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Author: Jeffrey Holmes, Founding Principal, Woods Bagot

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All Things are Not Equal: Responsive Façades for Tall Buildings
万事皆不同：超高层建筑响应式外立面

Jeffrey Holmes

Jeffrey Holmes

Woods Bagot
142 W 57th St
New York, New York
10019 USA

tel (电话): +1 646.573.5573
email (电子邮箱): jeffrey.holmes@woodsbagot.com
www.woodsbagot.com

Jeffrey is the founding principal of Woods Bagot's New York studio. Since its inception, the studio has been a global leader in designing innovative, urban projects around the world. Prior to joining Woods Bagot, Jeffrey, with Skidmore, Owings and Merrill (SOM), was responsible for the design of numerous landmark high-rise projects including Time Warner Center and One World Trade Center. Jeffrey received his Masters from the Massachusetts Institute of Technology and BArch from Cornell University. He has taught extensively and his work has won numerous awards and been widely published.

Jeffrey是伍兹贝格公司纽约事务所的创始人。自成立以来，该事务所一直是全球范围内设计创新性的城市项目的行业领导者。在加入伍兹贝格之前，他在SOM公司负责领导设计了大量地标式高层建筑，包括时代华纳中心和新世贸中心一号塔。Jeffrey先后于康奈尔大学和麻省理工学院取得建筑学本科和硕士学位。他广泛任教于各大学府，设计作品屡获嘉奖，并被世界各媒体广泛刊登报道。

Abstract

This paper explores how data-driven parametric design enables the creation of enclosures that respond to highly specific environmental, behavioral and urban inputs. In the wake of massive technological transformations, there is a vast amount of descriptive and analytical data instantaneously available to help assess exterior wall design options. A designer can now filter spatial and technical information through simulation, analysis and optimization processes to form integrated parametric building information models capable of generating an array of outputs. These outputs can then be used to re-inform the design process in an iterative, algorithmically driven design workflow that is more fluid, collective and responsive than past practices. A number of case studies drawn from around the world will illustrate both the flexibility and specificity of this approach, as well as how data-driven design opens vast potential for creating transformative façades for tall buildings to achieve new possibilities for a sustainable vertical urbanism.

Keywords: Façades, Parametric, BIM, Sustainable, Urban, Environment

摘要

本文探讨了如何通过以数据为导向的参数化设计，来实现建筑外立面对特定环境、行为模式、以及城市因素的响应。在当今科技变革大潮来临之时，有大量描述和分析性的数据可帮助评估外墙的设计方案。设计师现在可以通过模拟、分析和优化的流程来筛选空间和技术信息，以形成能够产出一系列结果输出的综合参数化建筑信息模型。这些输出结果可以一种循环迭代，算法驱动的工作流程向设计过程增加新信息，令设计过程比以往的工作模式更流畅、综合，且即时响应。位于世界各地的案例将展现这种新的工作方式的灵活性和独到之处，以及这种数据驱动的设计如何为创造高层建筑可变立面提供了巨大潜能，为可持续的垂直城市带来新的可能。

关键词：立面，参数化，BIM，可持续发展，城市，环境

Responsive Façades

The history of the façade is a history of the interface between often competing claims. In addition to its fundamental role in establishing the interface between inside and out, the façade must delineate claims for both openness and privacy; transparency and energy efficiency; maximum views and minimum glare; materiality and cost effectiveness; a unique identity as well as a responsiveness to the character of a specific place; and many more. Today, the number of parameters façades are asked to resolve only proliferates as performance, thought of most broadly, becomes the key metric in assessing their value.

Technology has transformed our ability to manage these competing claims and discover new expressive possibilities in their resolution. Building Information Modeling platforms such as Revit and Microstation facilitate integrated workflows by managing large quantities of information in a manner that was unimaginable just two decades ago.

响应式立面

立面设计的历史是建筑体系中各种对立要求相互接合的历史。它不仅起着建立区分室内外界面的基础作用，还应呈现出各种功能要求：开放性和隐私性，通透性和能源效率，最大视野和最小眩光，材质和成本效益，独特性和对特定场地的回应，以及其它更多要求。如今，广义上的性能表现已成为评估建筑价值的关键指标，因而立面设计所需解决的问题大大增加。

科技改变了我们管理这些对立要求和发现应对这些要求的新可能性的能力。诸如Revit和Microstation这类建筑信息化模型平台，以二十年前不可想象的方式管理着大量的信息，以促成综合性的工作流程。更重要的是，类似于Grasshopper的可视化程序语言，结合能源建模软件和其他插件，给予设计人员强大的新工具和途径，以重新定义设计、数据和效能的关系。而这些算法工具的创新性应用又最能体现于设计可响应住户、气候、城市、美学、建造和成本的各种复杂而对立的要求的立面上。

伍兹贝格的一项最近刚完成的LEED金奖项目，南澳大利亚医疗卫生研究所（南澳医

More importantly, visual programming languages such as Grasshopper, integrated with energy modeling software and other plug-ins, give designers powerful new tools and processes to reconceptualize the relationship between design, data and performance. Nowhere are the innovative applications of these algorithmic tools more pronounced than in the design of façades capable of responding to the complex and often conflicting demands of occupant, climate, urban, aesthetic, construction and cost requirements.

A recently completed project for the LEED Gold South Australian Health and Medical Research Institute makes a clear case for the transformative power of data-driven façade design. Through an in-depth briefing process with researchers, the design of the enclosure for this 25,000 square-meter low-rise research building, situated within a prominent civic greenway in the south Australian city of Adelaide, set out to optimize five key parameters: daylighting, views, glare, energy efficiency and reinforcing the structure's unique form.

