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Designing China's Tallest: DNA of the Ping An Finance Center

设计中国最高之巅: 平安金融中心的DNA

David Malott, *Kohn Pedersen Fox Associates*

The Ping An Finance Center is the next generation of the prototypical Asian skyscraper: megatall, hyper-dense, and highly connected. Encoded in the design of PAFC are the evolutionary building blocks of a modern megatall building. Ping An Insurance Company of China envisioned a tower which could represent stability, befitting the company's image and title (Ping An is the combination of the Chinese characters for "peaceful" and "safety"), while evoking the entrepreneurial spirit of Shenzhen. Also, the tower was to be intelligently designed to the highest international specifications: efficient, elegant, yet evocative. PAFC will symbolize a city which has witnessed unprecedented urban growth – from 300,000 people to approximately 10 million – in the 35 years since becoming China's first Special Economic Zone. This chapter outlines key architectural concepts centered on the Ping An Finance Center, relative to larger issues concerning supertall building design and the formation of tall building clusters, as a means to achieve sustainable vertical urbanism.

平安金融中心是新一代的亚洲摩天大楼的典型代表: 超高层，高密度，以及高度的通达性。平安金融中心的设计体现了现代超高层建筑体块的演变。本演讲将围绕平安金融中心讨论其主要的建筑构思，以及有关超高层建筑设计和高层建筑集群形成的问题，实现可持续的垂直城市化发展。平安金融中心是新一代的亚洲摩天大楼的典型代表: 超高层，高密度，以及高度的通达性。平安金融中心的设计体现了现代超高层建筑体块的演变。本演讲将围绕平安金融中心讨论其主要的建筑构思，以及有关超高层建筑设计和高层建筑集群形成的问题，实现可持续的垂直城市化发展。平安金融中心是新一代的亚洲摩天大楼的典型代表: 超高层，高密度，以及高度的通达性。平安金融中心的设计体现了现代超高层建筑体块的演变。本演讲将围绕平安金融中心讨论其主要的建筑构思，以及有关超高层建筑设计和高层建筑集群形成的问题，实现可持续的垂直城市化发展。

Introduction

In line with Ping An's commitment to quality, safety, and sustainability, the project team made a strategic decision to begin with a proven prototype for a megatall tower, and pull it to an unprecedented height. The design was less about a radical alteration of the tall building, but one of continuous refinement. The techniques in up-scaling were nonetheless challenging, and led to key innovations in the building's form, structure, and other systems.

A key challenge was addressing the tower's high population density. PAFC has a floor area to site area ratio exceeding 20, with nearly 350,000 square meters contained within the tower footprint alone. Compounding the issue is that the PAFC tower is almost exclusively an office tower, with a high design occupancy requirement, averaging 11 square meters per person (see Figure 2.1a).

To put this in perspective, PAFC's entire office population of 15,500 workers is stacked on a 72-meter by 72-meter footprint constrained by the tower's irregular piano-shape site. At this density, our entire global workforce, estimated at 3 billion workers, could be housed in a land area less than 1,000 square kilometers. *That is two planets full of workers, fitting within the borders of Shenzhen* (see Figure 2.1b).

Which Leads to the First Question: Why Build Such a Tower Here?

PAFC is what can be described as a Transit Integrated Tall Building. It speaks to the promise of the tall building as a sustainable paradigm, in which individual buildings form part of a larger ecosystem of dense vertical centers linked by horizontal networks of public transportation.

Increasing density in city centers is more effective in preserving land resources and reducing energy usage than the alternative of urban sprawl. The relationship between density, land use, and energy use is well documented. Amongst high-income societies, the dense city-state of Hong Kong ranks as the most energy-efficient in annual energy use per capita. The average Hong Kong resident uses less than a third as much energy as the average American, while enjoying the same purchasing power (World Bank 2012, IMF 2013). And, while Hong Kong is associated with images of tall buildings, less than 25% of its land area is urban or built-up;

前言

根据平安做出的质量、安全和可持续发展的承诺，项目组制定了一个战略决策，从经过验证的超高层塔楼原型开始逐渐将它拉高到前所未有的高度。这一设计不是高层建筑的彻底改变，而是不断的完善。随着建筑尺度的扩大，其中使用的技术毋庸置疑具有挑战性，并且能引起建筑形态、结构和其他系统的关键创新。

一个关键挑战是要解决塔楼中的高人口密度。平安金融中心楼层面积与基地面积比超过20，仅塔楼投影面积上就有近35万平方米建筑面积。使问题更复杂的是，平安金融中心几乎完全是办公楼，具有极高的人口入驻要求，平均每人占有11平方米（见图2.1a）。

从另一个角度看，平安金融中心内将有15500名办公楼员工叠加在一个72×72米范围的平面上，同时还受塔楼基地不规则钢琴形状的限制。按照这个密度，我们全球预计三十亿的员工可以安置在一个面积不到1000平方千米的平面上。*也就是说两倍于地球上现有工作人员的人数可安置在深圳市辖区内*（见图2.1b）。

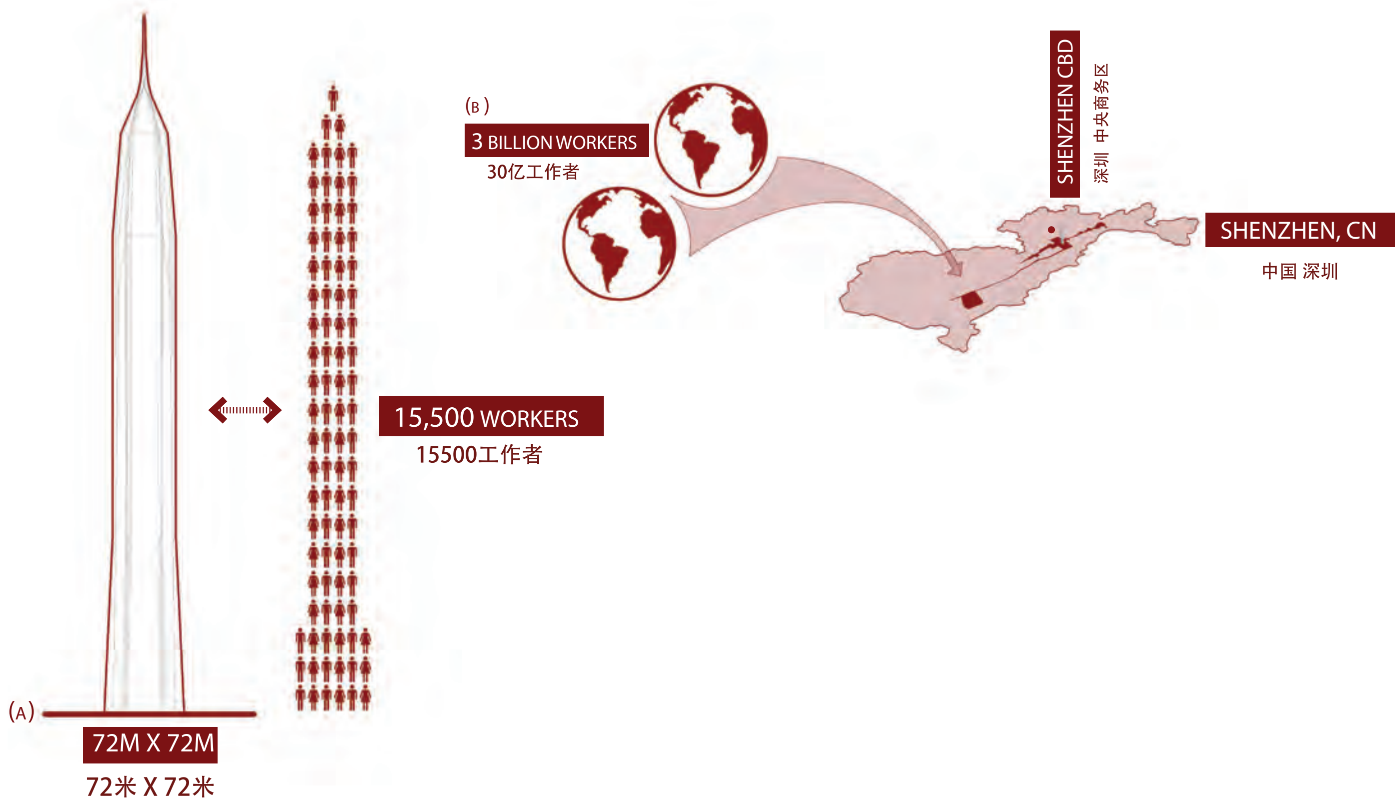

Figure 2.1. (a) PAFC offers 11 square meters per person for 15,500 workers,
(b) at this density twice the current global workforce could fit within the borders of Shenzhen. (Source: KPF)
图 2.1a作为一座绝无仅有的办公建筑，平安金融中心为15,500工人提供11平方米的空间。
图 2.1b两倍于地球上现有工作人员的人数可安置在深圳市辖区内 。 (来源: KPF建筑事务所)

nearly half of the remaining land area is reserved as park and nature preserve (Hong Kong Planning Department, 2008).

