层甲级办公楼层与顶部3层观光台与餐厅的塔楼，以及10层商业裙房与5层地下室所组成。办公楼分为7个电梯区，每区约14层，由往返于首层大堂与两个双层通高空中大堂之间的双层区间电梯以及穿梭电梯所服务，共10个避难/设备层分布于各区之间。塔楼顶部为高达550米的穹顶中庭，其将成为世界上最高的公共空间之一。

平安金融中心拥有数个地上与地下人行连接。连接香港、深圳与广州的广深港高速铁路位于基地东北角，与本项目以及相邻地铁中转站借助地下商业连廊相连，高铁将与PAFC一起于2015年完工。项目与周边项目借助步行天桥相连，同时将打造3层商业连廊与基地南侧的未来开发项目相连。

建筑造型

平安金融中心将办公塔楼高度提升到了合理范围内的极限。具备延展性的线性形体由地心引力锚定，向天空伸展至最高一点。八根巨柱在塔楼底部生根，向上汇聚成为桅杆直至660米高。主立面顺塔楼造型垂下，在转承边界处断开形成通透角部，而四个角部由结构构造相连。竖向不锈钢束紧贴纵贯立面，好似由织布机绷住一般，至此结构实现了天与地之间相对与相生的平衡（图 3).

在任命KPF与Thomton Tomasetti 作为设计顾问之时，平安人寿保险股份有限公司要求塔楼造型与结构应强调长远的稳定性与安全性，与公司的业务以及名字像匹配（中文里平安意为‘和平与安全’），同时亦期望塔楼造型可唤起深圳的‘先锋精神’。业主对打造高效实用设计的要求促成了渐变流线形的塔楼外型以提升塔楼性能。风洞顾问RWDI自项目早期便参与进来，审核并影响了塔楼的造型。此番对话引导了原先倾向于‘传统’造型的业主逐渐接受了由风作用而塑造的流线造型。.

风洞试验表明建筑性能可依靠对塔楼角部进行凹角或退进处理得到改善（打破尖锐转角）。塔楼主立面大部分为垂直立面，而角部则进行连续的收分处理以减弱风荷载，特别是侧风对结构的影响。塔楼外形在塔楼顶部四分之一处再次进行转变，主立面内收，斜削角部形成‘圆角’八边形平面以缓和角部周围的气流。

Figure 4. The form and structure of PAFC share a high degree of affinity. (Source: KPF and Thornton Tomasetti)
图4. 平安金融中心造型与结构高度关联（来源：KPF与Thornton Tomasetti）

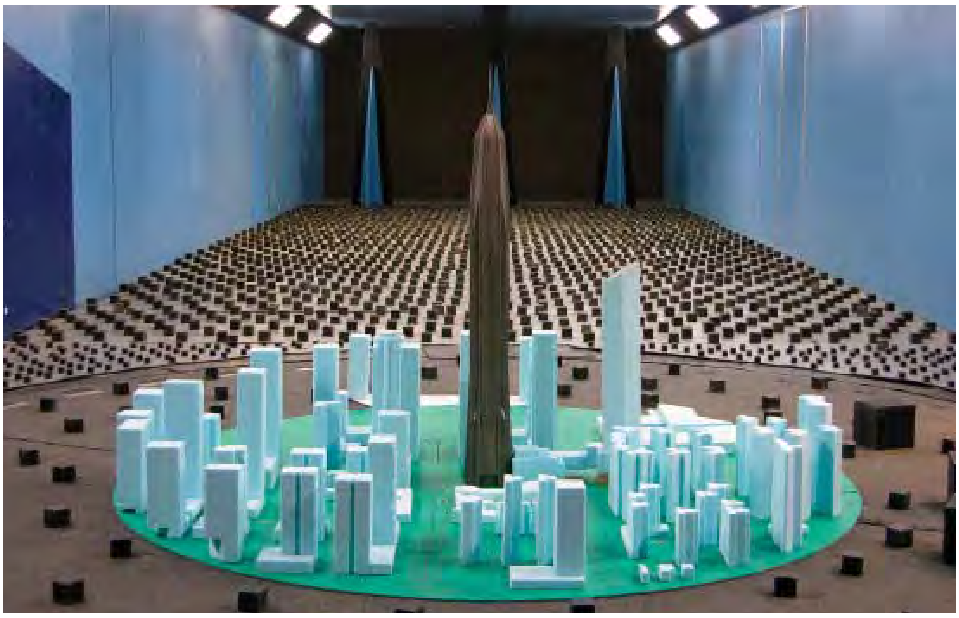

Figure 5.Aeroelastic testing of the PAFC. (Source: RWDI)
图5. 平安金融中心弹性风力动学测试（来源：RWDI）

