Computational Methods on Tall Buildings

The Bishopsgate Tower

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This paper summarizes the ongoing research done on The Bishopsgate Tower in the City of London using parametric design methodologies. The process is indicative of how computational methods will develop in the future and help designers find solutions for increasingly complex spaces.

Keywords: *Tall Buildings; Computational Geometry; Building Information Management; Façade Optimization.*

Introduction

In the world of commercial office development two factors are paramount: cost and return on capital. Often these considerations, in addition to technical issues, dictate relatively simple geometric solutions. The breakthrough in this development is achieving complex designs through simple fundamental geometries. These geometries can express architectural ideas while keeping their construction simple. Computer aided design systems enable architects to explore design concepts and integrate aesthetic and programmatic constraints.

Our research focuses on the aspects related to the architectural process of defining and evolving design, within its contextual requirements, using computation. Specifically we present the process we developed and employed in order to address pragmatic considerations, such as the explicit geometric definition of form, the calculation of building performance metrics and the optimization of design domains.

This ongoing research is part of the community's efforts to introduce and integrate cutting-edge digital methodologies into the design practice. We illustrate the potential of these technologies through the documentation of our solution.

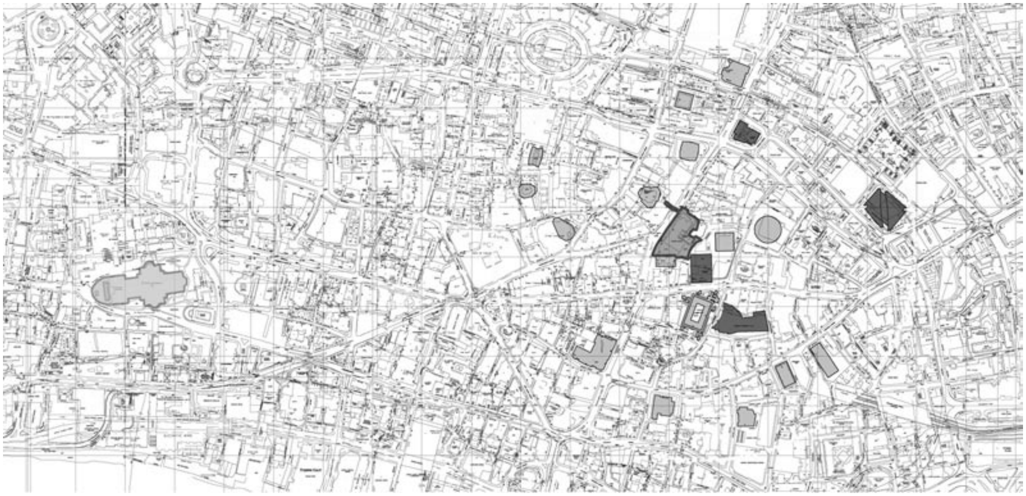
Architectural Description

The computational application was developed by Kohn Pedersen Fox Associates for the design of The Bishopsgate Tower. The Bishopsgate Tower, located at Bishopsgate and Crosby Square will become one of the most significant new buildings in the City of London with a design that will strengthen the overall character and identity of the emerging cluster of tall buildings in this location (Figure 1). The proposal will make a substantial contribution to the public realm, opening up the ground level area to pedestrians and linking a number of important urban spaces along Bishopsgate and St. Mary Axe.

Contextual Considerations

The overall design is highly location-specific resulting from the combined pressures of a very large office building (approx 1,000,000 sq. ft.) situated in the heart of the City of London. The design is responsive towards planning considerations related to its impact on both the overall townscape of London and

Figure 1
The Site in the City of London



the immediate urban fabric. In addition, it addresses several environmental considerations related to energy efficiency and natural ventilation.

The distant views from the Thames dictated that a distinctive profile was required, while the closer townscape views demanded that the form should be more visually fragmented. The effects of a rectilinear volume extending directly upwards from the site's footprint would have been massive; instead a form that diminishes vertically was more suitable. The form is meant to appear very slim and elegant when viewed from its narrowest southwest face, and very imposing when viewed about its wider faces. The basic form springs from a curvilinear canopy extending over the surrounding public space, evolves vertically while slowly reducing in size, and resolves itself into a helical shaped roof (Figure 2).