Hong Kong was home to the densest habitation in human history, the Kowloon Walled City (KWC), an ungoverned settlement of 30,000 residents packed into 4 square meters per person. Known in Cantonese as the "chaotic city of darkness," the Kowloon Walled City has enjoyed nostalgia as of late. As an urban model, it is fascinating: an agglomeration of individual buildings into one giant entity with skybridges, roof gardens, interwoven mechanical systems, and public space infill. Essentially, and with a touch of irony, it is a precedent for the buildings and cities we are trying to design today.

Now, imagine taking an interconnected building entity such as KWC, and gradually stretching it apart. As the distance between buildings grows, so must the connective tissue holding the entity together. For the connection to remain effective, it must become faster. Hold time constant, but increase our speed, and our perception of space is contracted (see Figure 2.2).

那么就引出了第一个问题: 为什么要在此建造这样一个塔楼?

平安金融中心可以被描述为一个"在高层建筑内的交通中转站"。它证实了高层建筑作为可持续发展典范的承诺，其中单个建筑是更大的高密度垂直生态系统的一部分，由公共交通组成的横向网络相连。

城市中心密度增加比城市扩张更能有效地保护土地资源及减少能源消耗。密度、土地利用和能源使用之间的关系是有据可查的。在高收入的社会中，高密度城市香港是年人均能源使用效率最高的城市。虽然香港居民平均使用的能源不到美国人的三分之一，但他们却拥有相同的购买力 (世界银行2012年，国际货币基金组织2013年) 。而且香港到处高楼林立，其城市土地使用面积不到25%，近一半的剩余土地被保留为公园和自然保护区 (香港规划署，2008年) 。

香港九龙寨城曾经是人类历史上居住最密集的地方。30,000居民不受约束地挤在人均4平方米的地方。在广东话中称为"黑暗混乱之城"，当时的状况近来对九龙寨城来说就只是可追忆之往事了。作为城市的模型，现在它令人着迷: 单个楼宇由天桥、屋顶花园、交织机电系统以及公共空间连接，集聚成一个巨大的实体。从本质上讲，并带有一丝讽刺意味的是，它是一个我们今天正在努力设计的建筑和城市的先例。

现在，想象一个相互联系的建筑实体，如九龙寨城，并逐步将它延伸拆开。随着楼间距的增加，其间的连接组织也需要扩张。为了保持原有连接的有效性，它必须变得更加迅速。维持时间不变，但速度增加，由此我们对空间的感受也得到了压缩 (见图2.2) 。

传统的城市关系网建立于空间接近性之上: 可步行、视线以及各类有形的联系。纽约的帝国大厦以及克莱斯勒大厦，就是这样的例子，它们距离彼此仅有15分钟的步行距离。曼哈顿的市中心和市区商业中心之间的距离同样也只有15分钟，虽然它们离得更远些。科技–如纽约地铁和轨道系统–使城市得以覆盖更远的距离。如今城市仍然被视作一个物理上连续的实体。

在不久的将来，就像从纽约市中心坐15分钟的地铁到达市区商业中心一样，你位于香港的同事也可以离开他位于ICC的办公室，通过位于山川和森林之下的隧道，穿越深圳中心的中国大陆边境，直达平安金融中心的基地。

到2017年，你和你的同事就可以乘坐连接珠三角三大城市的XRL地下高速铁路线。这就

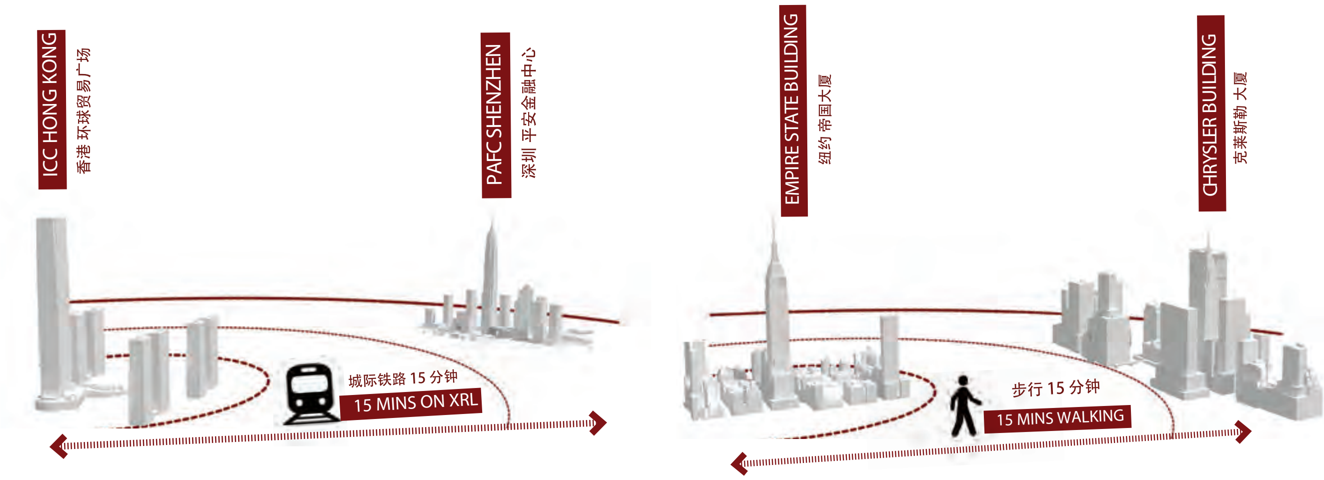

Figure 2.2. Perceptions of space contract as speed increases and time is held constant. (Source: KPF)
图2.2 增加的速度与恒定的时间使人产生空间被压缩的感受。 (来源: KPF)

Traditional urban relationships are based on spatial proximity: walkability, line-of-sight, and tangible connections. New York's Empire State and Chrysler buildings, for example, are built within 15 minutes' walking distance of each other. Manhattan's Midtown and Downtown business centers are connected within the same 15-minute boundary, but further apart. Technology – in this case the New York City subway and rail systems – allows the urban experience to span a greater distance. Still, the city is perceived as one physically contiguous entity.

In the near future, within the same 15 minutes it takes to ride a train ride from Midtown to Downtown, your colleague in Hong Kong can leave his office at the International Commerce Center (ICC), travel under mountains and forests, to emerge across the mainland Chinese border in the center of Shenzhen, at the base of the Ping An Finance Center. The urban experience is no longer one of physical contiguity.

The year is 2017, and your colleague rode the XRL subterranean high-speed rail line linking the three major cities of the Pearl River Delta. This is the promise of the transportation supercity of Hong Kong – Shenzhen – Guangzhou: home to 120 million people, five percent of the world's manufactured goods, and one-third of China's trade value. Hong Kong and Shenzhen, in particular, will become so interlinked by transportation, commuter, and financial ties that traditional boundaries will be blurred: it is, in essence, one urban experience.

