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Design Computation for the 21st Century High-Rise

21世纪高层建筑的设计计算

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Nathan Miller is an associate and design leader at NBBJ. Nathan's professional background combines experience in construction, leadership on international designs, and expertise in applied computation. Nathan's portfolio of work includes international high rise projects, master plans, and corporate headquarters. His projects make extensive use of customized computational tools for analyzing user efficiency, coordinating complex site criteria, and designing high-performance architecture with environmental simulation. Nathan has been also been leading NBBJ in the development and implementation of computational systems for maximizing production efficiency and increasing building performance.

Nathan是NBBJ公司的理事和项目设计师。他的专业背景包括建设施工，对国际设计项目的领导经验，并专长应用计算。 Nathan建筑作品包括国际高层建筑，总体规划，和公司总部等项目。他在项目中广泛使用定制的计算机工具分析用户使用效率，协调复杂场地标准，并通过环境模拟设计高性能建筑。Nathan 还负责NBBJ的计算机系统开发和使用以最大限度地提高工作效率和增强建筑性能。

Abstract

NBBJ projects will be used to showcase a variety of customized computational tools for different aspects of high rise design in the early stages of the design process. This paper will describe the capabilities for tools for master planning high-rise developments, analysis of internal organizations, and feedback loops for creating high-performance façade systems. By augmenting the BIM design and delivery process, parametric scripting and simulation tools are enabling NBBJ teams with the ability to rapidly explore tower designs with unparalleled efficiency and precision in the earliest stages of design. With the power of computation, teams are now capable of discovering new innovative solutions based on criteria for energy, constructability, and aesthetics.

Keywords: Computation, Parametric, Design, Performance, Simulation

摘要

本文将通过NBBJ的项目展示不同定制计算机工具在高层建筑早期设计阶段过程中的各种应用。本文将介绍这些工具在高层建筑总体规划，内部空间组织分析，以及建造高性能外墙系统反馈循环的能力。 通过探讨建筑信息模型（BIM）的设计和交付过程，参数化编程和模拟仿真工具使NBBJ团队在初步设计阶段能够高效准确快速地探讨塔楼设计方案。凭借计算机的功效，团队现在能够基于节能，施工能力和审美等标准发掘新的创新方案。

关键词：计算机、参数化、设计、性能、模拟

Introduction

Parametric frameworks and customized computational processes have become an essential component of NBBJ's design and delivery workflow. The primary role of these emerging capabilities has been to aid the designer in navigating uncertain aspects of an architectural concept and progressively build rigorous, multi-variable frameworks for decision making. This trajectory ultimately leads to the rapid evolution of flexible information models with embedded performance criteria and capabilities for tying into the BIM documentation and delivery process.

In the context of high rise design, computational design allows design teams to engage in an expanded conversation about performance: one that takes into account practical criteria such as site constraints, circulation, and environmental factors within a larger conceptual framework. By closing the gap between conception and performance verification, the computational tools enable a more robust role for the architect in setting the terms of effective design. Practically speaking, the computational processes can also be used help make more unconventional designs attractive to clients through provable

简介

参数化框架和定制计算过程已成为NBBJ的设计和交付工作流程中的关键组成部分。这些新兴功能的主要作用是帮助设计师探索建筑概念中的不确定方面，并为作决策逐步建立严格，多变量框架。通过这一途径，使内建性能标准和能力能够输入BIM文件和交付程序， 最终使灵活的信息模型快速地演变发展。

在高层建筑设计方面，计算机设计使设计团队能够参与关于建筑性能的广泛讨论中：考虑实际工程标准要求，如在较大概念框架中的场地限制，交通流线，环境等因素。通过弥合概念和性能验证之间的差距，计算机工具使建筑师在设定有效设计方面起重要的角色。从实践的角度来说，计算机过程也可以被用来帮助进行非传统设计通过可衡量的度量和投资效益来吸引业主。

计算机方法已被应用在最近一系列的总体规划和高层建筑项目中，成为在不同的尺度和粒度下进行设计探讨的主要工具。在每一个案例中，都有设计问题促使计算程序的采用：

- 总体规划：都市规模的规划复杂性需要采用可扩展的计算机系统来研究城市形态在不同的粒度的变化。定制总体规划工具，使团队能够基

metrics and value gains.

