Modelling Workflow Data, Collaboration and Dynamic Modelling Practice

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Abstract. This paper details the development of a digital model for a complex, large-scale façade design and presents an analytic framework for approaching design modelling as a case of distributed creative practice. Drawing on digital design theory, philosophy of mind and anthropology, we introduce the framework of cognitive ecology to analyse modelling practice around the façade design for the new IOC headquarters and show how this practice entails the simultaneous development of computational processes and collaborative workflows. Situated across 3XN architects and GXN innovation's internal R&D and design departments, we discuss how dynamic and coupled workflows add value to new forms of collaborative practice that are vitally engaged with extending capacity for computational and creative design thinking.

Keywords: Design modelling · Workflow · Computational design · Cognitive science

Introduction

As architectural modelling matures the scope and implications of its practice evolve. Increasingly, advanced computational tools play decisive roles in architectural design, leading to a profound questioning of relations between creativity and technics, geometry, data, tectonics, and materials (e.g. Oxman and Oxman 2011; Menges 2012; Picon 2010; Terzidis 2006; Kolarevic 2003). While these discussions often centre around formal and technical speculation, the transformative impact of design modelling holds the power to fundamentally restructure all stages in the design and delivery of complex buildings. In this paper, we discuss how computational modelling at 3XN architects and GXN innovation is expanding to entail the design of distributed collaborative processes that transform internal and external workflows at the studio.

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Modelling Workflow

This paper presents the modelling of a large-scale façade design for the new International Olympic Committee (IOC) headquarters in Lausanne (Fig. 1). We discuss how the model developed from a tool for extensive shape research informed by design intent to an environment for integrating complex formal concerns with structural and fabrication constraints as the project developed from a single to a double skinned facade. This data-driven integration of different areas of expertise from designers and collaborators lead to an increasing significance of modelling workflow as well as form.

While form is naturally visible in completed buildings, the workflow and calculations underlying formal expression in finished structures remain hidden—as noted by architect Richard Garber: "[b]uildings alone, especially complex ones, cannot convey the collaborative activities that design teams have developed in the service of construction execution." (Garber 2017, p. 10) On projects like the IOC headquarters, where complex form puts high demands on all partners during both design and construction phases, workflow modelling emerges as a manifest corollary of design and an essential part of project delivery. To perceive the full significance of these complementary sides of modelling practice it is necessary to expand the scope of analysis. Here, we forward an analytic framework integrating elements from computational design theory, philosophy of mind and anthropology to advance the notion that models and modelers not only serve as tools for computational design thinking (Menges and Ahlquist 2011), but also come to act as vital environments for distributed cognitive processes mixing geometry and data in ways that can transform the social and technical institutions of architecture. Shifting the unit of analysis from isolated individuals to dynamic patterns of interaction amongst designers, collaborators, design models and digital workflows will allow for an exploration of cognitive interdependencies within the design studio while facilitating a discussion of the linked modelling of form and workflow (Fig. 2).

Fig. 1. Rendered output of the IOC façade (*left*). Mock-up of the final façade design (*right*)

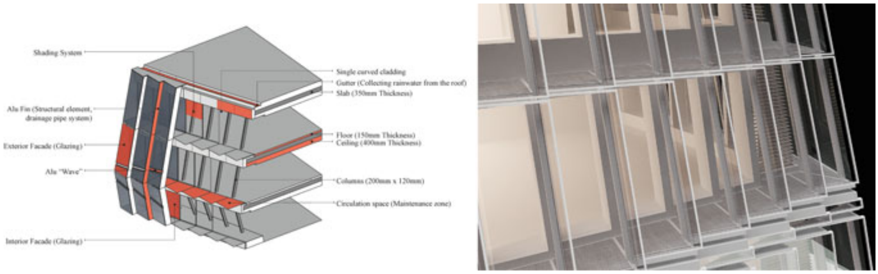


Fig. 2. Some of the complex interdependencies informing design of façade elements (*left*) and section from the façade model (*right*)

Cognitive Ecology

What are the theoretical, methodological and empirical commitments of taking workflow modelling serious? How might we begin to make sense of collaborative processes that are at once computational, aesthetic and material? How do these processes shape architectural imagination and practice? Proponents of digital modelling in architecture have been dealing vigorously with these questions for some time (e.g. Thomsen et al. 2006; Burry 2011; Davis 2013; Oxman 2008), but tend to stop short of analysing modelling as a distributed cognitive process bridging architectural design and construction. However, as design modelling matures, there is much to gain from applying a wider systemic perspective to its analysis (cf. Hight and Perri 2006; Garber 2009, 2017).