gradual streamlining of the tower shape to improve performance. Wind engineers RWDI were consulted early in the process to critique and influence the tower's shape. This dialogue guided the client, predisposed initially to 'traditional' forms, to embrace a fluid form contoured by the wind.

Wind tunnel studies demonstrated that building performance was greatly improved by recessing/stepping the tower corner profile (breaking up sharp corners). While the main facades are vertical for most of the tower's height, the corners continuously taper to reduce the wind load, especially the cross wind impact, on the structure. The building profile transforms again at the upper fourth of the tower, where the main facades taper and the corners are beveled to create a 'rounded' octagonal-shaped floor to smooth wind flow around the corners. In addition, the reduced width of the tower at the top reduces the seismic loading (see Figures 4 and 5). It should be mentioned that both lateral force components, wind and seismic, equally control the design of the building.

PAFC achieves a 32% reduction in overturning moment and 35% reduction in wind load compared to China code, due to the shape of the tower.

Structural System

Various structural solutions were discussed among the design team, including a vierendeel truss system which utilized the vertical piers expressed on the tower façade. Each proposal was evaluated under the consideration of material usage and cost as well as long term sustainability. The final lateral load resisting system chosen was a composite concrete core with embedded steel plates connected to 8 super columns by 4 two-story outriggers located on Levels 25, 48, 79 and 95 in combination with an exterior mega frame which consisted of 7-double belt trusses connected to the super columns at each mechanical floor (see Figure 6). This is a common solution in the design of super tall buildings nowadays. However, the distinctive cut back corners provided the unique opportunity to introduce a chevron brace system which increased the stiffness of the tower perceptibly (see Figure 7 and 8). As a result, Thornton Tomasetti was able to significantly reduce the steel material on the outriggers and belt trusses and was able to simplify their connections to core wall and super columns.

除此之外，缩减的塔楼顶部宽度也可减少地震荷载 （图4，图5）。需指出的是两个侧向力组成部分，即风荷载与地震荷载对建筑设计起到等同的控制作用。

与中国规范相比，塔楼的形体使得平安金融中心在倾覆力矩上减少约32%，风荷载减少约35%。

结构体系

设计团队讨论了不同的结构解决方案，包括在塔楼立面表达竖向立柱的空腹桁架系统。每个方案都根据其材料使用、造价以及长期可持续发展得到了考量。最终所选择的抗侧力体系为由布置在25层、48层、79层与95层的4组双层外伸臂连接内置钢筋的组合核心筒，结合在各机电层与巨柱相连的7组双层桁架所组成的外部巨型框架（图6）。该体系是当今超高层建筑设计的惯用解决办法。然而，独特的退角为在角部设置V型支撑提供了可能性，