A recent series of master plan and high rise projects have implemented computational approaches as the backbone for design explorations at different scales and granularities. In each case there have been generative problems that have driven the adoption of computational processes:

- Master Planning: The complexity of urban-scale planning has required the adoption of scalable computational systems to study variations in urban form at different granularities. Custom master planning tools are designed to allow teams to quickly gauge massing criteria and urban systems based on precise site constraints, environmental requirements and programmatic configurations.
- Internal Organizations: Clients wishing to evolve their interior operations will often expect the architect to explore multiple programmatic concepts with consideration to human-centered metrics. Computational algorithms are put to use to quickly generate and evaluate different spatial organizations using criteria such as line of sight, travel times, and employee interaction.
- Environmental Simulation: A growing interest and concern of many corporate clients is the architectural response to environmental conditions. Computational feedback loops with simulation tools are implemented to develop design features in direct response to solar heat, daylight penetration, and wind.

This paper will use three case studies to demonstrate the applications, benefits, and outcomes of the design computation process in the context of high rise design. The case studies demonstrate rigorous applications of algorithmic frameworks in early conceptual phases and the impact of computation on the larger design and delivery culture of NBBJ.

Computational Master Planning

The Beijing CBD master plan consisted of 13 sites which were planned as high rise commercial buildings near architectural icons such as the CCTV and China World Trade Center buildings (see Figure 1). At the outset of the competition, each of the building parcels was zoned with height limitations ranging from 100 to 400 meters. In addition, the sites also specified a range of floor area ratios and commercial program variations. In order to efficiently derive schemes which met the site constraints and program criteria a computational system was devised which allowed the user to link the site criteria to 3D parametric massing models (see Figure 2).

To achieve a data-driven feedback loop, a customized design system was devised which linked Excel to the 3D parametric building models. The live communication between data and 3D representation allowed the design team to fluidly adjust massing parameters while being continually informed of the site and program drivers. The 3D parametric models were designed to accept numeric variables for building area, floor area, floor height, and rectangular dimensions. The Excel documents supplied the model with the necessary information to derive an extruded volume in addition to the boundary conditions of the site. If the building mass were to exceed the height limitation or setback requirements, the building mass would report that the mass was not meeting the requirements and that some additional adjustment would be necessary.

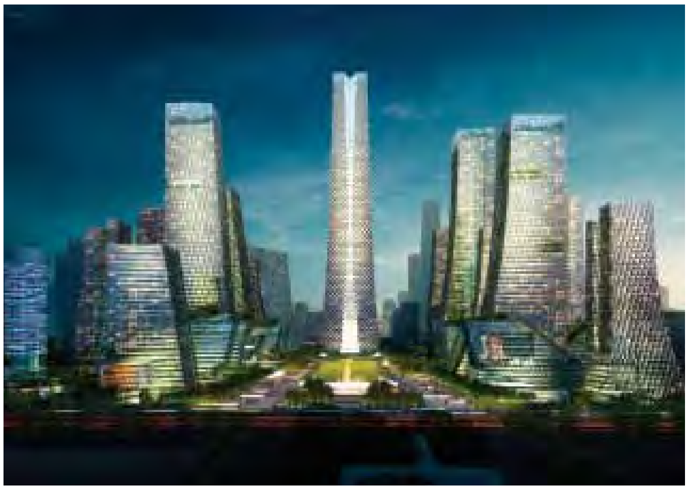

Figure 1. Rendering of NBBJ's proposed Beijing Central Business District master plan. (Source: NBBJ)
图1. NBBJ的北京中央商务区总体规方案渲染图。（资料来源：NBBJ）