After significant geometry optimization of the building form to increase modularity and continuity of the surface, daylighting, solar loading and view requirements were mapped in three dimensions across the enclosure. (See Figure 1) Environmental analysis of a variety of enclosure systems, including high shading coefficient glazing, fritting and exterior shading strategies were conducted. From this analysis, exterior shading was determined to best optimize the diverse array of parameters, as it yielded a 52% reduction of solar heat gain, significantly improved average annual illuminence levels while reducing glare and allowed unhindered views from write-up and shared spaces to the river and city beyond.

The parametric model was then further refined to respond to more specific programmatic and aesthetic requirements. Each triangular panel of the façade was assigned one of four panel types in response to program: a shallow shade with glass to maximize daylight and views in common areas and dapple them in sunlight; a deep shade with glass at write-up areas to maximize shading and minimize glare; a perforated metal panel with no glass at building system areas to allow for air intake and exhaust; and metal screens with no glass at external peristitial zones along the western face of the building. The relationship between each adjacent panel was scripted to allow a continuous transformation of panel types from one programmatic area to another. (See Figure 2). Further scripting of material amounts and costs were then utilized to optimize the number of panel types and the amount of shading, the imbedded energy of the shading materials and the life-cost energy savings. Output from the parametric model was used to confirm fabrication cost modeling and to create fabrication tickets.

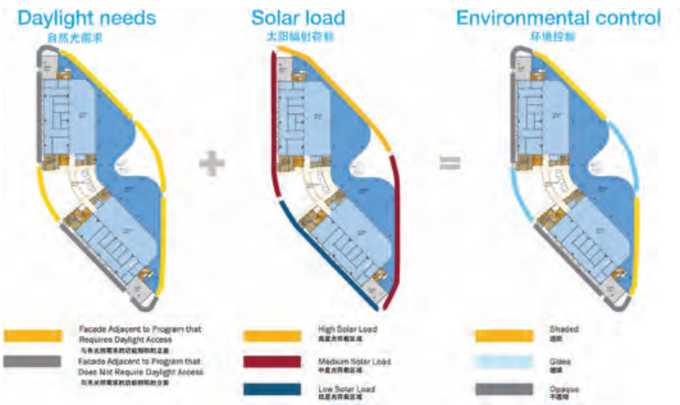

Figure 1. South Australian Health and Medical Research Institute: Typical floor plan illustrating façade performance requirements. (Source: Woods Bagot)
图1. 南澳大利亚医疗卫生研究所: 典型平面说明立面的性能要求 (来源: 伍兹贝格)

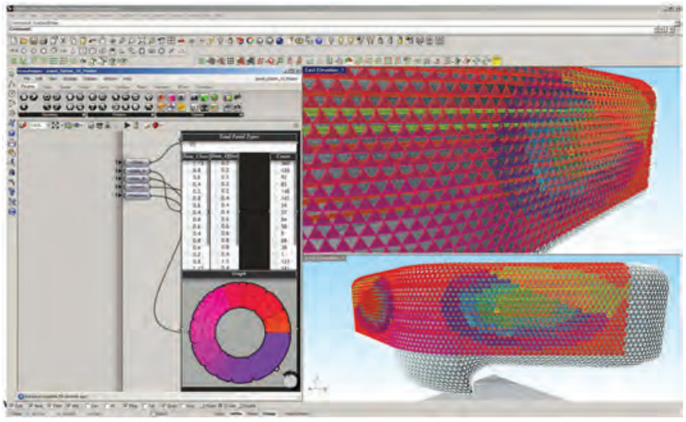
Figure 2. South Australian Health and Medical Research Institute: Parametric visualization. (Source: Woods Bagot)
图2. 南澳大利亚医疗卫生研究所: 参数的可视化 (来源: 伍兹贝格)


Figure 3. South Australian Health and Medical Research Institute: Photograph of façade. (Source: Woods Bagot)
图3. 南澳大利亚医疗卫生研究所: 立面照片 (来源: 伍兹贝格)

卫所)，可清楚展示数据驱动的立面设计的变革力量。通过对研究人员进行深入了解，这个坐落在南澳大利亚阿德莱德市著名绿道上，面积达2万5千平方米的低层科研大楼的立面设计着手于优化五个重要参数: 采光、视野、眩光、能源效率和加强结构的特殊形态。

在经过大量的形体几何优化，以提高建筑表面模块化和连续性之后，采光、日照荷载和视野要求被三维地映射在建筑围合立面上 (参见图1)，进行一系列围合系统的环境分析，包括高遮阳系数玻璃、釉面处理和外遮阳等策略措施，从而得出外部遮阳系统能最优化各种参数的结论。它可减少52%的日照辐射得热，在大幅增强年平均照度的同时减少眩光，并且工作区和公共空间面对河流和城市的视野也畅通无阻。

随后，对这个参数化模型再次细化以达到更具体的功能和审美要求。外墙的三角形面板对应不同的功能有四种类型，包括: 公共区域的浅遮阳玻璃，使采光和视野达到最大，并在日光下显现斑点; 工作区的深遮阳玻璃，最大化遮阳并尽可能降低眩光; 建筑设备区域的无玻璃穿孔金属板，能够进气和排气; 以及沿建筑西面的无玻璃金属围板。每个相邻面板之间的连接关系都经过程序脚本编辑，保证不同功能面板能连续变换 (参见图2)。进一步地对材料用量和成本进行脚本编辑，用于优化面板类型的数量和遮光量，遮光材料的自身能量和整个生命周期节约的能源。参数化模型的输出则被用来确认制造成本模型和形成生产工序。

由此分析所得出的结果是一个完全优化的立面，增强了建筑造型的连续性 (参见图3)。在平面上，立面由设备区的大幅遮挡过渡

The result of this analysis is a fully optimized façade that reinforces the continuity of the building's form. (See Figure 3). In plan the façade transforms from the deep screening of mechanical zones to carefully calibrated daylight and views at write-up areas and expansive atrium glazing. In section the façade flows from the building's smooth underbelly raised above the civic greenway to varied three-dimensional shading and screening profiles and smooth roof panels. The changeling nature of the enclosure makes legible the building's making and directly engages all who encounter it in a dialogue about the web of relationships between our buildings, the environment and the physical context.