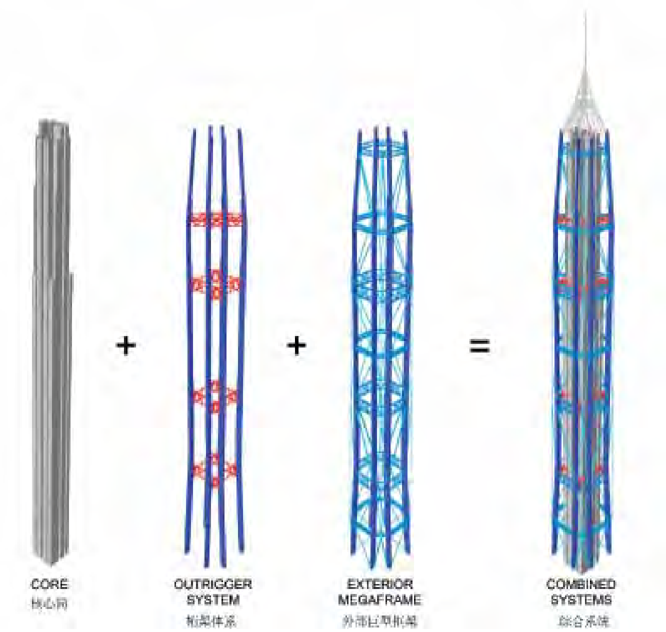

Figure 6. Lateral structural system components of the PAFC. (Source: Thornton Tomasetti)
图6. 平安金融中心的抗侧力结构系统 （来源：Thornton Tomasetti）

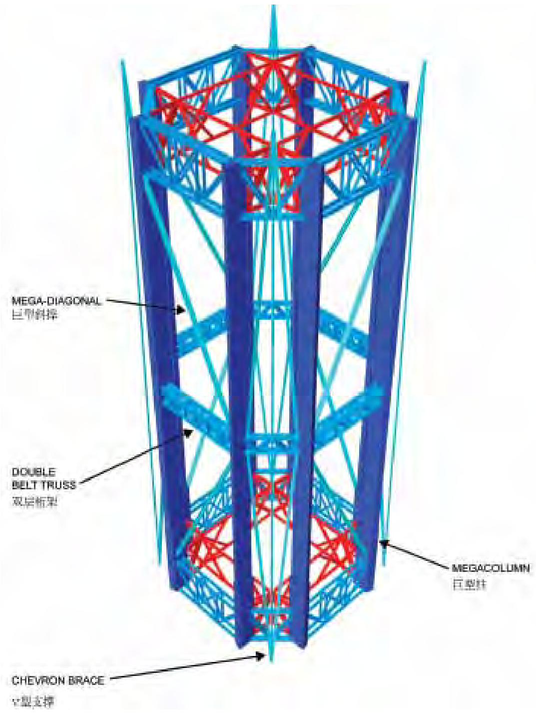

Figure 7. Exterior megaframe. (Source: Thornton Tomasetti)
图7. 巨型框架外部（来源：Thornton Tomasetti）

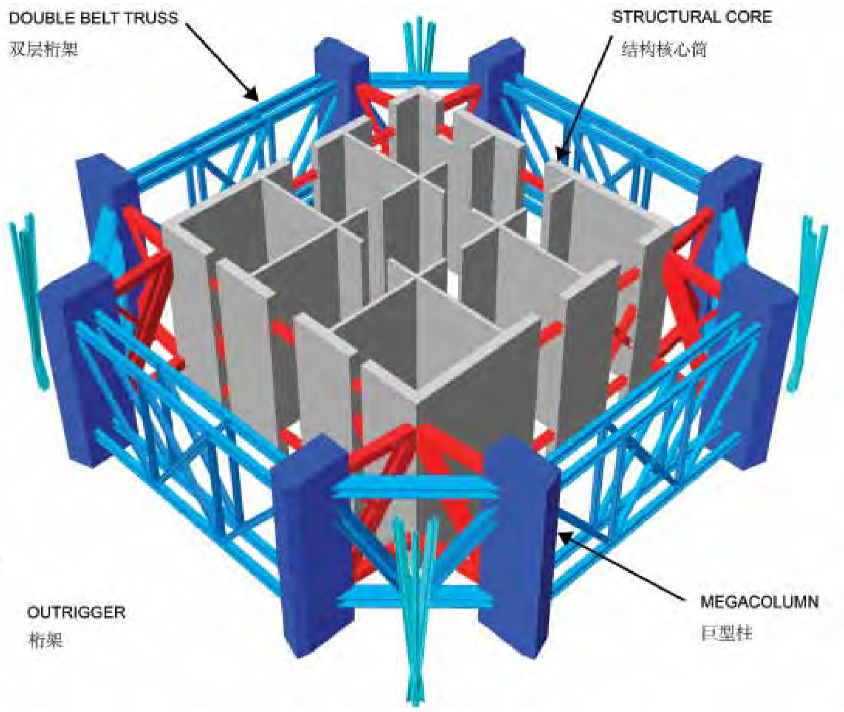

Figure 8. Section of outrigger mechanical level. (Source: Thornton Tomasetti)
图8. 设备层外伸臂剖面(来源：Thornton Tomasetti)

Due to seismic design requirements of Chinese code, a double belt truss and an exterior super diagonal that connected with all belt trusses were seamlessly incorporated into the architectural and structural design.