This is the answer given by Ping An's chairman Ma Mingzhe, as to why they decided to build a tower here.

Then he asked:

How Will You Design Such a Tower?

The promise of sustainable vertical urbanism is based on each building performing to the best of its capabilities. PAFC is the next generation in the evolution of a prototype: taller, denser, and higher performance.

是香港 - 深圳 - 广州三位一体的交通超级城市的愿景–广州是1亿两千万人口的城市，生产世界百分之五的商品，占全中国贸易价值的三分之一。尤其对于香港和深圳来说，在交通、通勤以及金融纽带的连接下，其传统的边境正变得日益模糊: 这本质上正是一种城市体验。

这是平安主席马明哲针对为什么决定在此建造塔楼做出的回答。

然后他问到:

如何设计这样的塔楼?

可持续垂直城市化立足于每栋楼都能实现其最佳功能。平安金融中心是原型演变而来的新生代: 更高、更密和更高的性能。

在一些方面，平安金融中心继承了KPF建筑设计用于上海环球金融中心 (2008年) 及香港环球贸易广场 (2011年) 设计上的创新元素。上海环球金融中心的一个主要特征是它有针对性的减少了能源的使用。上海环球金融中心的造型小巧，仿佛不必要的材料都省去了，只需满足室内的功能。上海环球金融中心的锥形轮廓和标志性的光圈有助于其空气动力学性能，并随后增加结构效率。一个重量较轻的模数化的结构非常简练地包裹在一个贴身的玻璃外壳内。

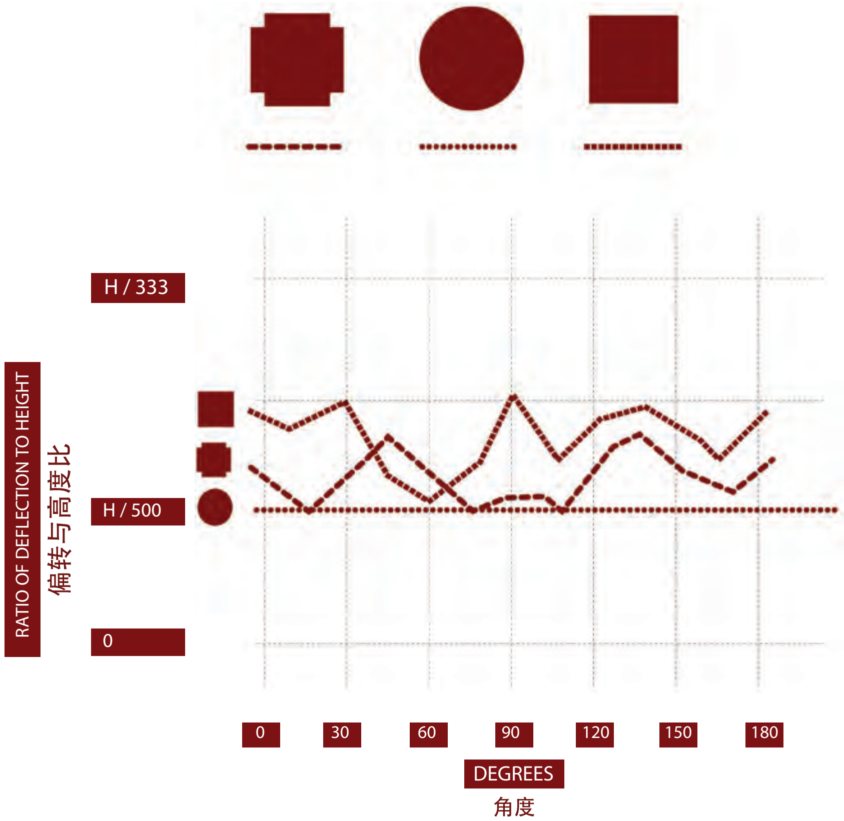

Figure 2.3. Notches effectively round the square tower in the wind. (Source: KPF)
图 2.3 四角凹口的方形塔楼在在风中有高效的表现。(来源: KPF)

In several aspects, PAFC inherits its DNA from KPF's innovative Shanghai World Financial Center (SWFC) (2008) and the ICC (2011). A primary trait of SWFC is its targeted reduction of embodied energy. SWFC's compact shape – as if unnecessary material were chiseled away – is tailored to suit the functions housed within. 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.

PAFC exhibits similar traits, although its compactness is one of tautness, rather than compression. Metaphorically, it is not so much a hardened diamond, but a steel cable pulled in incredible tension. The concept of "pulling" the tower skyward, rather than "pushing" it up from the ground, drove the design of PAFC's streamlined form.

Given the client's requirement for square, functional floor plates, the formal strategies used to shape PAFC were derived largely from ICC. The techniques to improve wind performance were more subtle, having less impact on the regularity of the interior tenant space, but were nonetheless effective. Preliminary wind tunnel testing done in advance of ICC compared the response of simple extruded geometries (a perfect square, rectangle, circle, and triangle) along with notched-corner derivatives of each shape. The results indicated that a square with notches, or re-entrant corners, had similar beneficial properties as the circular tower. Effectively, the notches "round" the square tower in the eyes of the wind (see Figure 2.3).

Other techniques deployed in the design of ICC which influenced the design of PAFC were the splayed base, to improve structural stance, and a slightly tapered top. Given PAFC's height differential above ICC, however, (approximately 100 meters between highest occupied floors) additional aerodynamic shaping was necessary. Notably, while the main façades are vertical for most of the tower's height, PAFC features continuously tapering corners. Corner tapering proved enormously effective in reducing wind loading on the structure, in particular the cross wind impact. PAFC's profile transforms even more significant at the upper registers of the tower, where the wind loads are greatest. Here, the progressive tapering of the main façades and beveling of the corners effectively "round" the tower and "dome" the top (see Figure 2.4)

The streamlining of the tower shape had measurable practical benefits in improving structural and wind performance. Thornton Tommasetti and RWDI were consulted early in the process to critique and inform the tower's shape. This dialogue aided the client, predisposed to traditional stepped-back forms, to realize the benefit of aerodynamic shaping. In all, PAFC achieves a 32%

平安金融中心表现出相似的特征，但它具有紧凑性而不是压缩性。打个比方来说，它并非坚硬的金刚石，而是承受着超凡拉力的钢丝绳。由于采用了将塔向天空的方向拉伸 (而不是把它从地上推起来) 的概念，因此平安金融中心才得以具备流线型的设计外形。

由于客户要求建筑要配有方形和功能性的楼板，因此平安金融中心外形设计的理念借鉴了香港ICC的设计理念。用于提升抗风性能的技术更为精妙，其对内部使用区域的整齐性影响极小，但却更为有效 。在ICC建造之前，曾进行了风洞测试，并将简单的挤压几何图形 (正方形、长方形、圆形和三角形) 与每种形状的凹凸角衍生图形相比较。测试结果表明，带有凹口的正方形，或带有凹角的正方形具有与圆形塔式建筑相同的优异属性 (见图2.3) 。

除此之外，在设计ICC时使用的其他技术，如倾斜基座也对平安金融中心的设计产生了影响，这种技术能够提升建筑物的结构姿态，并形成微微的锥形尖顶。由于平安金融中心与ICC有建筑高度差 (最高上人楼层间的高差约为100米) ，所以需要进行额外的空气动力学定型实验。特别是由于塔楼的大部分外表面都是垂直的，使得平安金融中心拥有连续的渐变角。实验证明，渐变角能够极为有效地降低作用在结构物上的风力载荷，尤其能够降低侧风的影响。平安金融中心高层部位的轮廓变换更为显著，而这一区域受侧风的影响最大。主立面的渐变式锥形轮廓以及倾斜角有效地使塔楼外形变得更为圆滑，且在顶端形成了圆顶 (见图2.4) 。