The refinement of the form evolved around factors related to both the existing built space and its future developments. The inclination of the façades was derived largely by the need to minimize the building's impact on the 'Strategic Views'. For instance, the view along the Queen's ceremonial route on Fleet Street, showing that the proposed building did not impinge upon the view of St. Paul's Cathedral removed a major point of objection from the Heritage bodies who had actually halted a previous project for a tall building the site by a different architectural practice. In addition, the adjacent proposed building by Richard Rogers Partnership features a distinctive sloping plane on its south façade which called for visual control and tuning of the void space between the two buildings. The springing point and the visual axes of the roof's helix were defined in relationship with the existing 'Tower 42' and the consented 'Heron Tower'.

Figure 2
Townscape View from the Tate Modern

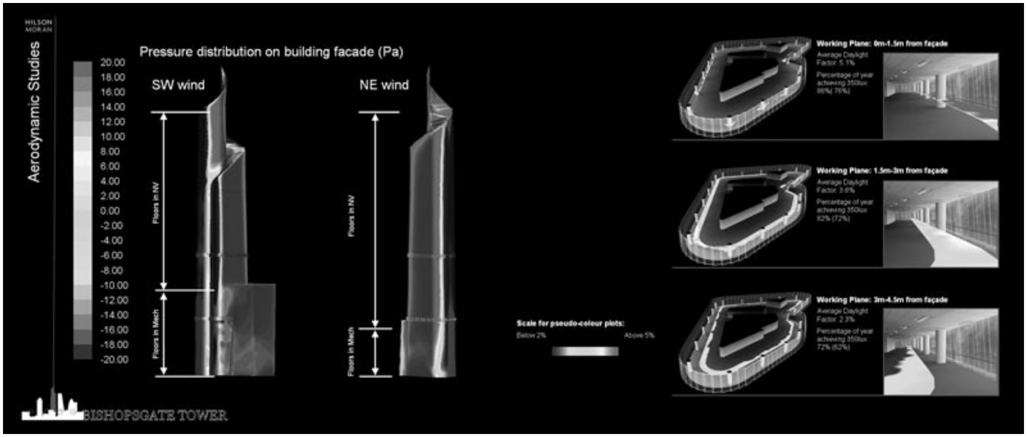


Figure 3
Environmental Analysis of the Snake-Skin Façade (courtesy of Hilson Moran)

Environmental Considerations

Sustainable systems are integral to the architectural design. The aerodynamic shape improves the performance of the naturally ventilating façade with its 'Snake-Skin' design. The outer layer of glass protects the sun-shading which reduces heat gain, and allows for operable windows at high levels (Figure 3). The glass façade allows penetration of ample natural light, thereby reducing the amount of artificial light required. A mixed-mode ventilation strategy optimizes all considerations of energy consumption and internal comfort. A computerized 'Building Management System' constantly reviews and optimizes the building's energy performance. Use of biomass and photovoltaic low and zero carbon technologies are used to further reduce the carbon emissions.

Methodology

The Bishopsgate Tower was designed with the facilities provided by a parametric geometry software; namely 'Generative Components'. We can identify three domains in which parametric design assisted in the development of the project:

a. The formal expression and exploration of the schematic design
b. The building information extraction and evaluation, and
c. The optimization of building performance criteria.

The implementation of the computational solution was developed as a C# plug-in for Generative Components. The selection of the development platform was driven by the need for high-performance and high-flexibility.

Geometric Description

The base geometry was constructed in order to facilitate various layout issues such as the site and office space utilization, the façade modularization and the structural configuration. It was organized as a hierarchical set of geometric concepts expressed as a parametric model. The model was built so that changes at any level of the hierarchy propagate to all downstream dependent geometries.

Footprint Geometry: is defined as a series of linear segments and tangent circular arcs in a spiral configuration. The length of these elements is a multiple of a standard planning module (Figure 4).

Envelope Geometry: is defined as an incremental arrangement of planes and sheared cones. Each planar face is expressed by a tipping factor towards the vertical direction and the edges of the faces are controlled by a pair of tapering factors about the

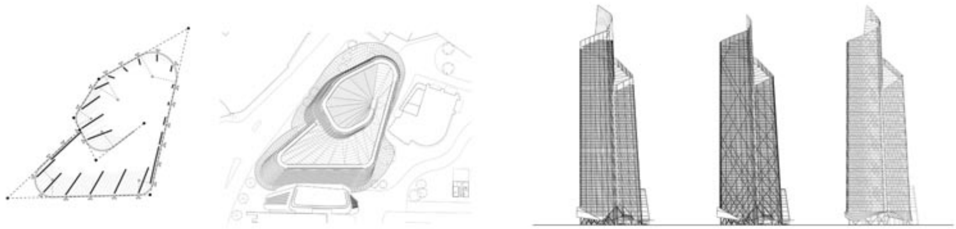


Figure 4
Base Geometry, Envelope Geometry, Structural Geometry

planar basis. The cones are implicitly derived by the edges of the planar faces and the constraint of tangency (Figure 4).