The typical floor framing is a traditional composite steel beam design with a 125mm thick concrete slab on metal deck. Only at the mechanical and refuge floors was a special horizontal steel diaphragm introduced to tie the outrigger and belt trusses back to the core in case the concrete slab diaphragm experienced cracks under severe earthquake conditions (Figure 7).

Structural Design Influence on the Sustainability of PAFC

The reduction of the Embodied Energy (EE), defined as the total primary energy consumed from direct and indirect processes associated with a product or service and with the boundaries of cradle-to-gate, played a major role in Thornton Tomasetti's structural design of the tower.

The structure, the construction and façade of the building consume more than 50% of the overall EE (Cole and Kernan, 1996). If the structural part is analyzed further and broken out in various construction and fit out materials it can be seen that the energy cost for steel is almost 35 times higher than concrete. Therefore it is important to reduce the steel tonnage of the design.

On the material side of energy savings the following items were implemented in the structural design:

- Major steel saving was achieved by the recessed corners of the building. The reduction in wind load led to smaller core and column sizes and reduced at the same time the building mass and therefore reduced the seismic forces
- The use of an outrigger system to engage the entire footprint of the building(to provide better lateral stiffness by creating a larger lever arm to resist the overturning moment) reduced the concrete core wall sizes (Figure 8)
- The use of recycled material, such as concrete and steel, was specified in the project documents.

该处理可明显提高塔楼的刚性（图7,8）。作为结果，Thomton Tomasetti能够显著减少外伸臂与桁架的钢材使用量并简化核心筒与巨柱之间的连接。

鉴于中国规范的特殊抗震设计要求所增加的双层桁架与连接全部桁架的外部巨型斜撑最终亦完美得与建筑及结构设计结合在一起。

标准层框架系统是传统的组合钢梁设计加金属台上布125mm厚混凝土楼板。仅在机电/避难层布置了特殊的横向钢隔板以将外伸臂及带状桁架连接至核心筒，以防混凝土楼板隔板在强震情况下断裂（图7）。

结构设计对平安金融中心可持续设计的影响

隐含能耗(EE)定义为由于一种产品或服务直接或间接，从初始生产到出厂，所产生的主要能量消耗。减少隐含能耗在Thornton Tomasetti的塔楼的结构设计中起到了重要作用。

建筑结构、施工以及建筑幕墙消耗超过50%的全部隐含能耗（Cole and Keman，1996）。若将结构部分进一步分解成为不同的施工与材料，钢材所消耗能源几乎是混凝土的35倍。因此减少设计中的钢材用量尤为重要。

从材料节能角度而言，结构设计结合了下述几个方面：

- 建筑角部收进实现了主要的钢材节省。风荷载的减少缩小了核心筒与巨柱尺寸，同时亦减轻了建筑体量，从而成功降低了地震力
- 外伸臂系统的使用将整栋塔楼面积进行整合（借助较大悬臂抗倾覆力矩以提供更好的抗侧力刚度）以减少混凝土核心筒尺寸（图8)
- 项目文件明确列出可循环材料的使用，如混凝土与钢材。
- 推荐使用飞灰或粒状高炉矿渣替代水泥。
- 主要选用当地材料以减少加工与运输的能源消耗。

从项目的长期可持续发展而言，进行了下述设计考虑：

- 循环冷却塔水系统每年节省约30%饮用水，需在楼板与墙面预留结构开口；

- Cement substitutes such as fly ash and granulated blast furnace slag was recommended.
- Mainly local materials were used to reduce manufacturing and transportation energy costs.