While SAHMRI stands only five-stories tall, the data-driven design tools and methodologies utilized in the design of its enclosure are particularly well suited to address the specific opportunities and constraints of tall building design. Nowhere are the complexities of the interface between extraordinarily divergent parameters of occupancy, orientation and context more intensely made manifest. Highly responsive tall building façades hold the promise of reestablishing the multi-dimensionality of our cities and fostering new expressive possibilities for a Sustainable Vertical Urbanism.

Responding to Occupancy

All too often, tall buildings' façades set out to standardize the diversity of functions and occupants within. Cost constraints, manufacturing standards and construction methodologies, as well as architects' formal interests in creating compositions that bring classical order, legibility and identity to our urban environments have all played significant roles in homogenizing the design of tall building enclosures. If you doubt this point, consider this: try to draw from memory where the change in use occurs in any of the tallest mixed-use towers in Shanghai. Not one has a façade that provides a clue.

A 390-foot-tall residential tower in construction in Brooklyn, New York demonstrates how data-driven design can lead us away from this universalism toward more particular, customized design solutions that are no less cost effective or arresting in their expressive potential. Located at the foot of the Brooklyn and Manhattan Bridges, this 300,000 square-foot mixed-use development is comprised of a 32-story residential rental tower and a 9-story hotel that defines the street wall of a major street linking the burgeoning DUMBO neighborhood to downtown Brooklyn. Working closely with residential brokers, a three-dimensional parametric model was developed to account for unit and room types, views, prescriptive glazing and natural ventilation regulation as well cost effectiveness and rent rate data. Optimum exterior window wall panel, glazing and natural ventilation sizes and areas requirements were also integrated into the model.

Initial three-dimensional view calculations and massing analysis quickly confirmed that maximizing the height of the project to capture the extraordinary views of Manhattan yielded the highest value for the project. Blocking and stacking of unit and room types was then analyzed and optimized to yield the highest rent roles. (See Figure 4). Unit mixes and tiers were assessed to meet specific market demands.

The parametric model was then scripted to reassess the quality of specific views in plan and section in conjunction with glazing and the natural ventilation percentages allowed by building and energy codes. Living spaces in the upper floors with the best views reach 80% glazing, while bedrooms in the lower floors incorporate less glazing.

到经过精密日照和视野测算的工作区，以及大片玻璃的中庭。在剖面上，幕墙顺滑地由架在市政绿色大道之上的建筑腹部延伸开去，演变成多种三维的遮阳和围幕轮廓，及平滑的屋顶面板。立面的多变性让建筑的功用清晰易读，并直接使所遇见它的人进入关于建筑和环境及其周遭关系的对话。

虽然南澳医卫所只有五层楼高，其立面设计所使用的数据驱动的设计工具和方法却特别适合应对高层建筑的设计机会与限制。各种有关功能、朝向和环境的差异巨大的参数间复杂的交叉影响在此得到最强烈的表达。高响应性的高层建筑立面将重建我们城市的多重维度，并为可持续的垂直城市孕育极大的新可能。

响应使用者

多数情况下，高层建筑立面将内部功能和使用者的多样性进行统一。造价限制、生产标准和施工方法，以及建筑师对于创造融和传统秩序、可识别性和在城市环境中的个性于一体的造型的兴趣，这些都在高层建筑立面设计的统一中扮演了重要的角色。如有疑虑，回想一下那几座上海的地标高层综合体是如何处理使用功能转换的区域。它们无一在立面上给出一丝线索。

正在建造中的一座位于纽约布鲁克林，高390英尺的住宅塔楼，则就显示了由数据驱动的设计如何使我们摆脱这种统一，而走向更为独特，为客户量身定制的设计解决之道。既符合成本效益，又释放建筑立面的表现潜力。这座位于布鲁克林桥和曼哈顿桥桥头的30万平方英尺的综合体是由一座32层公寓楼和一个9层的酒店组成的，它形成了连接生机勃勃的DUMBO社区和布鲁克林中心区的街道立面。通过与住宅经纪人的紧密合作，一个三维参数化模型建立起来，用以综合考虑户数和户型、景观、幕墙玻璃和自然通风的规范要求，以及造价和租金数据。优化的室外窗墙面板、玻璃和自然通风的尺寸和面积要求也被整合在了模型里。

最初的三维观景的计算结果和体量分析，能够很快的得出最大化项目的高度可以尽可能多的捕捉曼哈顿的美景，从而最大限度体现这个项目的价值。体块和单元及户型的排列组合则依据获得最高租金的原则进行分析与优化 (参见图4) 。单元的组合和分类也遵从特定的市场需求而定。

随后，对这个参数化模型进行脚本编辑，结合建筑和能耗规范所允许的玻璃面和自然通风比率要求，对平面和剖面上特定景观的质量再次评估。高区具有最佳景观的起居空间，达到80%为玻璃幕墙，而低区的卧室会有较少的玻璃。塔楼的东界墙依据规范只允许不超过20%的玻璃幕墙。为了曼哈顿的景观，设计采用了从