Structural Setting-out: is registered on a geometry produced by an inwards parallel offset from the Envelope Geometry. The column arrangement is defined by a constant stepping in relation to the standard planning module (Figure 4). The column spacing is further fine-tuned by a symmetry constraint about the circular arcs' bisectors.

Diagonal Bracing: follows a set of continuous helical paths springing from the base of the building. The density of the bracing diminishes towards the top subject to structural constraints (Figure 4).

Snake-Skin: mullion-set is generated by a fixed-size façade module marching forward from a registration point per floor. All registration points lie on a vertical edge of the Envelope Geometry. Each panel has an overlap area with its previous and each floor-set of panels is overlapped by its previous floor-set (Figure 4).

Helical Top: is an embedded boundary representation in the Envelope Geometry. The clipping curve, in relation to the Envelope Geometry, is subject to constraints derived by the townscape analysis (Figure 5).

Canopy System: is expressed by a series of arcs spanning from every interval of the notional mullion set. The arcs are tangent to the Envelope Geometry and their endpoints are defined by a 'height from the ground level' and an 'offset from the Footprint Geometry' factors (Figure 5).

Within the parametrically defined system, a very large range of options that are related to overall functional and aesthetic performance of the building were explored and are currently under further refinement. Two prominent characteristics of the basic geometric layout set the grounds for further in-depth research and development in computational technologies for the Bishopsgate Tower, namely the structural configuration of the diagonal bracing (Luebkeman and Shea, 2005) and snake-skin façade configuration described in this paper.

Information Management

A custom-made building information management

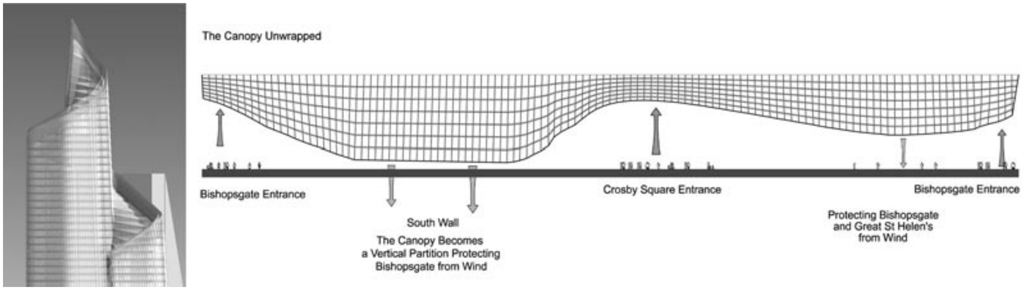


Figure 5
Helical Top and Canopy System

solution was developed for the Bishopsgate Tower to allow the regular evaluation of various design metrics. The computational solution introduced and utilized a variety of experimental methods of design metrics representation.

The parametric model produced calculations which were initially presented in a spreadsheet format. The metrics included primarily floor plan and façade areas, along with various calculations and serializations of members. Two aspects of this system were further developed into new solutions: a metrics publication system through XML data streaming and an automated error detection system.

In the first instance, the need for intuitive and prompt evaluation of the façade optimization metrics led the development of an information publication system using web technologies. During the optimization process, the parametric model produced an enormous amount of information - anecdotally known as the 200 meters long spreadsheet. This ended up being practically impermeable. The need for contextual filtering of information and the intuitive presentation of it, led to the incorporation of a 'data server' module in the same parametric model. The application produced XML data sheets formatted as web pages and published in the local intranet.

In the second case, we observed that in some instances, numerical errors produced by geometric operations affected the generated design information. These numerical stability issues (Shewchuk, 1996) generated a few irregular elements. For this purpose we developed a validation system to prevent visually undetectable discrepancies. Specifically, the parametric model integrated a module that outputted scripting files for the 'Rhinoceros' platform. The scripting file contained a series of commands capable of reproducing the geometry accurately and a set of functions that performed the validation. For example, the script compared all façade panels against their set-out paths as well as with each other for the detection of registration errors.