流线型的塔楼形状提高了塔结构的P结构和防风性能。在对外形进行审核的过程中，以及将塔形通告客户之前，我们咨询了Thornton Tommasetti 和 RWDI这两家顾问。这次对话使倾向于传统设计的客户了解了空气动力学外形的优点。在进行了综合设计之后，得益于塔楼的独特外形，与中国的设计规范相比，平安金融中心降低了32%的倾覆力矩和35%的风力载荷。

由Thornton Tomasetti设计的典型结构方法也在平安金融中心的综合巨型结构中得到了验证。与ICC以及TT的先驱作品台北101大楼相似，该建筑的主要结构系统为钢筋

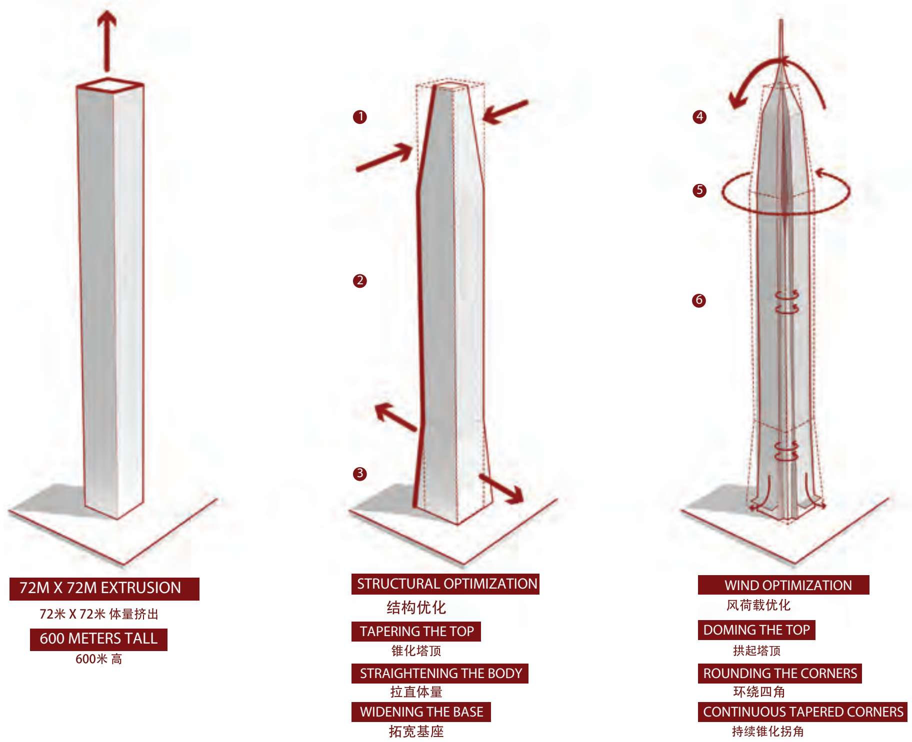

Figure 2.4. The splayed base and tapered top along with tapered corners reduce wind load. (Source: KPF)
图 2.4 向外敞开的底座与具有锥形拐角的锥形顶部减小了风荷载。(来源: KPF)

Figure 2.5. Designed by Thornton Tomasetti, the primary structural system works in combination with an exterior mega frame. (Source: KPF)
图 2.5 由宋腾添玛沙帝设计的主结构系统与外部巨型结构相互协作。(来源: KPF)

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

The prototypical approach is also evidenced in PAFC's composite mega-structure, designed by Thornton Tomasetti. Similar to ICC, and TT's pioneering work on Taipei 101, the primary structural system is a steel-reinforced concrete core connected to eight composite super-columns by four double-story outrigger trusses. To meet mainland China's stringent seismic code, which requires the perimeter structure to contribute a large percentage of the overall lateral load resistance, the primary system works in combination with an exterior mega frame consisting of seven levels of belt trusses connected to the super columns at each mechanical floor (see Figure 2.5).

Initial structural proposals utilized a vertical vierendeel truss, aligned with every other façade pier, to provide additional lateral stiffness. Subsequently in the seismic review process, diagonal bracing proved to be a more efficient and acceptable means to address the stiffness requirement. The composite mega-structure bears similarities to SWFC, Hong Kong's Bank of China, and of course Chicago's John Hancock Center – the first to adopt a braced exterior frame. However, the distinctive cut-back corners provided the unique opportunity to introduce a chevron brace system, which increased the stiffness of the tower while allowing greater transparency at the corners.

Another distinctive feature of PAFC is the expression of the super-columns, which project beyond the plane of the façade. The outward push of the columns allowed the perimeter bracing to move proportionally closer to the façade. This subtle refinement both increased structural stance, and minimized distance of structure protruding into the interior leasing space (see Figure 2.6).

Architecturally, the exposed columns provided the opportunity to articulate structural elements on the façade. Linen-finish stainless steel was selected for the column finish to enhance the ductility of the overall form. Eight stainless columns trace the edges of the tower and converge into the spire in one continuous gesture. Each column is clasped by a stone buttress, stylized like the talons of some great bird gripping the earth before taking flight. Vertical strands of stainless steel are drawn tightly along the full height of the tower to express the underlying tension.

Essentially, the tower is pulled taught by opposing forces of gravity and lift. It is uniquely neither heavy nor light, but poised in equilibrium.

混凝土核心筒，使用四套双层外伸臂桁架与八套综合超级立柱相连接。中国的抗震规范十分严格，其要求建筑物的周边结构需要具备抵御大部分整体横向载荷的能力。本建筑的主要系统与外部巨大的框架一起组成了七层的带状桁架，并在每一设备层与超级立柱相连接 (见图2.5) 。

初始结构设计使用垂直的空腹桁架，与每个外立面支撑梁相对齐，以提供额外的横向刚性。而在接下来的抗震评估阶段，对角支撑设计被证明是一种更为有效也更为实用的方法，完全能够满足刚性要求。综合巨型结构类似于上海环球金融中心、香港中国银行大厦以及位于芝加哥的约翰汉考克大厦——该大厦首次采用了外部支撑框架设计。但是，独特的退角设计为塔楼提供了采用人字支撑系统的极为难得的机会，使用这一系统可以在增加塔楼刚性的同时，提高楼角处的透明度。

平安金融中心的另一项独特之处在于其超级立柱的外形，其投影超出了建筑物立面的平面图。立柱外推使得建筑的周边支撑结构得以成比例地靠近建筑立面。这一设计上的微妙改进不仅增加了建筑物的结构态势，同时也缩小了建筑结构所占用的内部租赁空间的面积 (见图2.6) 。

从建筑学角度来看，外露的立柱有助于连接建筑物外立面的结构部件。在进行立柱

Now, Give it an Engine.

"Core" is a static word. It conveys a stationary object and does nothing to express the dynamism of the machine that drives today's megatall buildings. Borrowing a cue from the automotive industry, PAFC does not have a "core". It has a high-performance engine: 8 cylinders, twin-turbo, and 0–500 meters in less than 60 seconds.*

[*Translation: eight elevator zones, two office shuttle banks serving two sky lobbies, and high-speed observation shuttles]

Car manufacturers have succeeded in making engines that are lighter, more fuel-efficient, with fewer cylinders, yet more powerful, and very glamorous. Comparing the new Audi A6-C7 with its C6 predecessor, horsepower increased 34%, 0–to–100 acceleration improved by 2.0 seconds, and fuel economy improved 31%. Weight reduction (–2%) and reduced drag coefficient (–10%) contribute to performance. But according to Audi, the main contributor is in direct fuel injection and forced induction technology, which "makes it possible to achieve a seemingly improbable combination of lower fuel consumption and enhanced power and performance." Likewise, it is time to "turbo up" our towers.

To improve core performance, PAFC features an all-"4xD" elevator system: double-deck (2-story) elevators with destination-dispatch controls. As is standard with tall buildings today, each elevator is equipped with regenerative lift drive technology which, similar to a hybrid car, produces electricity during braking.