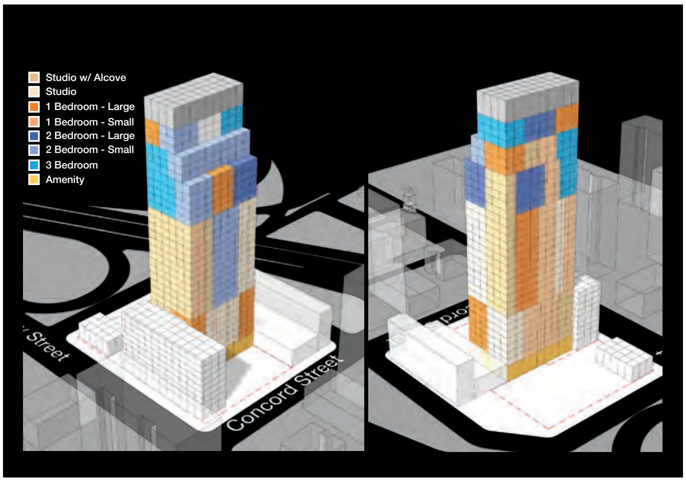

Figure 4. Brooklyn Residential Tower: Axonometric of building massing with unit type analysis. (Source: Woods Bagot)
图4. 布鲁克林住宅大厦: 建筑体块轴测图与住宅单元类型分析 (来源: 伍兹贝格)

Party wall regulations at the east face of the tower allowed a maximum of 20% glazing. With all glazing uniformly extending from floor to ceiling in response to the vector of views toward Manhattan, the width of glazing and profiled metal panel units vary along and across all of the façades. Further scripting established a maximum number of glazing sizes and panel types to ensure modularity and cost effectiveness. (See Figure 5). Perimeter structure, vertical heat pumps and other building systems were integrated into the model and were significant parametric determinants. As with SAHMRI, model outputs will be used to generate fabrication protocols and reduce fabrication and erection costs.

The result is an ever evolving façade that expresses the varied uses, views and values of the project while reinforcing the singularity of the tower's sculptural form. The steady rhythm of the hotel façade that contains repetitive guest rooms gives way to the more particular and differentiated façade of the residential tower that appears to swell and constrict horizontally and vertically in response to shifting internal and external parameters. By embracing the specificity of occupation and use through robust data-driven design, this project charts a path in which façades can be more responsive to the programmatic diversity that enlivens our cities.

Responding to Orientation

Each level of a tall building has the opportunity to draw from an array of environmental parameters which vary widely by orientation and height. Wind, sun, rain and temperature differ on each face and at every elevation. While builders and architects have incorporated climatically responsive strategies for millennia, data-driven design provides tools and methodologies that support new levels of integration, optimization and expressiveness.

One William Street, a new 220-meter-tall 5-Star Green Star tower rising along Brisbane's riverfront for the Queensland State Government, integrates façades strategies that extend the rich tradition of external shading in the region. Situated on a prominent urban site between the city and the Brisbane River, the three-sided plan affords a majority of each floor spectacular southern views of the river while the third face incorporates multistory sky gardens that support a highly collaborative workplace environment. Extensive physical and energy modeling analysis refined the building form to reduce direct solar gain by seven percent over a more conventional tower form and decreased lateral forces due to wind and the structural tonnage needed to resist them.

The façade is tailored to the unique shading requirements of each face. Horizontal and vertical exterior sunshades extend from the aluminum curtainwall system in depths that vary around the perimeter of the tower to address specific solar angles and heat loads. (See Figure 6). Vertical sunshades are deepest at east and west exposures, decreasing incrementally in depth on the north and south exposures. Horizontal sunshades extend farthest at north exposures and decrease incrementally as the façade curves gradually around to the south. With the building's primary orientation rotated in relation to the sun's path, this play of variability produces an ever-changing façade that expresses directly the tower's relationship to the sun. Deep vertical sunshades along east and west orientations of the tower transform continuously around the curves of the façade, first into shallower grids of vertical and horizontal shading elements before transforming again into horizontal sunshades. (See Figure 7). Further energy modeling has shown that this shading strategy yields a twenty percent reduction in peak solar load.

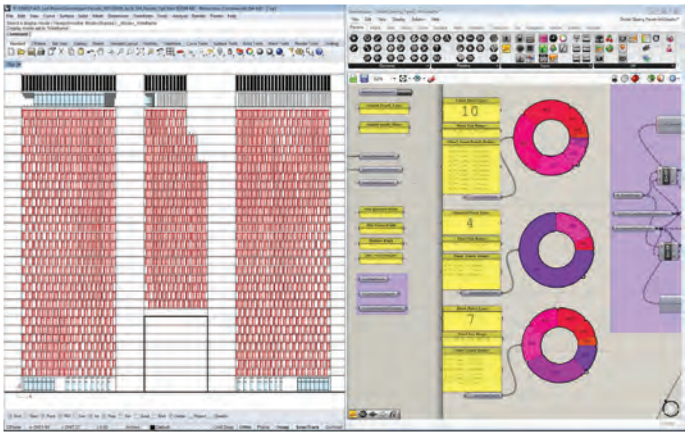

Figure 5. Brooklyn Residential Tower: Parametric visualization. (Source: Woods Bagot)
图5 布鲁克林住宅大厦: 参数的可视化 (来源: 伍兹贝格)