Architecture is a deeply distributed practice, intimately bound up with specific worldviews, technologies, materials and institutions, all of which shape creative collaboration. In this paper, we introduce the notion of *cognitive ecology* as an analytic framework for understanding design and workflow modelling across its various dimensions. Cognitive ecology has been advanced in anthropology to explain how the cognitive properties of synthetic or biological systems come to differ from the properties of individuals within these systems (Hutchins 2010, 2005 cf. Bateson 1972). It entails the study of cognition in context; a cognitive ecology describes a bounded system advancing and anchoring collective human thought. In this vein, computational design models and workflows can be analysed as co-constitutive of cognitive ecologies encompassing designers, engineers, software, scripts, and screens as well as organisation and memory of projects and the wider project team. This analytical framework is committed to a systemic perspective and shifts the unit of analysis from the inherent properties of elements within the system (designer, script, software) to the emergent properties of dynamic patterns of interaction between these elements (Varela et al. 1991; Thompson 2007; Malafouris 2013).

The sheer complexity of contemporary modelling practice seems to lend itself well to this type of analysis as computation, mathematics, and simulation become ever more integrated into design thinking. Computational tools bring together diverse teams around the creation of advanced 3D forms by integrating the vast calculations that often

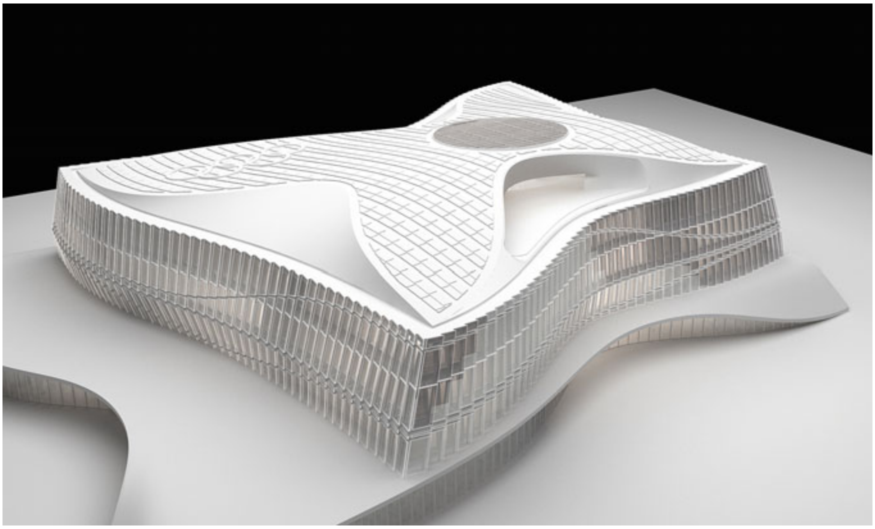


Fig. 3. Full façade model

underlie these into computational systems where geometry translates to data, and data to geometry. This shared informational basis permit functional integration across a range of software environments allowing for modular manipulation, combination and re-use of input and outputs from models across all phases of architectural design and fabrication. Data exchange and dynamic interaction between people, tools, expertise and models lead to emergent designs whose formal and computational properties exceed anything that could be achieved in isolation. In line with an ecological perspective on cognition, it seems the designing mind is vitally collaborative, distributed and emergent in contemporary design modelling (Poulsgaard and Malafouris 2017). Design thinking is empowered by the dynamics of specific modelling environments, models and workflows and creative agency becomes and emergent property, located not in the brain of the individual designer but in distributed transactions within larger cognitive ecologies. This perspective permits extending the analysis of design modelling, to also encompass collaborative workflows, through empirical investigations of the modelling and integration of diverse software, data streams, and areas of expertise during design and construction of complex buildings (Fig. 3).