In regards to long term sustainability of the building the following design considerations were made:

- Recycled cooling tower bleed-off water system, which reduces portable water use by 30%, required additional structural openings in floors and walls.
- Ice storage system in the basement levels provides a savings of 4% of the total annual energy consumption, requiring additional strengthening and support for multiple heavy ice tanks in these areas.
- Optimized structural framing to achieve high clear ceilings, combined with occupant lighting controls and daylight sensors, save 4% of annual energy consumption.
- Podium roof structurally designed to incorporate special rainwater collectors to reduce water consumption and operation of the green roofs, leading to 100% water savings for summer irrigation needs.
- Efficient construction method targeting more than 50% reduction in construction waste.

Core Design

The design of the services core not only functions as a vital structural element, but also determines the floor plan efficiency, key to the usability of a tower and ultimately the success of a development. The common challenge for a super-tall tower like PAFC to achieve desired floor plan efficiency is that the core size is considerably bigger than the core of a lower tower with similar floor plate size. Such increase is driven by increased core wall thickness, mechanical equipment and number of elevators required by tower's increased height.

In addition to designing a core with minimum wasted space as a general rule, designing a core responding to the 'Shape' of the tower is an integral part of the design process. The more unique challenge for the PAFC tower is that while the shaping of the tower provides the most efficient aerodynamic form by stepping the corners, tapering, and chamfering the top, it also imposes greater challenge for the core planning because of decreased floor plate size at the upper zones.

One of the most distinguishing characteristics of the PAFC tower is its symmetry. PAFC's core is mirrored about its north-south axis while providing the most efficient layout for user circulation and freight delivery, as well as mechanical service distribution and fire egress. 12-meter leasing depths and above 70% efficiency are achieved at the lower zones.

At the upper zones, the floor plate size is decreased as the four corners slope inwards and the tower tapers. The core's cruciform configuration follows the change in tower form to maintain similar leasing depth and efficiency as the lower zones. The two banks of sky-lobby shuttle elevators located at the north-east and north-west corners of the core terminate below Zone 4 and Zone 6, respectively. Floor space is reclaimed above the lift shafts, offering dramatic views and higher efficiencies at the corners areas which are considered more valuable (see Figure 9).

Spire Design

The converging lines of PAFC resolve in an emphatic spire, starting at level 585m and rising to the tower's apex at 660-meters (see Figure 10). While the spire was necessary to conclude the tower's form, finding its

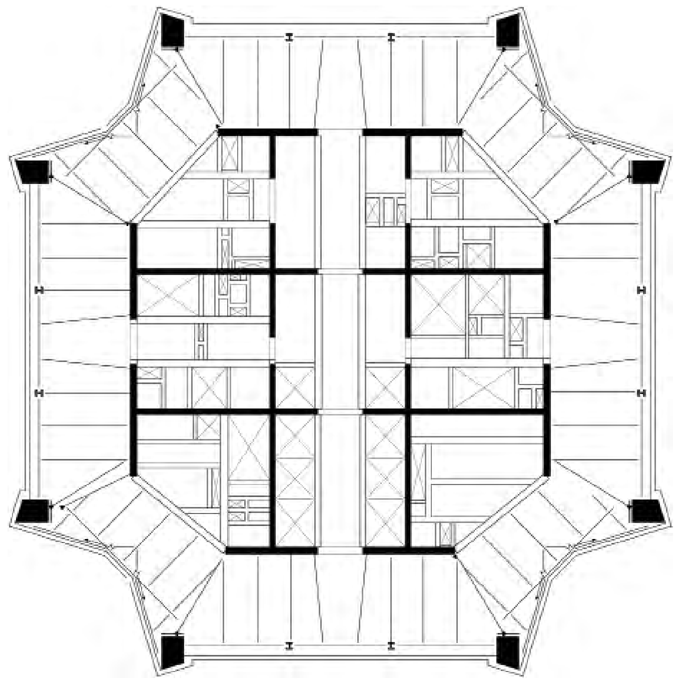

Figure 9. Upper zone office plan of PAFC showing the cruciform core. (Source: KPF)
图9. 平安金融中心高区平面十字形核心筒(来源：KPF)