Configuration & Optimization

The development of a computational solution enabled us to push the design research one step further by integrating optimization processes in our parametric model. The configuration of the façade was performed by a specialized optimization algorithm. In particular, an iterative process was developed that targeted the minimization of the double skin façade's cavity and the maximization of the gross internal area.

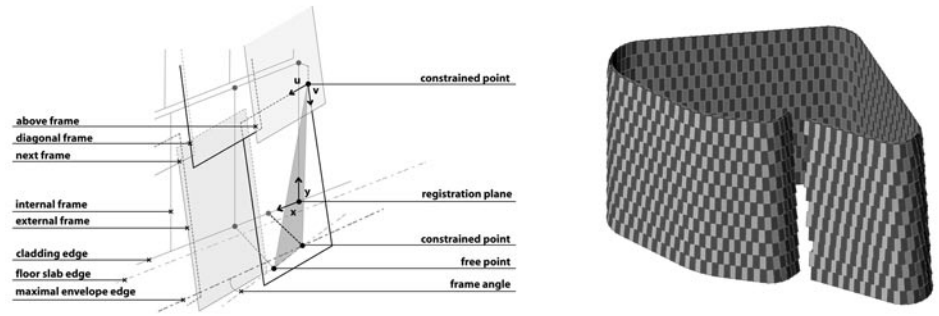
Two basic alternatives were originally explored for the mullion arrangement. The initial idea was of a constant set of mullions per floor, running on top of notional envelope's domain. The base geometry was capable of producing a pre-constrained planar panel configuration. Yet the desire for a regular and modularized façade scheme shifted the attention towards a fixed-size linear set-out solution.

The façade is composed out of a single flexible module type. The module is composed of an internal upright frame, positioned on the slab-edge, and an external spatial frame which registered in space in relation to the internal. Both panels are rectangular and their sizes are constant all along the façade. The internal continuous skin forms the building's enclosure while the external overlapped skin provides weather proofing and natural ventilation.

A thorough study suggested the crucial characteristics of the façade system which were expressed as optimization constraints. The façade module induces a constant misalignment between the mullion-sets due to the perimeter reduction per floor. The cavity is part of the natural ventilation scheme and thus the air in-taking open-edges between the overlapping panels are subject to dimensional constraints. The physical dimensions and functional tolerances of the final members were also incorporated in the optimization's collection of constraints. The challenge of the study was to define a self-optimized panel configuration system that avoids panel-to-panel collisions, achieves tightest packing and visual continuity.

In detail, the upper left corner of the snake-skin

Figure 6
Panel Configuration Diagram



panel is constrained in space by a minimum distance from the spanning floor level and a functional void between the module's panel pair. The snake-skin panel is also constrained by a maximal allowable notional volume around the building (Figure 6).

For setting a snake-skin panel it is necessary to identify the location of three points in space which define the registration plane. With one of them explicitly defined and a second implied, it was practically a matter of a resolving the position of a single point. Three incremental solutions were developed and tested for the layout, each of which redefined the priority of the constraints.

The first solution forced a regularity constraint between the spacing of the internal and external panel and simultaneously a constant dimensional constraint between the external panel and the maximal containing volume. The goal was to achieve exactly the same cavity dimension all around the façade and gain constructional simplicity. The number of modules per floor though is diminishing towards the top of the building due to its constant layout and its inward tapering. This rendered the scheme as practically unfeasible due to the change of curvature around the perimeter which caused panel-to-panel collisions. In addition, the constant spacing relationship by ignoring the subtle curvature characteristic of the notional envelope created visually unpleasant artifacts around the rounded corners of the building.

The second approach amended the constraint of constant spacing and focused on constancy of angle between the set-out path of the internal and snake-skin panels. Thus it incorporated the curvature concerns into the solution space and allowed the external envelope to 'take the turns smoothly around the corners'. Furthermore, the flexibility of a non-fixed cavity opened a modest window of solutions to the collision prevention constraint. The optimization scheme achieved a 19.05% average cavity reduction or 1.23% of gross internal area gain. The obvious benefits of the process led to a third cycle of study.