Case: IOC Façade Model

In 2013, the International Olympic Committee celebrated the 100th anniversary of its establishment in Lausanne, confirming the Swiss town as its base for another 100 years to come by holding an architectural competition for a new headquarters. 3XN architects developed the winning entry as an embodiment of Olympic values with a Scandinavian twist: a context aware dynamic design seeking to merge aesthetics, functionality, and performance. In recognition of the symbolism of the Games and needs of the organization, the new IOC headquarters was designed around three key elements: movement, flexibility and sustainability. The 3XN architects and GXN innovation design and modelling teams has been faced with developing and maintaining this design language while steering the project through design development and construction documentation with a team of expert collaborators.

Modelling Ecology

By using three freeform curves as basis for subsequent façade detailing, the modelling team established and explored parametric links between curves and surfaces in the façade geometry (Fig. 4). Within a short time, the team had constructed a flexible parametric model that formalised design concept in a computational environment; this allowed them to iteratively test geometric impacts of design interventions and fabrication constraints while fleshing out design concept from competition phases during early design development.

This initial exploration sought to establish a workflow that could combine flexibility and speed with high precision in order to meet tight deadlines with collaborators. The dynamic design of the building and façade meant that any iteration could have unpredictable consequences as it scaled through the parametric model while affecting geometric integration, structural integrity, aesthetics, comfort and building performance. To understand and manage these complex relations, the team sought a solution that would tie the specialisation and expertise of design modelling and design development into an efficiently working whole. To do so, the modelling team established a live data structure linking façade model across Rhino and Revit software environments using Grasshopper, Dynamo, Flux and Python to create a two-way data link (Fig. 5). The initial data structure was set up around a comprehensive building grid for locating each individual façade module; additionally, individual modules were assigned four corner points, a perpendicular vector describing its angle and orientation, and a unique id number. This established an explicit data structure allowing for connecting and