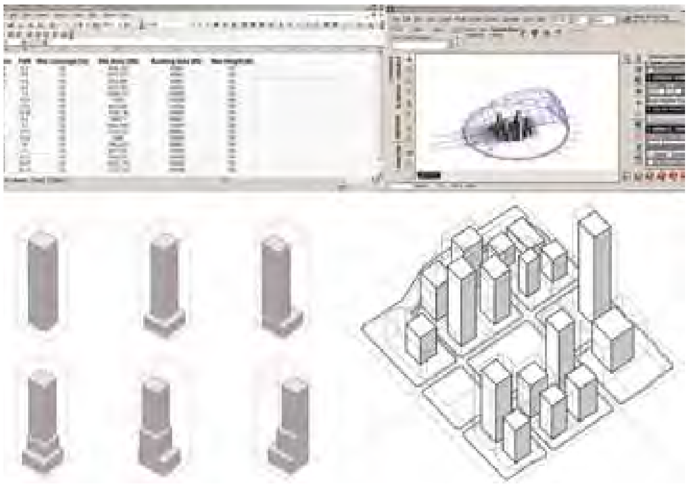

Figure 2. Diagram demonstrating the custom parametric FAR massing tools. (Source: NBBJ)
图2. 示意图展示定制的参数化容积率体量工具。（资料来源：NBBJ）

于精确设定的场地限制和环境要求，以及方案布局快速评价体量标准和城市系统。

- 内部组织：期望发展自己的内部运作的业主往往会希望建筑师探索多种功能概念并考虑以人为本。投入使用计算机算法能够利用视线，行走时间，和员工的互动等标准快速生成和评估不同的空间组织方式。
- 环境模拟：许多企业客户越来越注重建筑对环境条件的反应。带有模拟仿真工具的计算机反馈循环被用来发展直接对太阳能辐射，日光穿透和风作出回应的设计特色。

本文将使用三个案例研究展示计算机设计过程在高层建筑设计中的应用，效益和成果。案例研究展示了在早期概念阶段中对算法框架的严格应用和计算机对NBBJ大型设计和交付方式的影响。

计算机总体规划

北京中央商务区（CBD）的总体规划包括13个计划用于高层商业建筑的地块，与其相邻的是大型标志性建筑，如中央电视台和中国国际贸易中心（见图1）。 在竞赛开始时，每个建筑地块被划分为高度限制从100米到400米不等的区块。此外，地块还有指定的容积率范围和商业功能变化。为了高效地生成符合场地限制和功能标准的设计方案，在设计中使用了计算机系统，它允许用户链接场地标准和三维参数化体量模型（见图2） 。

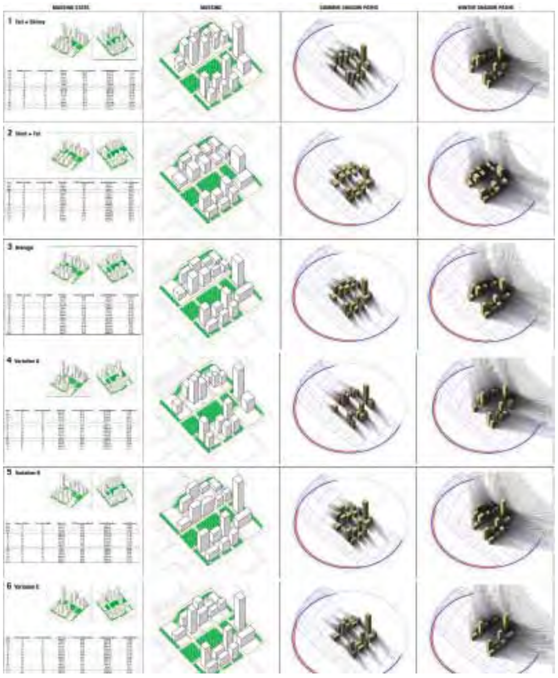

Figure 3. A spreadsheet showing massing alternatives with environmental effects. (Source: NBBJ)
图3. 电子表格显示不同环境效果下的体量替代方案（资料来源：NBBJ）

Figure 4. Rendering the Tencent Seafront headquarters designed by NBBJ. (Source: NBBJ)
图4. NBBJ设计的腾讯海滨总部渲染图。（资料来源：NBBJ）

In addition to the program and site constraints, environmental analysis and simulation were used to develop the master plan massing and sculpt the urban form. Solar analysis was used to compare different massing distributions based on solar access and self-shading (see Figure 3). A selection of diagrams and reports were created from this process which allowed the design team to make informed decisions about tower massing distribution within the master plan. As the design concepts evolved, the team was able to use the generic tower massing as a baseline condition with which more specific architectural concepts and narratives could be developed with embedded metrics.