地板到天花通高的玻璃面，而玻璃面和压型金属面板的宽度则在各立面上不尽相同。进一步的脚本编辑确定了幕墙玻璃的最大尺寸和金属面板的类型，以确保模数化和经济性 (参见图5) 。围护结构、管道和其他的建筑系统也被整合到模型里，成为重要的参数的决定因素。如同南澳医卫所，模型的输出可以用来生成装配制造的草案，减少生产建造成本。 随后，对这个参数化模型进行脚本编辑，结合建筑和能耗规范所允许的玻璃面和自然通风比率要求，对平面和剖面上特定景观的质量再次评估。高区具有最佳景观的起居空间，达到80%为玻璃幕墙，而低区的卧室会有较少的玻璃。塔楼的东界墙依据规范只允许不超过20%的玻璃幕墙。为了曼哈顿的景观，设计采用了从地板到天花通高的玻璃面，而玻璃面和压型金属面板的宽度则在各立面上不尽相同。进一步的脚本编辑确定了幕墙玻璃的最大尺寸和金属面板的类型，以确保模数化和经济性 (见图5) 。围护结构、管道和其他的建筑系统也被整合到模型里，成为重要的参数的决定因素。如同南澳医卫所，模型的输出可以用来生成装配制造的草案，减少生产建造成本。

最终的结果是一个不断演化的立面，实现了建筑的多种功能用途、景观视线和项目的价值，同时强化了建筑雕塑般造型的独特性。均匀节奏的酒店立面反映了内部重复的客房布局，也反衬了住宅塔楼立面因应不断变化的内外参数而展现的水平和纵向收放。通过强大的数据驱动设计对住户及功能的特性的探究，这个项目开辟了一个新的途径，来使建筑立面更好的响应空间功能的多样性，以活跃我们的城市。

响应朝向

高层建筑中，每一层都可以根据千差万别的高度和朝向产生一系列环境参数。风、光照、雨和温度在每个立面和标高上不尽相

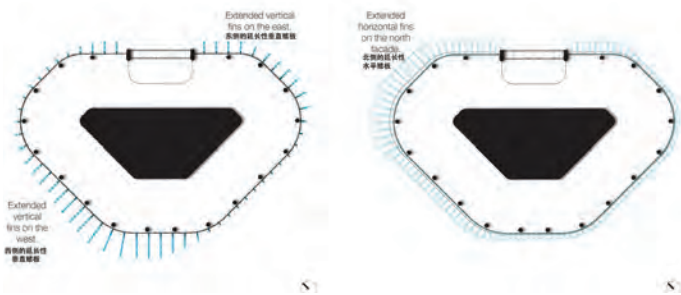

Figure 6. One William Street: Diagrammatic plan illustrating the parametric sunshading deployment (scale is exaggerated). (Source: Woods Bagot)
图6. 威廉街一号: 图解平面说明参数化遮阳系统 (比例有夸大) (来源: 伍兹贝格)

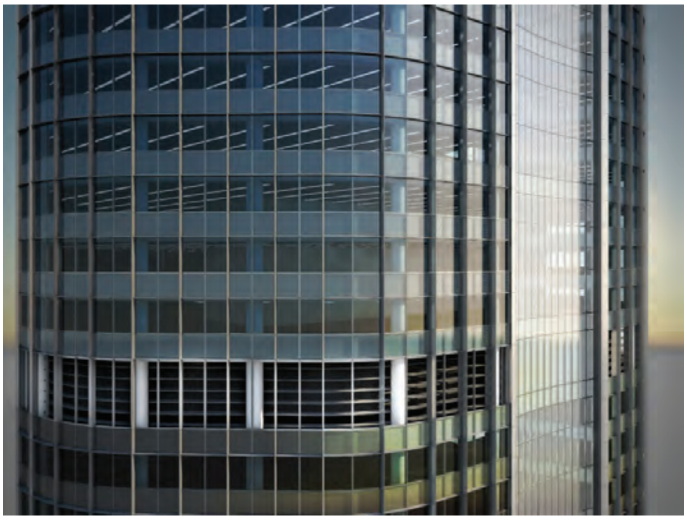

Figure 7. One William Street: Rendering of façade. (Source: Woods Bagot))
图7 威廉街一号: 立面效果图 (来源: 伍兹贝格)

Responding to Context

In addition to responding to an array of programmatic and environmental parameters, tall building façades must interface with their urban habitats and respond to the characteristics of the city, building adjacencies and urban grain that vary widely from place to place as well as from one side to another and from one elevation to the next. Data-driven design provides additional tools and methodologies to create a single, integrated design environment for tall buildings and the urban context they reside within.

The Four Seasons Hotel and Residences within the Delhi One development in India is a recent example that demonstrates the potential of responding directly to an urban context in the design of tall building façades. The Four Seasons Residences occupy three towers ranging in height from 28 to 39 stories and are situated within a dense urban development with four other high-rises. Reinterpreting the tradition of the Jali in Indian architecture, the three cruciform towers are wrapped in an oval of terraces and screens. (See Figure 8). This threshold between inside and outside mediates the heat of the sun and provides a wide array of outdoor social space for the extended families who will call these residences their home.

Following the initial briefing, blocking and stacking of the residential units, a three-dimensional parametric model was developed that integrated unit and space types, privacy and view considerations, annual solar heat gain as well as passive shading from adjacent towers. (See Figures 9). Modular screens were then arrayed across the façades with densities and geometries tuned to optimize these parameters. More public living spaces incorporate less densely spaced screens while private spaces integrate more densely spaced screening. The highest densities screen services, support areas and building systems. Lower floors that receive direct sunlight have higher density screening elements to ensure privacy while higher floors in the same orientation have lesser densities. The passive shading one tower lends to another was calculated throughout the year and yielded areas to eliminate screening elements all together. Through the placement of screens to address views and shading between towers, each tower responds to the other and expresses their interdependence.