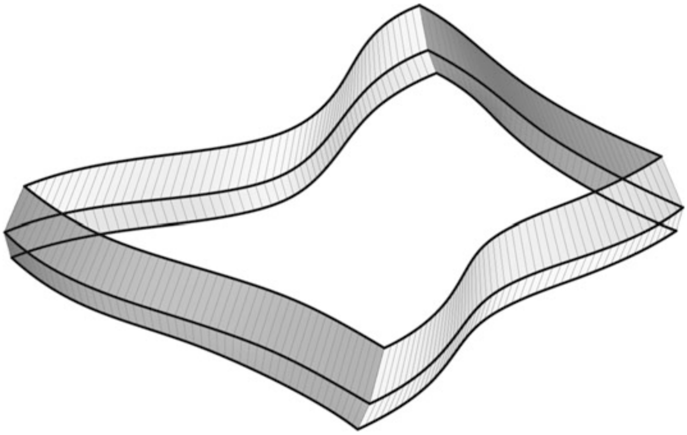


Fig. 4. Three free-form curves guide the global design of the façade model

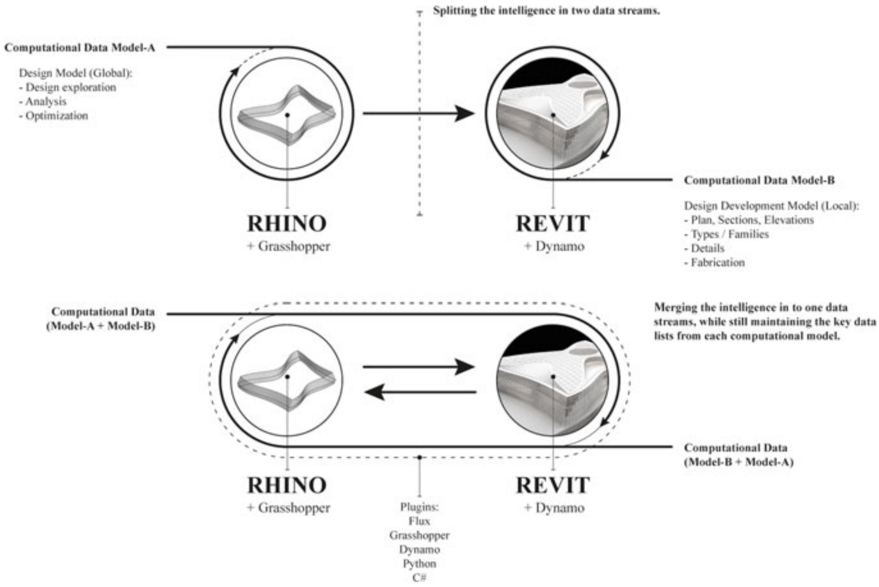


Fig. 5. Modelling environment establishing two-way data feed between Rhino and Revit to keep building intelligence live and able to inform local and global design development

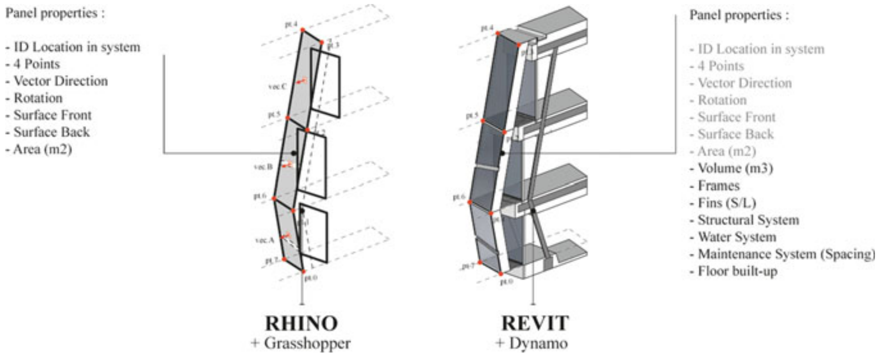


Fig. 6. Predefined data structure linking elements across modelling environments enables iterative integration of element data in Revit while maintaining geometric flexibility in Rhino

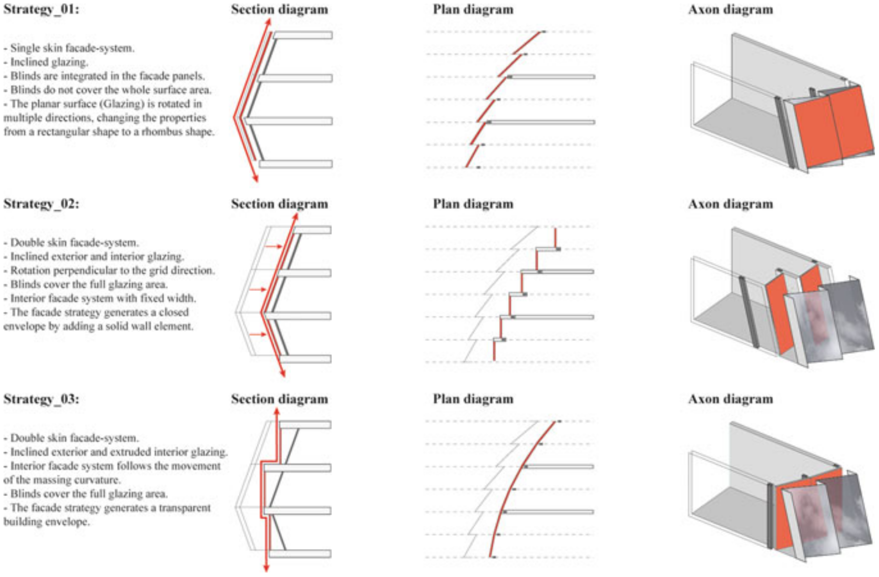
updating elements across the Revit–Rhino environment. This live data connection meant that any iteration, calculation or change in one environment would inform the other. The link established continuous feedback between models, connecting different resolutions of design and detailing; Rhino was continuously used for global and local surface level analysis and optimisation, while Revit was used for local detailing, documentation and type based data flow (Fig. 6). This permitted efficient collaboration with partners and consultants around specific structural problems using Revit while the design team maintained control of overall design expression and modelling in Rhino.