Algorithmic Spatial Analysis

The design of the Tencent corporate headquarters in Shenzhen challenged the conventional podium-tower typology by proposing a workplace environment which hybridized the office program with recreational resources and collaborative functions (see Figure 4). The 'inside-out' approach resulted in a building form which breaks the conventional office tower mass into two slender volumes. The split tower is connected together by large, horizontal 'link' volumes to create the effect of a vertical campus. The links contain recreational programs such as gymnasiums, cafeterias, and conference space. By distributing these functions throughout the tower, the concept created opportunities for discovering new vertical transportation scenarios based on different day-to-day user routines.

In order to better understand the programmatic organizations within the volume, elevator stops, transfer floors, and floor plate circulation were mapped within the 3D design model (see Figure 5). A network-analysis algorithm based on "A*" was used to compute travel distances and efficient travel paths for the elevator core configuration. This allowed the team to study and diagram different possible user movements over the course of a working day. The visualizations helped the team compare efficiency variables and determine areas of high traffic. Graphically, the tool became a communication device for conveying the different spatial organizations to the client (see Figure

为实现了数据驱动的反馈循环，采用定制设计系统将Excel链接至三维参数化建筑信息模型。三维模型和数据之间的瞬时沟通允许设计团队顺畅地调整体量参数同时不断获得场地和功能控制参数。三维参数化模型设计接受数字变量，如建筑面积，楼层高度，和形状尺寸。 Excel文件提供场地的边界条件和产生建筑体量模型所必需的信息。如果建筑体量超过高度限制或退界要求，建筑体量会报告其不符合要求并需要作一些额外的调整。

除了功能和场地限制，环境分析和模拟也被用来发展总体规划和塑造城市形态。日照分析被用来根据日照角度和阴影分布比较不同的体量分布（见图3）。 从此过程中建立一系列示意图表和报告，这使得设计团队能够对于塔楼体量在总体规划内的分布做出明智的决定。随着设计概念的演变，该设计团队能够以通用的塔楼体量作为基准条件，并根据内建的条件来发展更具体的建筑概念和表达。

算法空间分析

深圳腾讯公司总部的设计对传统的裙房塔楼类型提出了挑战，该项目建议设计一个兼有办公，休闲空间和其他辅助动能的工作环境（见图4）。 “由内而外”的设想使建筑形式打破传统的办公大楼体量， 一分为二， 成为两个细长体量。分开的塔楼相互以大型的水平“链接”体量连接，创造出一个垂直园区效果。链接包含休闲活动，如体育场馆，餐厅和会议空间。通过将这些功能分布在整个塔楼中，此概念为根据每天不同使用者的路线产生新的垂直交通方案创造了可能性。

为了更好地理解体量内的功能组织，三维设计模型记录了电梯停靠，转换楼层，楼层流线等信息（见图5）。 基于“A *”的网络分析算法被用来计算交通距离和有效交通路径， 并以此确定电梯核心筒的配置。这使团队可以研究和标示出不同的用户在一个工作日中可能存在的运动模式。这些可视化效果帮助团队比较效率变量和确定交通流量较大区域。它成为与业主沟通不同空间组织的视觉工具（见图6）。 基于原有的概念，Arup公司的垂直交通工程师所作的详细的模拟电梯方案和交通计算，允许团队开发一个有效的系统，以满足客户的需求，同时保持原有的概念。