In the same development, the new Four Seasons Hotel extends this exploration of façade design in response to its immediate urban context. Situated among a number of high-rise buildings, this 26-story

同。千百年来，建筑师和营造者已经合作对气候做出各种响应措施，而数据驱动设计则提供了新的工具和方法来支持更新层次的整合、优化和表现。

威廉大街一号，一座崭新的220米高的五星级绿色之星塔楼沿布里斯班河岸拔地而起，它是为昆士兰州政府所设计的，立面融合了当地室外遮阳的悠久传统。项目坐落在城市和布里斯班河之间一个位置显著的基地上，三边形的平面可以让每一层的大部分空间都看到南边的河道景观，而第三个面与一系列多层的空中花园结合，提供高度协作的工作环境。大量的实体和能量模型分析完善了建筑造型，直接日照得热相比传统塔楼减少7%，侧向风压力以及相应结构的重量也得以减小。

立面依据每一个建筑面对遮阳的不同要求而度身订造。水平和垂直的室外遮阳板从铝制幕墙延伸出来，深度沿塔楼周边不尽相同，以应对特定的光照角度和热负荷 (参见图6) 。垂直的遮阳板在东西两侧最深，在南北两侧逐渐变浅。水平方向上的遮阳板在北侧向外延展最多，并随着立面弧线转向南侧而逐渐减小。由于

Figure 8. Four Seasons, Delhi: Floor plan of oval of terraces and screens. (Source: Woods Bagot)
图8 新德里四季酒店: 椭圆露台与幕墙的平面图 (来源: 伍兹贝格)

Figure 9. Four Seasons, Delhi: Unfolded elevation mapping screen panel types. (Source: Woods Bagot)
图9 新德里四季酒店: 立面幕墙面板类型展开图 (来源: 伍兹贝格)

tower splits service and elevator cores at each end of the oblong tower where proximity to adjacent buildings is closest and views are most compromised (See Figure 10). Guest rooms are arrayed along northeast and southwest exposures with premium views. The split core also efficiently and effectively allows the tower's concrete building structure to slope around a large ballroom and banquet rooms placed directly under the tower footprint due to the constrained site.

Again reinterpreting the Jali screen in Indian architecture, the façade is comprised of vertical screens placed in front of floor-to-ceiling glazing. In core and service areas, these screens, made of perforated, anodized aluminum in varied bronze hues, are rotated parallel to the exterior wall cladding the solid masonry walls or mechanical louver areas behind. The continuity of the building's surface and curvilinear form is strengthened through the scripting of the vertical screen and panel geometry across each floor in continuous increments. This imparts to the façade an appearance of being set in motion: the building seemingly opens to views, closes along adjacent building frontages and, around the next bend, opens again. The depth and geometry of each panel is calibrated to specific uses, solar angles and views, animating the façade further. The result is a façade responding to a rich, three-dimensional matrix of varied parameters, including the dynamic expression of its urban context (See Figure 11).

Chongqing Tower, a 431 meter-tall, mixed-use tower in central China, integrates a transformative façade to respond to entirely different programmatic, climatic and contextual parameters. Composed of a six-story retail podium, a 32-stories of commercial office, a 28-stories of residential condominiums and crowned by a 23-story 5-star hotel, Chongqing Tower is conceived of as a direct expression of its mix of uses. Each use occupies a floor plate optimized for efficiency, effectivity, flexibility and daylighting. Each block of uses is then stacked one on top of the other with gaps between each that become places where the occupants, as well as building systems, come together: double-height sky lobbies have access to terraces; outrigger and belt trusses efficiently increase the lateral support of the tower; the gaps "confuse the wind" and minimize vortex shedding and lateral loads; and mechanical systems "breathe in and out" the air that is circulated throughout the building.

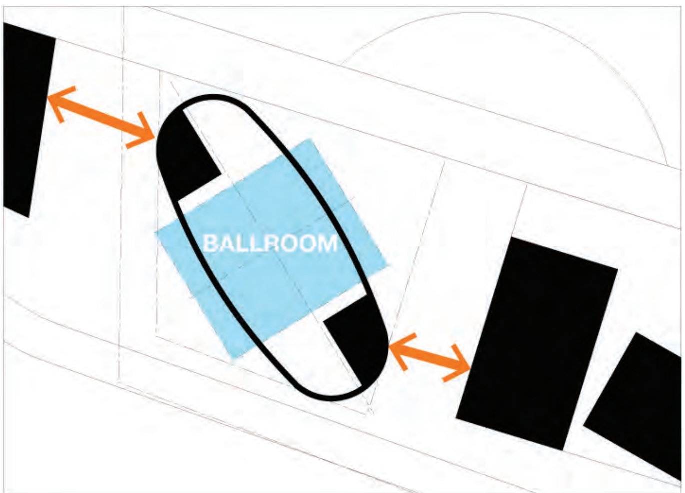

Figure 10. Four Seasons, Delhi: Plan diagram illustrating the tower's relationship to adjacent buildings. (Source: Woods Bagot)
图10 新德里四季酒店: 平面图说明塔楼和相邻建筑的关系 (来源: 伍兹贝格)

建筑的主要朝向依据日照路径而定，这一渐变的设计产生了不断变化的立面，清晰点明建筑与太阳之间的关联。东西朝向的深垂直遮阳沿着幕墙曲线不断演变，先是变成较浅的水平和垂直网格遮阳，进而又转变为水平遮阳 (参见图7) 。进一步的能量模型分析显示，这一遮阳设计减少了20%的高峰日辐射负荷。

响应周边环境

除了对一系列功能和环境参数的响应，高层建筑的立面必须与其所在城市环境相交流，并响应城市、相邻建筑和城市肌理的特质。而这些特质又处处不同、面面各异，从一个立面到下一个立面都不尽相同。数据驱动的设计提供了另外一种工具和途径为高层建筑项目及其所处的城市文脉创建一个单一综合的设计平台。