Through this dialectic between local problem solving and global design modelling, the model and workflow integrated aesthetic concerns with technical solutions to problems posed and explored in with a range of collaborators during design development phases.

Iterative Computation

Feedback from façade engineers and structural engineers led to a specific focus on geometric optimisation of façade elements and the introduction of a double-skinned façade to strike a balance between structural performance, maintenance criteria, and aesthetics (Fig. 7). The double-skinned façade placed high demands on both design team and collaborators for developing design and construction documentation while maintaining the overall dynamic expression. As each section of the façade is unique and all elements are computationally connected, this required continuous iteration and control of a wide variety of parameters and their integration; as complexity grew, the model and data structure developed during early design phases proved an essential environment for collaboratively solving the geometry of the complex façade under tight deadlines.

Utilising the linked modelling environment and data structure, 2D sections detailing construction principles for the double-skinned façade were developed in association with façade and structural engineers. These principles initially focused on defining a viable angle domain for the loadbearing steel columns supporting façade and floors (Fig. 8), as well as minimum and maximum spacing between inner and outer skin required for maintenance (Fig. 9).



Strategy_01:

- Single skin facade-system.
- Inclined glazing.
- Blinds are integrated in the facade panels.
- Blinds do not cover the whole surface area.
- The planar surface (Glazing) is rotated in multiple directions, changing the properties from a rectangular shape to a rhombus shape.

Strategy_02:

- Double skin facade-system.
- Inclined exterior and interior glazing.
- Rotation perpendicular to the grid direction.
- Blinds cover the full glazing area.
- Interior facade system with fixed width.
- The facade strategy generates a closed envelope by adding a solid wall element.

Strategy_03:

- Double skin facade-system.
- Inclined exterior and extruded interior glazing.
- Interior facade system follows the movement of the massing curvature.
- Blinds cover the full glazing area.
- The facade strategy generates a transparent building envelope.

Fig. 7. Design research for geometric implications and optimization around introduction of double skinned façade