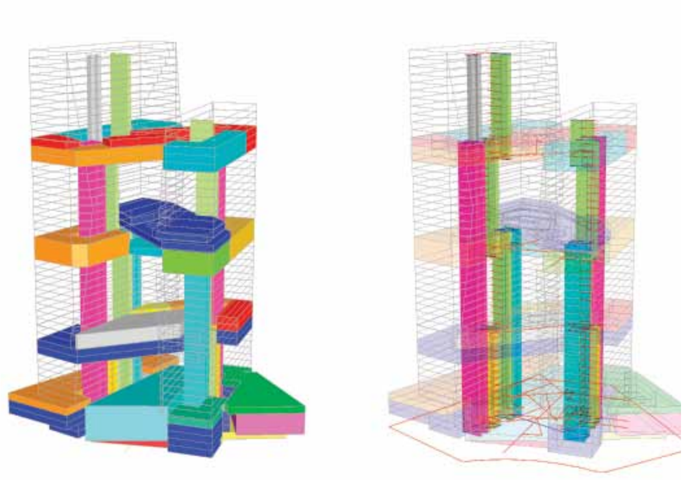

Figure 5. X-Ray views of the headquarters showing interior programming and core complexity for the linked tower. (Source: NBBJ)
图5. 总部X-射线图显示相连塔楼的室内功能和核心筒的复杂性。（资料来源：NBBJ）

Figure 6. User scenario diagrams were produced using A* path analysis algorithms on the tower circulation network. (Source: NBBJ)
图6. 使用A＊路径分析算法制作在塔楼流线网络上的用户活动示意图（资料来源：NBBJ）

6). Building upon the original concept, detailed simulation of elevator options and travel calculations led by Arup's vertical transportation engineers allowed the team to develop an efficient system to meet the client's needs while maintaining the original concept.

The capability to analyze and measure the performance of the space with respect to human experience is a key conceptual driver for evolving the use of computational tools within the firm's architectural practice. The initial implementation of the network analysis tools as a conceptual driver has also led to the development of other spatial analysis and user experience tools in other projects (see Figure 7). For example, a series of tools were created to analyze line-of-sight and evaluate the intelligibility of spaces based on obstructions. Additionally, the subject of user experience has led to early investigations into the use of agent modeling and 3D gaming engines to better understand and explore the function of spaces.

Solar Simulation for Façade Design

This corporate headquarters will serve as the new home of a major electronics company in Beijing (see Figure 8). The tower is a 260m

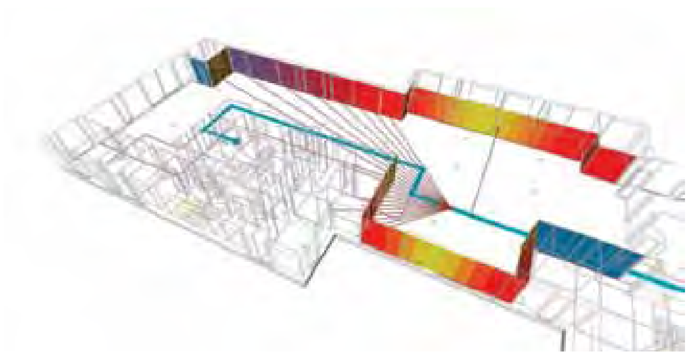

Figure 7. Different user experience tools have been developed to create visual analysis of sightlines, intelligibility and path of travel. (Source: NBBJ)
图7. 开发不同的用户体验工具，以建立视线，清晰度和移动路径的可视化分析（图像来源：NBBJ）

Figure 8. Rendering of the Beijing Samsung Center designed by NBBJ. (Source: NBBJ)
图8. NBBJ设计的北京三星中心渲染图（资料来源：NBBJ）

根据用户经验来分析和衡量空间性能是该公司在建筑实践中发展计算机工具使用的一个关键理念动力。作为理念推动力的网络分析工具的初步实施也带动了其它空间分析和用户体验工具在其它项目中的应用（见图7），例如，一系列工具被开发来分析视线和根据障碍物来评估空间清晰度。此外，用户体验的主题导致对使用代理模型和3D游戏引擎的早期研究以更好地理解和探索空间的功能。