装饰的过程中，选用了布纹不锈钢材料，用于增强整体结构的延展性。八根不锈钢立柱以同样的姿态沿着塔楼的边缘汇集于塔尖的一点。每根立柱都由一座石质支架支撑，支架的形状犹如一只即将展翅高飞的巨鸟抓入泥土中的爪子一样。不锈钢立柱上雕刻着严密的垂直线，直达塔楼的顶端，这表现了建筑物潜在的张力。

本质上，这座塔楼克服了重力和提升力拔地而起。它既不轻浮也不压抑，而是泰然自若地保持着和谐的平衡。

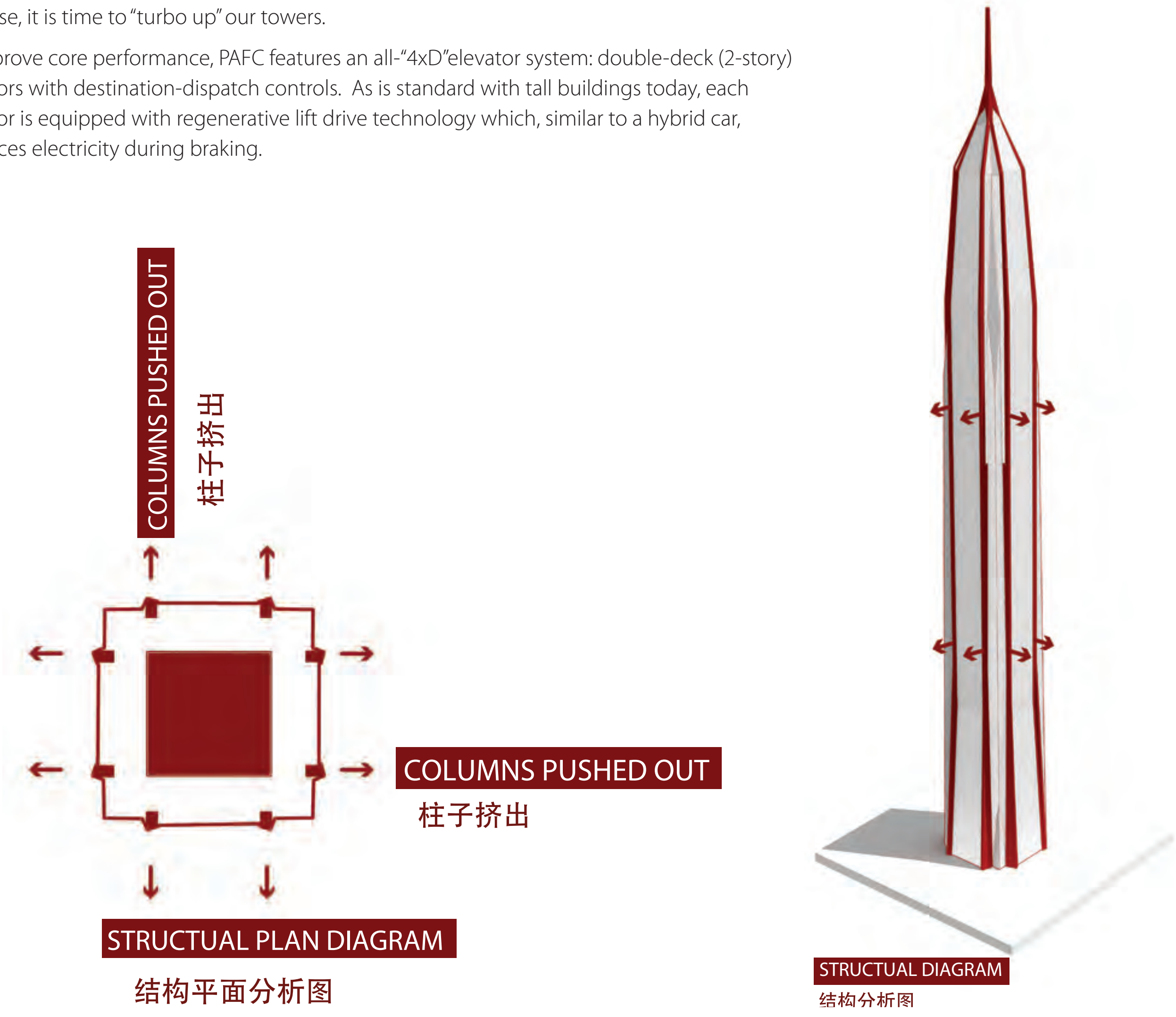

Figure 2.6. The outward push of columns allows the perimeter bracing to move proportionally closer to the façade. (Source: KPF)
图2.6 立柱外推使得建筑周边支撑结构得以成比例的靠近建筑立面。（来源: KPF）

Upper local elevators were stacked in the same shaft atop mid-zone elevators, which in turn are stacked above low zone elevators, to save space in the core. Two banks of six shuttle elevators each provide access to one of two double-deck sky lobbies, where occupants can transfer to the mid-and-upper local elevators. To improve flow at the entrance levels, double-deck access is staggered across three entry floors: shuttles serve lobbies located at the B1 and L1 levels, and low-zone local elevators serve lobbies located at the L1 and L2 levels. Single-story escalators and double-story express escalators connect from the subway link located at the B1 lobby to the L1 and L2 lobbies.

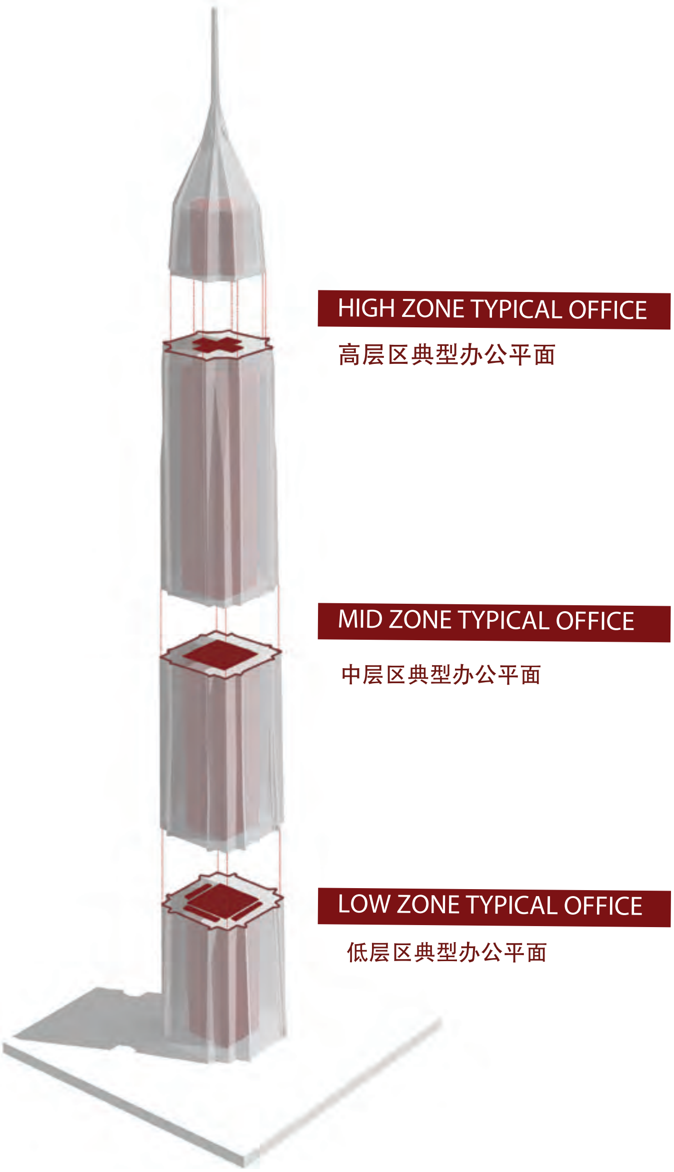

Figure 2.7. The core develops parallel with the tower's form. (Source: KPF)
图 2.7 核心筒与塔体造型一致。(来源: KPF)