- 地下室蓄冰系统每年节省约4%能源，需为布置多个重量蓄冰池的区域提供额外结构加强与支持；
- 优化的结构框架可实现高净高，与租户照明控制及日光感应器相结合，每年节省约4%能源；
- 裙房屋顶结构设计结合特殊的雨水收集以节约用水并降低绿色屋顶维护费用，从而实现节水100%以满足夏季灌溉；
- 采用高效施工方法，旨在减少50%施工垃圾。

核心筒设计

核心筒不仅仅是至关重要的结构元素，同时也直接决定了对塔楼可用性非常关键的平面得房率，乃至整个项目的根本成功。对于与平安金融中心类似的超高层项目来说，若要实现理想的得房率，其通常所面临的挑战为超高层建筑的核心筒面积比楼层面积接近的较低高度塔楼要大很多。塔楼高度的提高造成核心筒剪力墙厚度加厚、所要求机电设备以及电梯数量增加，从而造成核心筒面积的增加。

尽可能减少浪费空间是核心筒设计的基本原则，然而设计一个与塔楼‘外形’相呼应的核心筒亦是设计过程不可缺少的部分。平安金融中心的塔楼造型借助平面凹角，整体收分以及顶部斜削打造了最高效的风气动力学形态，但同时高区的缩小平面则为核心筒设计带来了更大更独特的挑战。

平安金融中心塔楼最显著的特点之一是其对称性。塔楼核心筒沿南北轴线镜像，此布局形式不仅提供了最高效的使用流线与货运流线，亦提供了最高效的机电服务分布与消防逃生流线。塔楼低区因而实现了12米的出租进深与70%得房率。

在高区，由于平面四角向内倾斜同时塔楼体型收分，平面楼层面积减小。核心筒的十字型布局随塔楼体型变化而变以保持与低区类似的出租进深以及得房率。同时，两组空中大堂穿梭电梯分别布置在核心筒的东北与西北角，在4区与6区之下结束其竖向行程。因此，位于高区此两组电梯井道之上的面积得到释放，从而提高得房率，同时为价值更高的平面角部空间提供了更激动人心的视野（图9）。

塔尖设计

平安金融中心的线条向上会聚成为引人注目的塔尖，自585米处升起达到660米高（图10）。塔尖对于如何为塔楼造型收笔非常必

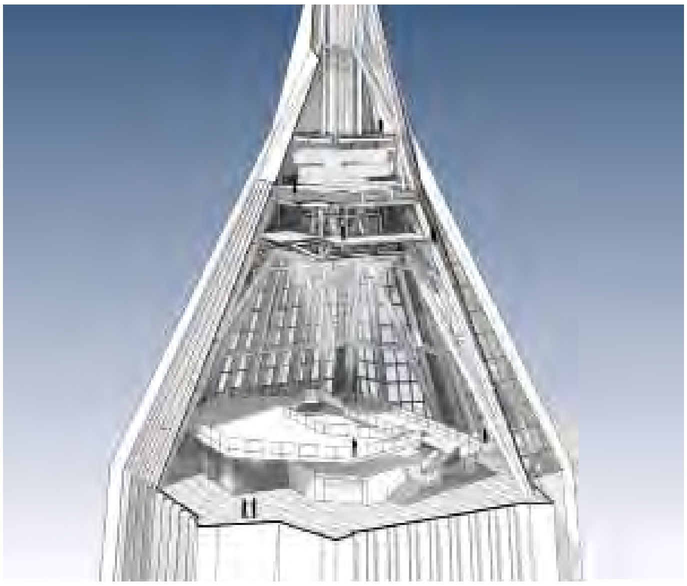

Figure 10. Cutaway view of PAFC's dome and spire. (Source: KPF)
图10. 平安金融中心顶部与塔尖侧透图(来源: KPF)

raison d'etre on sustainable grounds proved vexing. Initial simulations for a wind turbine at the spire's base predicted only 2100 kilowatt-hours per year. Furthermore, the spire's slenderness ratio meant that a tuned mass damper (TMD) would be required within the spire shaft to counterbalance possible aeroelastic flutter, i.e., galloping.