印度德里一号项目内的四季酒店和公寓是一个新近的案例，能很好的演示在高层建筑立面设计中直接响应城市文脉。四季公寓由三座28层到39层高的塔楼组成，和另外四座高层同处一个高密度的城市开发项目之中。通过对印度建筑中迦利 (Jali，一种透空石雕，译注) 传统的重新诠释，这三座十字平面的塔楼包含在椭圆形的平台和帷幕之中 (见图8) 。这一介乎室内外之间的空间平衡了热辐射，并为居住在此的家庭提供了一系列的室外社交空间。

依据最初设计要求，切分叠合住宅单元，建立起一个三维的参数化模型，其中综合了不同的单元和空间类型，私密性和观景的考量，以及日照得热和来自相邻塔楼的被动遮阳 (参见图9) 。随后模块化的帷幕应用于立面，并在密度上和几何形式上根据这些参数调整。相对私密的空间会有较为密集的帷幕，公共起居空间的则会相对稀疏。密度最高的帷幕覆盖后勤服务区域及建筑设备系统。受阳光直射的低区楼层有相对密集的帷幕确保隐私性，而相同朝向的高区楼层的帷幕就稀疏一些。经过对全年塔楼间互相遮挡的计算，部分区域的帷幕被完全取消。通过帷幕的调整，塔楼间的景观和遮阳得以解决，而每个塔楼即相互呼应又彼此独立。

在同一个开发项目内，新四季酒店的立面设计将这一探索延伸到对临近城市文脉的响应。由于坐落于众多高层之间，这座26层的

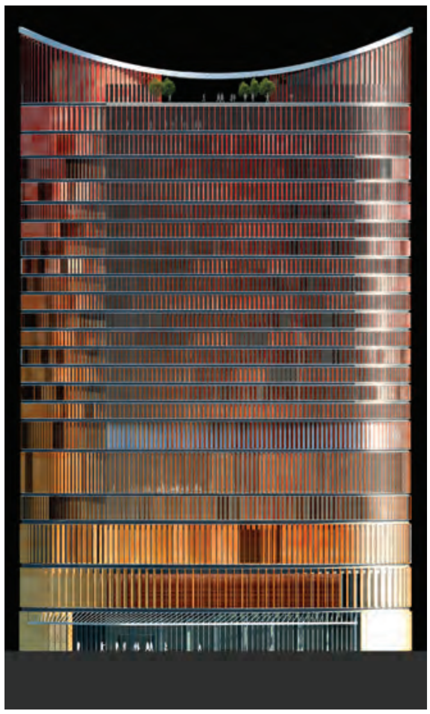

Figure 11. Four Seasons, Delhi: North elevation. (Source: Woods Bagot)
图11 新德里四季酒店: 北立面 (来源: 伍兹贝格)

The façade extends this elementalist concept through an array of vertical stainless steel rods situated in front of the curtainwall glazing. Their purpose is threefold: they provide shading and screening tuned to the uses, the environment and the urban context, they respond to the unique character of diffuse daylight in Chongqing by capturing and magnifying light while controlling glare and they provide a framework for dynamically lighting the building at night and participating in the extraordinary tradition of celebrating the civic pride of Chongqing's citizens each evening.

The scale, density and rhythm of the rods vary first by solar orientation and view parameters. (See Figure 12) High solar loads and privacy requirements call for a denser screen; low solar loads and expansive views call for the screen's elimination. The screening at building systems and mechanical plant rooms transforms to meet ventilation requirements. At the retail podium, screens transform into dynamic signage and drop away at storefronts. High in the tower, where solar orientation allows, the screens are eliminated, transforming the tower from its more solid, textured base into a smooth, crystalline form.

This transformative façade registers its urban context as well. Parametric modeling integrates the surrounding context and adjacent buildings as well as their uses and view corridors. Passive shading and privacy requirements from these existing structures were mapped across the new tower façades, yielding a further transformation of the screen's density. Where new commercial spaces are adjacent to neighboring residences, in plan or elevation, screening is increased to enhance privacy. Street level view corridors and intensities of occupation in surrounding streets were also mapped to locate urban-scaled signage.

Like Hong Kong, Chongqing has a rich urban tradition of celebrating its unique geography and culture through a nightly demonstration of architectural lighting. The façade of Chongqing Tower integrates LED lighting into the vertical rods, projecting the dynamic interplay of occupation, orientation and context across the city each evening. The lighting is also programmed to subtly shift its color and intensity to mark the lunar calendar and respond to the civic traditions that it measures.

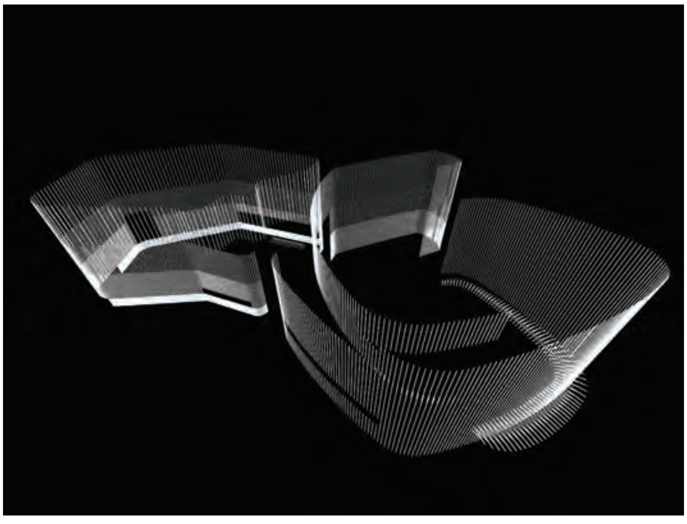

Figure 12. Chongqing Tower: Diagram of screening elements at podium. (Source: Woods Bagot)
图12 重庆塔: 裙房幕墙元素图解 (来源: 伍兹贝格)