现在，给它一个引擎

"核心筒"是一个静态的词，它表达的只是一个静止的物体，而无法描述机器的动态特性–快速驱动今天的超级高层建筑。借用一句汽车工业里的术语，平安金融中心不具有核心。它具有高性能发动机: 8缸，双涡轮，并在60秒内从0加速到500米。

[*注: 8个电梯分区，两组办公穿梭电梯服务于空中大厅，以及高速景观电梯]

汽车制造商们已经成功地使发动机的重量更轻，更省油，用较少的汽缸，但功能更强大，而且非常迷人。新奥迪A6-C7与C6的前身相比，马力增加了34%，0到100加速改进了2.0秒，燃油经济性提高了31%。重量的减少 (-2%) 和风阻系数的降低 (-10%) 提升了整体性能。但对于奥迪来说，主要贡献者是直接燃油喷射和压力感应技术，这「使得它可以实现一个看似不可能的组合，即低油耗和高动力性能。」换句话说，现在是时候用涡轮增压启动我们的塔楼了。

为了提高核心筒性能，平安金融中心采用了一套"4×D"电梯系统: 双层轿箱电梯，并配备目的地派送控制系统。如今，作为高层建筑物的标准配置，每部电梯都配备有再生电梯驱动技术，这种技术就像混合动力汽车一样，在刹车时产生电能。

高区的区间电梯位于中区电梯的电梯井之上，共用一个电梯井，因而节省了核心筒的空间。两组六部短程穿梭电梯，每组都能够直达两个双层空中大厅中的任意一个，在空中大厅，住户可以转乘中区或高区的区间升降电梯。为了提升入口层的人流量，在三个入口楼层错落布置了双层进入通道: 大厅的短程穿梭电梯位于B1和L1层，大厅的低层区间升降电梯位于L1和L2层。单层自动扶梯和双层特快自动扶梯位于B1大堂的地铁入口处，能够直通L1和L2大厅。

核心筒的最高处是三部超高速电梯，直达塔楼顶部的多层观景台。为了缓解由于高速的高度变化导致的"耳鸣效应"，电梯采用了加压设计。设计的电梯每日运输能力为单趟550米高度运送8,000人——这是目前主流电梯的运载极限。这一数据是根据"目前"的情况推断的，而Kone的碳纤维超级绳索技术设计将有望打破这一极限。

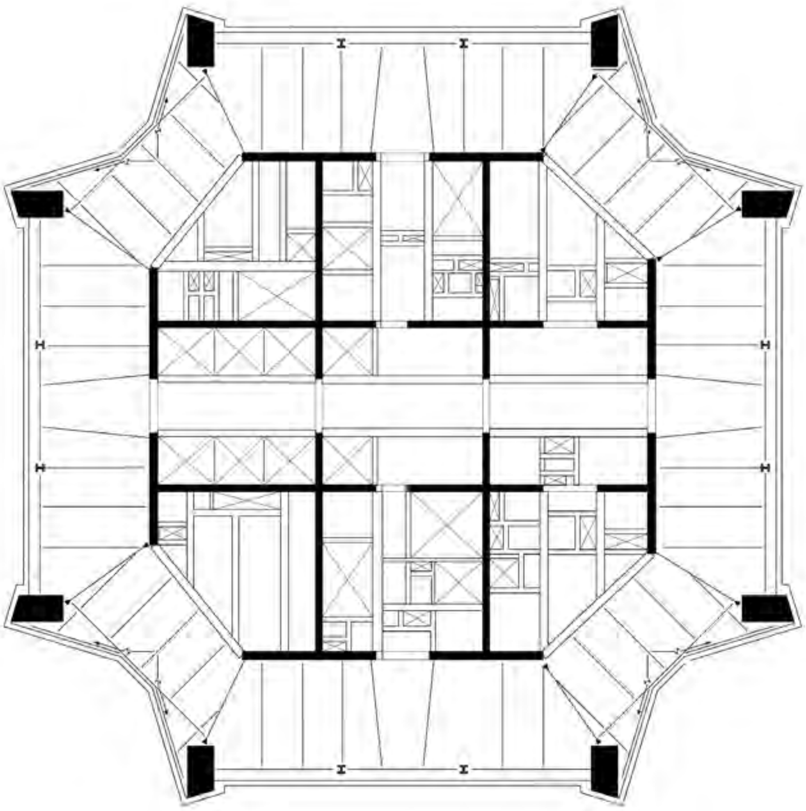

Figure 2.8. Typical high zone floor plan showing pinched corners. (Source: KPF)
图 2.8 高层区典型办公平面图展示了收缩的四角（来源: KPF)

Completing the core is a trio of super-high-speed elevators serving the multi-level observatory at the tower's crown. Pressurized to alleviate the "popping ear effect" due to high-speed altitude adjustment, the elevators are designed to move a daily capacity of 8,000 visitors in a single run up to a height of 550 meters – the current limit of prevailing elevator technology. The inference here is "prevailing," as KONE's carbon-fiber UltraRope technology is designed to outperform current limitations.

Notwithstanding performance, any engine needs to fit within its housing. The core should necessarily develop in parallel with the tower's form, literally. The ideal configuration of the inner geometry should be a parallel offset of the outer geometry, with a consistent dimension between, for efficient layout of the office interiors (see Figure 2.7).

In PAFC, the core is designed as a cruciform embedded within a square, with a target 12.5-meter leasing depth all around. As the exterior form tapers and bevels at the upper floors, the structural walls drop off at the corners, resulting in a flange-shape cruciform structure which responds to the octagonal geometry of the upper floors. The pinching of the primary leasing depth is compensated by opening up the corners in the 45-degree orientation, which coincides with the best views out from the tower (see Figure 2.8).

Again, transformation of the core occurs in parallel with the formal transformation at the tower's lower floors, where the splayed-out base provides larger internal spans. Low zone elevators and base-level building systems are strapped outside the main body of the core. These "booster"

无论性能如何，任何发动机都需要适应其所在的建筑。核心筒必然要与塔楼的形态发展相匹配。从字面上看，这意味着，内部几何形状的理想配置都应该与外部几何形状平行，并应与办公室室内有效布局设计相一致 (见图2.7) 。

在平安金融中心， 核心筒被设计为嵌入正方形内的十字，四周有12.5米的租赁深度。外部形状逐渐变细，在高处呈现倾角，结构墙在角落逐渐变低，造成凸缘形状的十字形结构，与上层的八角形几何形状相呼应。租赁深度的收缩通过在墙角处打开45度的角得到了补偿，这与塔楼外部的美观造型相互呼应 (见图2.8) 。

此外，核心筒的造型变化与塔楼下部楼层的造型变化是一致的，其向外开展的基座能提供更大的内部跨度。低层电梯和基层建筑系统在核心筒主体的外部相连。这些像"增压器"的次核心筒将主要核心筒的垂直部件承受的压力向楼体进行传导释放，并提供了额外的结构支撑，减小了基层部位的结构跨度。当主塔收拢至更加紧凑的垂直部位时，"增压器"就此退出。

这些充分节省空间的措施将核心筒内部投影面积降低至30×30米——考虑到塔楼的高度和密度，应认为核心筒是极为紧凑的。

1%在塔尖内，还是99%来自塔尖?

平安金融中心的外形线条聚拢于引人注目的塔尖，从585米开始直至660米塔尖。这无疑是塔楼的标志性特征，而这也是在其建造过程中遇到的最有趣的技术挑战之一。 作为位于塔楼顶部的独立尖塔，为了在塔楼的顶部建立一处公共空间，设计师设计了一座"拔起式"的尖塔，跨立于玻璃观景穹顶之上 (见图2.9) 。

虽然塔尖似乎有理由成为塔楼结束的形式，但是为其存在找出一个可持续发展的理由确实伤脑筋。最初模拟的塔尖基础部位的风力涡轮机经预测仅发电2100千瓦时/年。

出于类似目的，设计团队测试了每个V形外墙支柱内浮力空气的利用，用于发动位于支撑梁上的微型涡轮或将它们聚集在一起发动分布于各设备层的较大型涡轮。预计后者更积极可行。最终，由于抗震评审

cores alleviate the pressure to house all the vertical elements within the main core and provide additional structural support to reduce the deeper spans at the base. The boosters drop off by the time the tower tucks into its more compact, vertical portion.