The design team's recommendation was to pursue an aerodynamic solution to reduce the spire's complexity and self-weight. Amongst other alternatives such as adding fins or contouring the spire profile, RWDI proposed to perforate the spire, which KPF re-interpreted as four individual masts joined by a structural lattice (see Figure 11). As of the time of this writing, a spire-specific wind tunnel will be conducted to determine the validity of an aerodynamic damping solution. Also, sustainable strategies such as high-altitude cold air intake and stack-effect driven turbines, may be incorporated in the final design.

Conclusion

With the capability of computer simulations for different wind conditions and building orientations and the verification through real wind tunnel tests, we have the tools to optimize the aerodynamics of buildings. Similarly, BIM and other computer tools enable the design team to achieve a greater level of precision and compactness through focused coordination and optimization of building systems. These results inform and generate design strategies in pursuit of a form ideally suited for each function contained within the super tall building.

Performative strategies influencing a tower's form include:

- **Compactness:** Optimization of the floor area to volume ratio. Intuitively, the more compact the form, the less the forces acting upon it, with fewer resources and energy required to construct and maintain.
- **Suitability:** Degree to which the floor profile and dimensions suit its internal functions.
- **Performance:** Aerodynamic optimization of the tower form greatly improves structural efficiency.
- **Affinity:** Degree to which the structure and services core relate to the building form. Highly correlated systems yield the most efficient and usable internal space.

Figure 11. Proposed aerodynamic modifications of the tower spire. (Source: KPF. Photography: Jock Pottle)
图11. 塔楼桅杆空气动力学修改方案 (来源: KPF. 摄影: Jock Pottle)

要，然而在可持续发展方面则有争议。最初考虑在桅杆底部安装风轮机，但预计每年仅可产生2100千瓦小时。而且桅杆的细长比例要求在桅杆内部安装阻尼器以平衡可能产生的晃动。

而设计团队的建议为寻求基于空气动力学的解决方案以减消桅杆的复杂程度与自重。在其它备选方案中，包括增加竖向翼或改变桅杆造型，RWDI建议镂空塔尖，KPF继而将其诠释为由结构元件相连的四根独立立柱 (图11)。在完成此文的同时，我们正在计划进行针对桅杆的风洞试验以确定空气动力阻尼方案的可行性。同时，其它可持续发展策略例如高空取风以及堆积效应风轮机，都将在最终设计得到体现。

结论

通过不同风环境与建筑朝向的电脑仿真模拟以及真实的风洞试验校验，我们掌握了优化建筑物的风气动力学的工具。类似的，BIM以及其它电脑工具可通过建筑系统的集中协调与优化帮助设计团队实现更高层次的准确度以及紧凑度。这些工作的结论可报告并生成设计策略，旨在寻求一种建筑造型可理想得适用于超高层建筑内的每个功能。

影响塔楼造型的性能化策略包括：

- **紧凑：** 楼层面积与体积比例的优化。从直观讲，造型越紧凑，作用在其上的势能越小，因而施工与维护所需的资源与能量就越少。
- **适用：**楼层形体及尺度与其内部功能之间的适用度
- **性能：**塔楼造型的空气动力学优化可大大改善结构效率
- **关联：** 结构及核心筒与建筑造型的关联度。高度关联的系统可生成最高效与最适用的内部空间
- **模数：**可实现重复结构元素的造型将降低复杂度以及施工时间。施工阶段所消耗的时间与资源被看作是隐含能耗的标志。

- **Modularity:** Form enabling repetition of structural elements will reduce complexity and time-to-construct. Time and resources expended during the construction process should be regarded as an indicator of embodied energy.

The results are that engineers and architects are providing more efficient design and reducing construction material, excavation volume, time and cost of construction, and operating energy.
In addition, to all the economic advantages, we make a greater contribution towards a smaller carbon footprint for a greener world

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结果即工程师与建筑师合力打造更高效的设计，减少施工耗材、开挖时间以及施工造价，及其运作能耗。另外，除了经济上的优点，我们旨在为打造低碳建筑做出更大的贡献，实现一个更绿色的世界。

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