外墙设计中的日照模拟

该公司总部大厦将作为在北京某一家大型电子公司的新址（见图8）。 这是一栋260米高的塔楼，位于北京中央商务区的中心地带，与中央电视台和中国国际贸易中心等标志性建筑相邻。此塔楼的参赛作品设计是一个有效的方形体量逐渐融入一栋具有动态的裙房并以退台和悬挑的形式来活化街道。塔楼外墙的设计概念是以一种无定形的’云’包裹整个建筑表面并模糊塔楼的矩形边

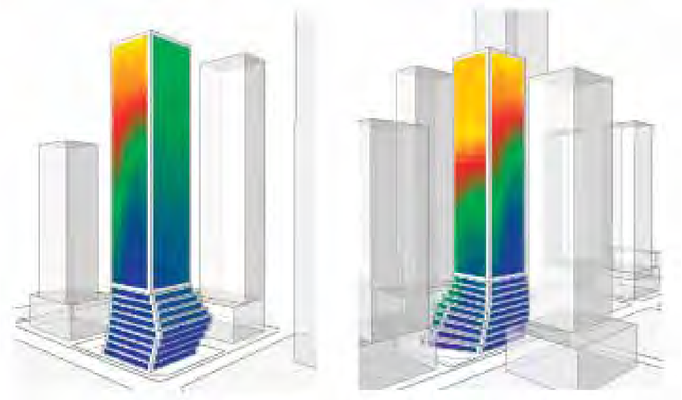

Figure 9. Annual Solar radiation analysis of the tower reveals irregular patterns due to the tall urban context. (Source: NBBJ)
图9. 塔楼的年度日照辐射分析显示由于高层城市环境造成的不规则图案。（资料来源：NBBJ）

high-rise structure and will be located in the heart of Beijing's central business district near architecture icons such as CCTV and the China World Trade Center. This competition entry for the tower is designed as an efficient square extrusion which dissolves into a dynamic podium composed of terraces and overhangs to activate the street. The tower's facade was conceptualized as an amorphous 'cloud' which would wrap the entire surface of the building and blur the boundaries of the rectangular form. Computational processes were used to derive a facade which responded to the solar conditions of the dense urban site. The facade systems were also designed with consideration to constructability constraints and efficient installation.

The design team made use of daylight simulation analysis as a driver for developing a practical, high-performance façade. Working with facade consultants, the design team started with a two-story unitized curtain wall module. The module grid was used as the analysis grid for annual solar radiation analysis which mapped the analysis values on all faces of the building surface (see Figure 9). The building is to be surrounded by towers of similar height which resulted in a unique distribution of solar radiation values across the curtain wall modules. Five variations of custom ceramic frit patterns were developed and arranged on the facade according to solar exposure and opacity. Highly exposed areas would have a higher density of frit. Areas in shade would have very little or no frit.

The variations in solar exposure became the genesis of further development of modulated surface patterns (see Figure 10). For additional user control, the computationally generated facade allowed the design team to exaggerate the solar exposure values and weave other gradient patterns into the parametric drivers. This approach gave the designers flexibility to develop detailed 3D design models while still being able to explore alternatives which remained true to the original performance drivers (see Figure 11).

Conclusions and Future Work

Clients for high rise architecture—especially those clients who are able to invest brand-specific end-user buildings—demand holistic, visionary, and practical designs. It falls to the architect, therefore, to prove the value and feasibility of design decisions while balancing the complexities of multi-variable frameworks and larger conceptual ideas.

As demonstrated by the Beijing CBD master plan, a computational approach can be used to rigorously implement site constraints and program criteria into a flexible design framework. The capabilities offered by this kind of system allow the designer to rapidly iterate