While both of the first two schemes operated on an 'educated guess' style of optimization, the third one introduced an iterative heuristic search method. In this instance, the constraint of constant distance from the maximal envelope was amended along with the constant angular relationship between the pair of panels. Instead, the actual physical spacing between the snake-skin panels themselves was taken as the driving force of the method. The topology of the skin was examined and three possible collision cases were formalized into procedural evaluators. The locus of panel planes revealed a highly non-linear collision occurrence pattern which necessitated the introduction of a set of numerical solvers.

In detail, the position of an initial seed panel is defined in the end of the sequence of the set-out of the first floor. The following panels resolve their positions in space by iteratively searching for a tightest packing orientation while retaining a minimum distance between the previous panels. This distance is directly related to the physical dimensions of the panels themselves and the ventilation constraints. Graphically, the role of the solver was in fitting the plane of each panel tangentially about a series of distance preserving spheres, hooked on the vertices of the previously placed panels.

The optimization method achieved a 33.34% of cavity reduction or a 2.62% of gross internal area gain. A future development of this method is planned to incorporate global optimization criteria such as cavity regularity constraints which may yield construction simplification.

Computational optimization methods for architectural and engineering design have been presented in the near past (Shea, 2000; Jagielski and Gero, 1997). Geometric and numerical constraint solvers are increasingly embedded in many CAD software packages and the role of these digital methodologies has been delineated in recent publications (Kilian, 2005). The specific design and implementation suggests a methodology of how these technologies may be employed in the resolution of everyday architectural considerations which prove to be quite non-trivial problems.

The optimization of any multidimensional solution space entails numerous cognition-oriented issues which derive from the fact that both the initial conditions of a given problem and its solution domains are typically unintuitive to comprehend (Eilbert, Campbell, Santoro, Amerson and Cannon-Bowers, 1998). Thus, the need for developing intuitive methods of accessing these spaces becomes prominent. The implementation of the algorithm contained several interfacing features targeting the augmentation of the 'educated guessing' process. Instead of blindly shooting the problem with brute-force computational methods, the approach avoided taking the human observer out of the equation. In particular, the geometric elements under inquiry were equipped with 'software sensors' which triggered 'attention events' once violated. The parametric model in response to these events developed 'geometric indicators' around the 'irritated areas' and graphed out diagnostic statistics about the causes of the problem.

This concept of intuitive computational design operators apart from its measurable benefits was also extremely successful in identifying characteristics of the process which were lurking invisibly within the streams of numbers. For instance, we were able to identify the patterns of the problem occurrence in relationship to the base geometry changes. We were able to observe and understand how the optimization behaved over loosely described formal criteria such as the skin's apparent smoothness. In conclusion, the role of this elaborate computational effort was not in itself validated but rather though its ability to let us access the complex domain of the design by expressing simple architectural inquiries.

Evaluation

The evaluation of the presented research will be discussed in relation to its two primary areas of consideration: one that comes from the context of an architectural practice in the development of tall building designs, with strong focus on performance criteria; and another, which springs from an academic endeavor in exploring the potential of digital design media and the modes of the interaction between the designer and the machine.

On one hand, the goals brought about in this research were driven by the need for explicit building performance evaluation and control. These performance criteria among others were economic, environmental and aesthetic. Through our implementation, we identified specific methods of expressing and integrating these diverse criteria through computation. We evaluate as the success of our approach, the gained ability to impose implicit and explicit constraints in both sub-domains but also the entirety of the design space. We understand these results as the evidence of an emerging digital economy and ecology in architectural design: A new mode of thinking empowered by higher cognitive resolution and broader accessibility in the complex domains of architectural design.

On the other hand, the challenge of delivering a computational solution itself brought about several opportunities to investigate the modes of digital design making. The necessities in this case were related with expressive and cognitive criteria: inventing methods for describing certain behaviors, making sense of their results and feeding back the knowledge into the system. The experiment conducted in this case was one of externalized perceptual mechanics: expressing methods of understanding in the form of computational constructs. The strategy behind those was to keep the human – computer interaction open-ended in an attempt to expand the exploration potential while converging to a solution space. The success of the approach was that many previously underlying patterns of the system where revealed and employed in the overall design. In this sense, we envision the future development of architectural design systems that exhibit tighter integration and more sophisticated modes of interaction between the designer and the machine.

Conclusions

In conclusion, we suggest that our research and development of digital design methodologies highlight aspects of the potential of a computation in architectural design which will be widely available in the near future. In fact, many of the domains investigated in this paper are open for further research and development. Our on going efforts are founded on the principles of tighter integration of technologies with the design process and the development intuitive and expressive solutions.

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