These space-saving measures reduced the core internal footprint to 30 x 30 meters–remarkably compact given the height and density of the tower.

1% In-spire, 99% Per-spire?

The converging lines of PAFC resolve in an emphatic spire, starting at 585 meters and rising to the tower's apex at 660 meters. It is undoubtedly the tower's signature feature, and one of its most interesting technical challenges to note. Starting as a stand-alone mast atop the tower, the desire to create public space atop the tower led to the current design of a "pulled-up" spire straddling a glass observation dome (see Figure 2.9).

While the spire seems necessary to conclude the tower's form, finding its 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.

Of related interest, the design team examined the utilization of buoyant air contained within each V-shaped façade pier to drive either micro-turbines located at the piers, or gathered into larger centralized turbines located at each mechanical floor. The latter was predicted to have positive and viable results. Ultimately, it could not be implemented, due to lack of space in each mechanical floor following the addition of a redundant belt-truss layer requested during the seismic review period. However, it is still possible to implement the concept at the tower's dome, possibly leading up to a turbine housed at the base of the spire.

Thornton Tomasetti and RWDI predicted the spire's slenderness ratio would necessitate a tuned mass damper (TMD) within the

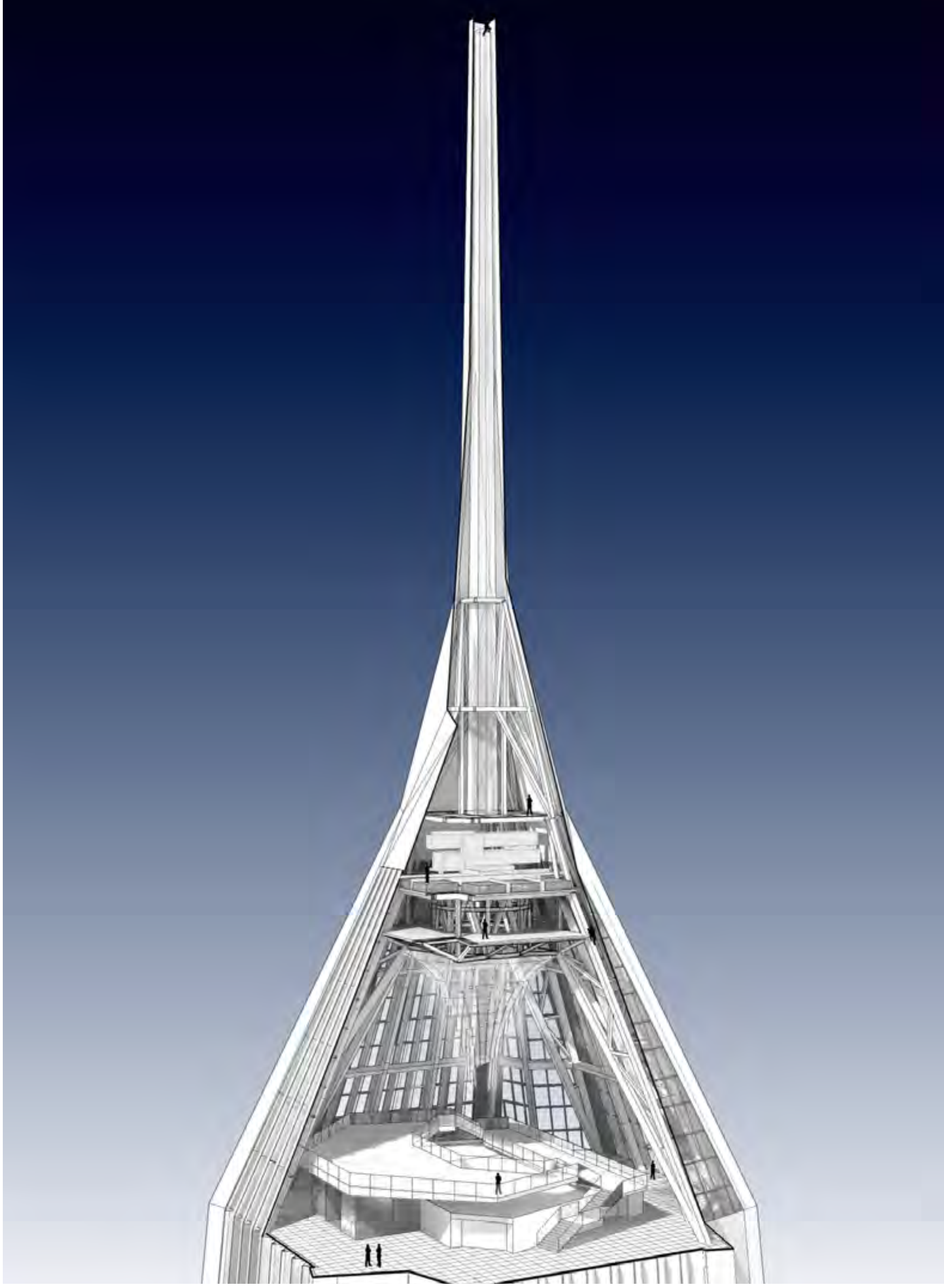

Figure 2.9. The desire to create public space atop the tower led to the current design of a "pulled up" spire. (Source: KPF)
图 2.9 为了在塔楼的顶部建立公共空间，设计师设计了一座"拔起式"尖塔顶。(来源: KPF)

需要额外增加带状桁架，各设备层缺乏空间，因而未能实施。然而，塔楼穹顶处仍有可能实现这一设计，有可能最终在尖顶基础部位安置一个涡轮。

TT 和RWDI预测塔尖的长度直径比需要在塔尖井道内加动力阻尼器 (TMD)，以抵消空气弹性振动，即快速振动。RWDI设计了一个简练优雅的系统，由两个平板阻尼器组成，一个在x轴方向，另一个在y轴方向，在两个阻尼器之间有一个校准的垂直距离，来调整全方位的移动。

为了检验这一假设，该小组进行了专门的尖顶风洞实验，分别测试了安装和没有安装附加阻尼的情况。RWDI证明 (用出色的视频效果) 如果没有提供额外的阻尼，在预期的风速范围内将发生漩涡脱落和快速震动。同样令人震惊的是，尖顶内的动力阻尼器只需提供百分之一的阻尼，就能稳定塔尖。

鉴于平安对塔尖阻尼器的长期可使用性的担忧，设计团队的建议是运用空气动力学以减少塔尖的复杂性和自重。其它的方案还有增加竖向鳍片或增设横向尖顶轮廓等高线，RWDI提出塔尖穿孔，KPF解释为将四个独立的桅杆用一个结构网格连起来。截至本文撰写之时，将进行另一个风洞实验以确认开放式塔尖设计作为空气动力阻尼的有效性 (见图2.10)。