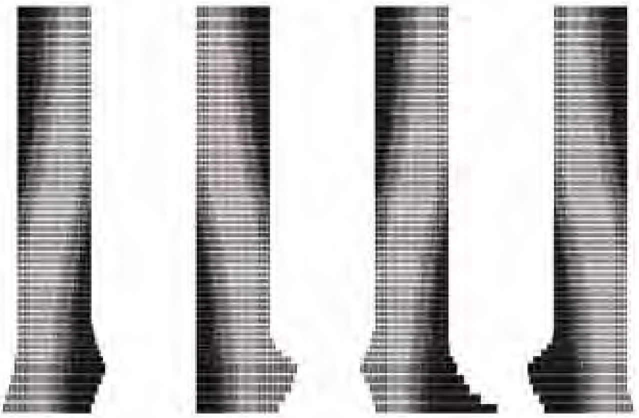

Figure 10. The elevations of the tower were developed using a parametric system which allowed the designer to integrate solar analysis values and explore gradient overlays. (Source: NBBJ)
图10. 开发塔楼外立面使用参数化系统设计，可允许设计者结合日照分析值并探索渐变图案覆盖。（资料来源：NBBJ）

Figure 11. The facade concept was realized using a practical and efficient unitized curtain wall with ceramic frit variations. (Source: NBBJ)
图11. 外墙概念采用一个带有不同的彩陶饰点图案的实用和高效的单元式幕墙。（资料来源：NBBJ）

界线。计算过程被用来生成一个回应高密度城市地块的日照条件的外立面。外立面系统的设计也考虑到施工条件的局限和高效的安装。

设计团队利用日光模拟分析来深化设计实用，高性能的外墙。设计团队与外墙顾问合作从两层楼高的单元式幕墙模块开始着手设计。模块的网格被用来作为年度太阳辐射分析的分析网格，分析记录了建筑的各个表面所有的分析值（见图9）。 建筑周围是高度类似的塔楼，这使得在整个幕墙模块上的太阳辐射值分布独特。五种定制彩釉饰点图案根据日光辐射和透明度被设计和排列在外墙上。高度辐射区将有高密度的彩釉饰点。而在阴影区则有很少或没有饰点。

日光辐射的变化成为进一步发展模数化表面图案的基础（见图10）。 为了提供额外的使用控制，计算机生成的外墙允许设计团队放大太阳辐射值并将其它渐变图案输入到参数化驱动程序中。这种方法使设计者能够灵活地深化详细的三维设计模型，在保持原有性能驱动程序的同时，仍然能够探索其它方案（见图11）。

结论和未来工作

高层建筑的客户，尤其是那些能够投资专一品牌的终端用户建筑的客户，需求全面的，有远见的，实用的设计。因此，建筑师就有责任证明设计决策的价值和可行性，同时兼顾多变量框架的复杂性和更大的概念想法。

on design problems at the urban scale with embedded metrics. Computational tools can also allow for inside-out approaches to tower design by enabling the exploration and evaluation of interior organizations resulting from vertical transportation and floor plate design. In the case of the Tencent Seafront Headquarters, understanding the office program in relationship to day-to-day user scenarios allowed for the team to investigate new organizations and prove operational performance and evaluate the user experience. The use of environmental analysis as a generative driver is another capability which has given teams the ability to develop facades which are anchored in performance and constructability variables. The Beijing Samsung Center practically implemented solar simulation software to drive the development of a unique aesthetic effect for the architecture.

Future investigations and implementations are sure to evolve from the computational capabilities outlined in this paper. Clients with an appetite for innovation, in combination with designers willing to adopt and develop new processes with provable value, are central to the success of computation in practice.

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北京中央商务区（CBD）的总体规划表明，计算方法可以在灵活的设计框架中严格采用场地限制和功能标准。此系统所提供的功能允许设计人员能够以内建指标迅速说明城市规模的设计问题。计算机工具还允许在塔楼中采用从内到外的设计方法，通过探索和评价由垂直交通和楼板设计产生的内部空间组织来进行设计。以腾讯海滨总部大楼（Tencent Seafront Headquarters）为例，对办公功能与使用者日常活动方式之间关系的理解允许设计团队探讨新的空间组织并证明使用性能和评估用户体验。北京三星中心（Beijing Samsung Center）以实际采用日照仿真软件发展建筑的独特审美效果。

文中所述的计算机在设计中的能力必将会有助于今后研究与应用的逐步发展。期待创新的客户与愿意接受和开发有价值的新设计方法的设计师是取得计算机在实践应用中成功的关键。

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