酒店将后勤与电梯芯筒分置于椭圆体塔楼的两端，这里最接近周边高层，景观视野限制最大 (参见图10) 。客房朝东北和西南方向布置，以便拥有最好的景观视野。由于基地的限制，分开的芯筒也有效的使塔楼的混凝土结构得以斜绕过位于塔楼下的大宴会厅和宴会包房。

为了再次重新诠释印度建筑里的迦利，建筑立面包括了一个竖向帷幕，其后是地板到天花通高的幕墙玻璃。在芯筒和后勤区域，以不同黄铜色穿孔电镀铝材制作的帷幕板与外墙平行，用于覆盖实体砖墙或其后的机械百叶。通过垂直帷幕和面板的几何形体在每层的逐渐连续递增，建筑表皮的连续流畅和曲线形态得以强化。这使得建筑的立面被赋予动态的外观: 建筑的表皮在视野好的地方打开，在与相邻建筑正面相对的时候闭合，然后又在下一个转折处再次打开。 每个面板的形状和深度都依据具体的用途、太阳角度和视野而定，这令立面更显生动。其结果便是建筑立面对丰富的三维参数的响应，包括对其城市文脉的动态表达。(参见图11)

高431米的重庆塔，一座位于中国中西部的综合体塔楼，通过对完全不同的功能、气候和文脉参数的响应，形成了一个变化的立面。项目功能众多，包括一个6层的商业，32层的办公，28层的住宅公寓和顶端23层的五星级酒店。对此，重庆塔的设计构想是对其混合功能的一种直接表达。每个功能相应的标准层设计都充分考虑了使用率、高效性、灵活性和充足的自然采光。每个功能区块依次叠放，中间的间隔区域成为人们聚集的场所，而设备系统也集中于此: 双层通高的大堂可以通向露台; 伸臂和带状桁架有效的提高了塔楼的横向支撑; 间隔区域"迷惑了风向"并且减少涡流和侧向荷载; 而设备系统"呼吸着"环绕整个建筑的空气。

建筑立面通过位于幕墙玻璃前的一系列立式不锈钢杆件使得元素式的概念得到延伸。这一设计有着三重含义: 顾及功能、环境和城市文脉，杆件有效的提供了遮阳; 针对重庆独特的漫射日光，杆件通过捕捉和放大光线并控制眩光; 而在夜间，杆件为建筑提供了动态照明的架构，同时成为每晚重庆市民引以自豪的山城夜景的一部分。

日照朝向和视野的参数决定了杆件的尺度、密度和韵律变化 (参见图12) 。高太阳能负荷和私密性需要密集的杆件帷幕，低太阳能负荷和宽广视野则需要稀疏。设备系统和机房外的杆件帷幕，通过变化满足通风的需求。在商业裙房，杆件帷幕转化为动态的广告标识并在沿街店面之上收住。在塔楼的高处，当日照朝向允许，杆件帷幕被取消，建筑从较实和有纹理的基层逐渐转变成晶莹光滑的形态。

这种变化的立面也是对城市肌理的体现。参数化的模型结合了周边的环境和相邻建筑的同时也结合了它们的功能和景观视线。被动式遮阳和现有建筑对私密性的要求被投射到新的立面上，促使了立面杆件密度的进一步转变。在新商业空间临近周边住宅时，不管在平面还是立面，杆件帷幕的密度得到加大，以提高私密性。街道上的视线和周围街道人流的密集度同样被映射到立面上，以确定城市尺度的广告标识位置。

同香港一样，重庆有着用夜间建筑照明来庆祝其丰富独特的地理和文化的传统。重庆塔的立面将LED灯和竖向杆件结合，在每天晚上用动态的灯光来映射不同使用功能，朝向和文脉的互相作用。同时照明通过巧妙的颜色和强度改变来标记农历日历，以此来响应农历所代表的市井传统。

结论

Conclusion

Data-driven parametric design opens new territory for the exploration of façades that respond more directly to occupation, orientation and the urban context. Designers now have the tools to resolve increasingly complex and expansive design problems within a more iterative, fluid, dynamic and collective work flow. New evolutionary solvers and genetic algorithms can now propose solutions for complex geometric problems with multiple parameters. While these tools and methodologies don't make design decisions, they do provide designers access to more and higher quality data from which to build design intelligence. This design intelligence is scalable and applicable in reconsidering the relationships of tall buildings to each other and to their urban habitats.

Computational and parametric technologies can now be used to evaluate an entire urban ecology and provide designers an environment to think beyond buildings and consider cities as a whole.

数据驱动的参数化设计为探索更直接的响应功能、朝向和城市文脉的立面设计开辟了新的领域。设计师们现在有了新的设计工具，可以用更迭代、更流畅、更动态和更合作的工作流程，来面对日益复杂和膨胀的设计问题。现在，新演进的解决方法和原生算法可以为复杂的几何问题提供多种参数与解决方案。虽然这些工具与方法的技术本身不能作为设计的主导，但是他们为设计师提供了更多更高质量的数据来构建设计智能。这种设计智能可扩展并应用于重新思考高层建筑之间关系，以及高层建筑与其城市栖息地之间的关系。

如今，计算机和参数化技术可以用于评估整个城市生态环境，并给设计师提供了一个可以超越单体本身而把建筑与城市作为一个整体来考虑的平台。