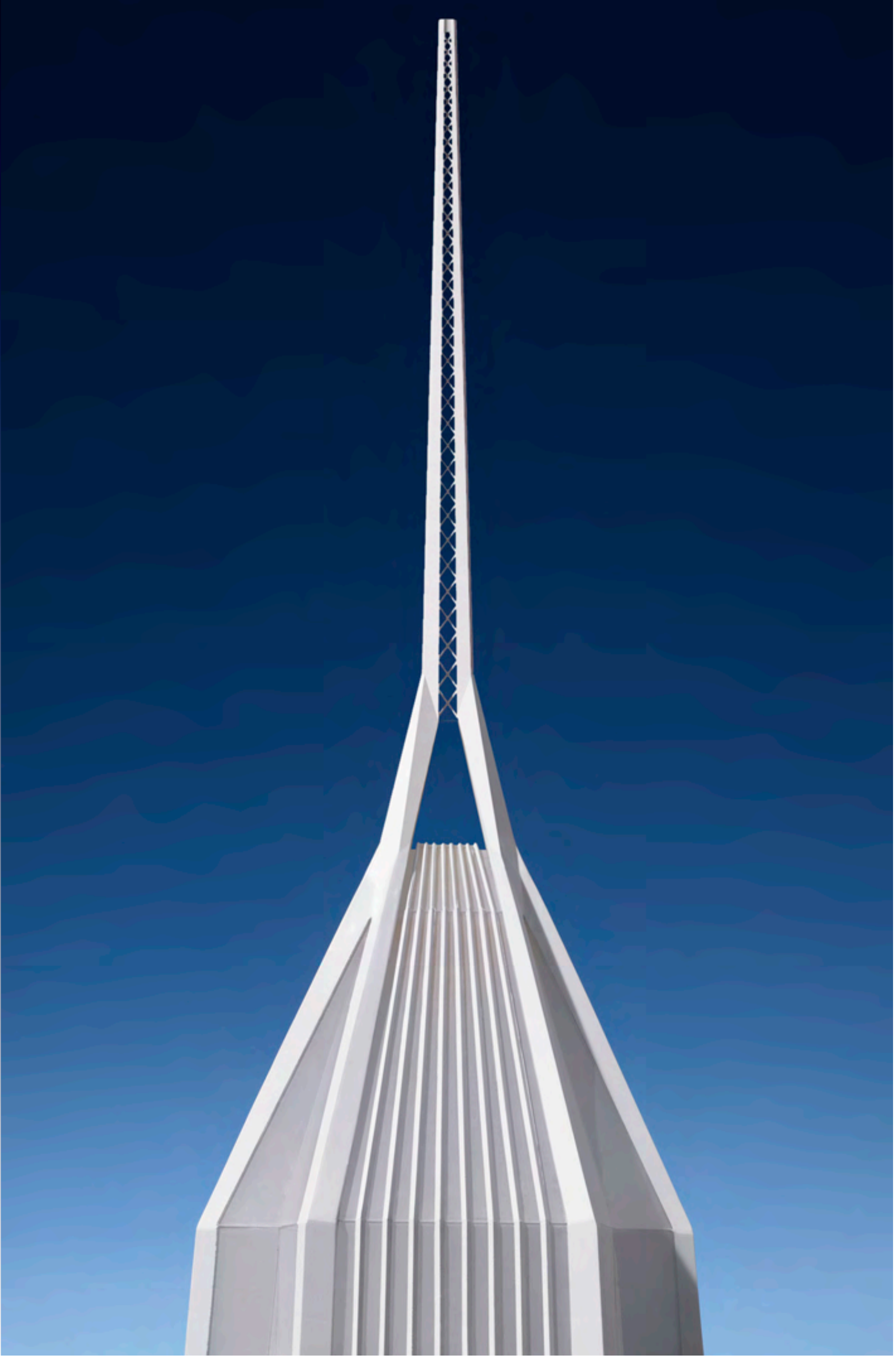

Figure 2.10. PAFC's design team's recommendation was to pursue an aerodynamic solution to reduce the spire's complexity and self-weight. (Source: KPF)
图 2.10 平安金融中心的设计团队建议以空气动力学方法降低塔顶的复杂性与自重。(来源: KPF)

spire shaft to counterbalance aeroelastic flutter, i.e., galloping. RWDI designed an elegant system comprised of two flat-plate dampers, one in the x-direction and the other acting in the y-direction, with a calibrated vertical distance between the two dampers, to tune for the full range of motion.

To test the hypothesis, the team conducted a spire-specific wind-tunnel test, with and without additional damping. RWDI demonstrated (with spectacular video results) that vortex shedding and the onset of gallop would occur within anticipated wind speeds if no additional damping was provided. Equally spectacular, just one percent additional damping, as provided by the in-spire TMD, stabilized the spire.

Given Ping An's concerns for long-term serviceability of the in-spire damper, 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. As of the time of this writing, another wind tunnel test will be conducted to determine the validity of the open-spire design as an aerodynamic damping solution (see Figure 2.10).

总结

通过采取正确的DNA，可更多地关注超高层建筑的基因规则变量之间的微妙关系。平安金融中心的过人之处是对互相矛盾的元素之间的相互作用及其平衡，例如，建筑外部形态和服务于内部的核心筒之间的平衡。在节能方面，建筑系统之间的凝聚力对一个高层建筑固有的可持续性产生重大影响。当系统协同工作时，该解决方案是简单高效的。当变量不协调时，其结果是浪费空间和能量。

更加复杂的是，该解决方案不是一成不变的，而是一个动态的平衡。当变量变得越来越有限时，必然需要调整和努力解决问题。平安金融中心的设计过程在原先的基础上循序渐进，具有最佳实践性，每日从顾问处获得反馈信息。五年后，在平安金

Figure 2.11. Night view of the tower under construction. (Source: Ping An)
图2.11. 正在建设中的平安金融中心夜景 (来源: 平安)

Conclusion

Adopting a starting DNA allowed for greater focus on the nuanced relationship between variables in the megatall building's genetic algorithm. PAFC excels its balance of the interplay of competing objectives, for instance, in the external shaping of the form versus the internal needs of the services core. In energy terms, cohesion between building systems has a major effect on a tall building's inherent sustainability. When the systems work together in tandem (in-phase), the solution is elegant and efficient. Where the variables are out-of-phase, the result is wasted space and wasted energy.

Adding to the complexity is the fact that the solution is not static, but rather a dynamic equilibrium. The design necessarily needs to adjust and work towards resolution as the variables become more finite. In the design of PAFC, now well under construction (see Figure 2.11), the iterative process was incremental and based on precedent, best practice, and daily feedback from consultants. Five years later, computing advances in parametrics and BIM have enabled thousands of iterations in the design of PAFC's sister tower to the south.

融中心的姐妹塔南塔的设计中，计算机在参数和BIM上的优势可运用成千上万的重复元素。

平安金融中心的设计是现代超高层建筑的进化（见图2.11）。大部分原则都得到了世界高层建筑与都市人居学会圈内的理解。尽管如此，下面的列表以供将来参考:

特征:

加宽的基础，以提高结构的稳固性

锥形轮廓，以减少作用于结构的地震力和风力

特殊形状的转角，以提高空气动力特性

大雨棚，以减轻下沉气流

巨型结构体系，经济结构弹性的手段

Encoded in the design of PAFC are the evolutionary building blocks of the modern megatall building. Most of these principles have come to be well understood within the circles of CTBUH. Nonetheless, a list for future reference:

Traits:

Widened Base, to increase structural stance

Tapered Profile, to reduce seismic and wind forces acting on the structure

Shaped Corners, to improve aerodynamic performance

Large Canopies, to mitigate downdraft

Mega-structural System, as a means of economic structural resiliency

Multi-stage Vertical Transport, to minimize the size of the services core

Modular Design of the structure and façade systems

Mass Transit Connectivity, to network with other urban clusters

Public Space at the Tower Crown, to lift the urban experience to new heights

It is this final trait that differentiates necessity from vanity. While the tall tower is fundamentally about increasing density, it also bears civic responsibility. Public participation and interaction with the tall tower is at the heart of the project team's interest in height. Elevating the human experience is the goal.

Acknowledgement

The author would like to thank Zhizhe Yu, Florence Chan, Angela Davis, and Michael Bentley of KPF for their long service and innovative contributions to the project, and to Ying Xu for providing many of the illustrations.

多级垂直运输，以减少服务核心区域的大小

结构和幕墙系统的*模数化设计*

与其它城市*公共交通网络连接*

位于塔楼冠部的公共空间，对城市的体验提升到新的高度

最终的特征是将必要性与浮华区分开来。虽然高塔的基础作用是增加居住人口密度，但是它也承担着重要的公民责任。在我们不断增加建筑物高度的同时，心中始终坚持认为公众的参与和互动在高层塔楼的建设过程中极为重要。不断提升公众的体验一直都是我们所坚持的目标。

致谢

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