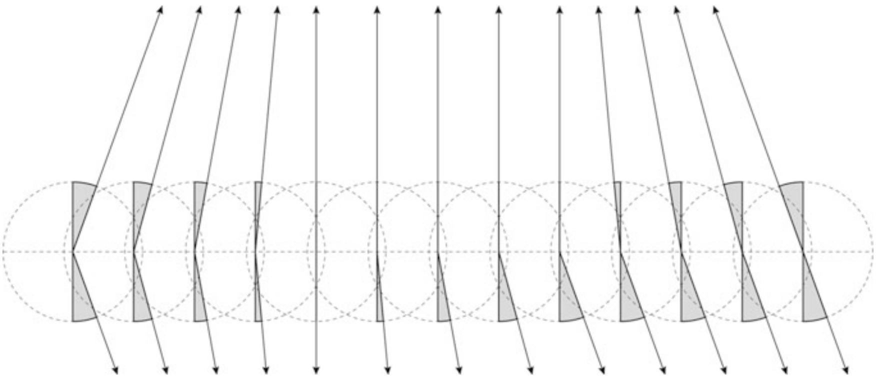


Fig. 8. Exploration of inclination and angle domain for outer façade

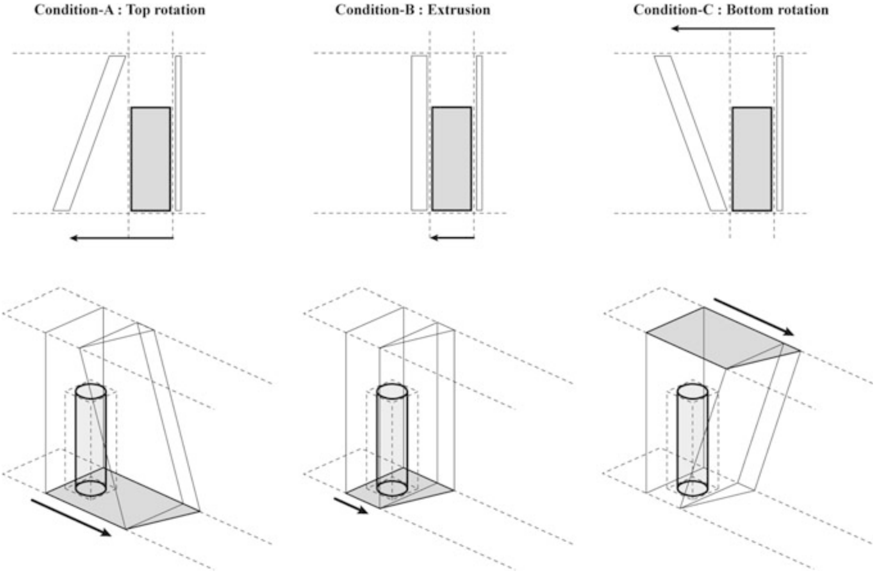


Fig. 9. Computing 3D spacing between interior and exterior skin to meet performance demands

The design team applied these principles across the full 3D model to generate relations between each individual section of the façade following the grid and data structure established during initial modelling phases (Fig. 10). Once these principles where applied at a surface level, the model was used to iteratively circulate data packages to collaborators for additional design detailing and structural computation. Structural engineers received continuously updated angle domains and vectors for calculating structural performance of the façade, while façade engineers received the latest updated surface model, plan outlines and updated area calculations for façade elements and glazing; all partners had access to the full design model as it developed

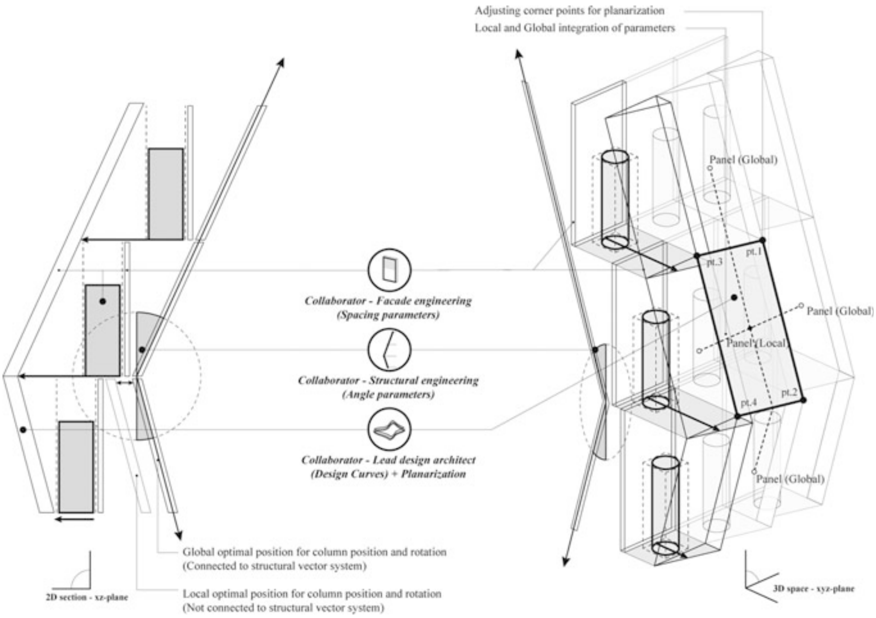


Fig. 10. Local and global integration of structural principles and design parameters across 2D and 3D environments

with time, allowing them to follow the evolving façade as additional parameters and data were added. For each successive iteration, the design team used the modelling environment for comparative analysis and manipulation across form, angle and spacing domains to ensure that all sections remained within the established baseline parameters while also maintaining the global design expression (Fig. 11). In turn, sections and construction details were continuously updated in collaboration with the different engineering teams as more and more detailed information was added to the model: window glazing and frames, dimensions of columns, joints, materials, insulation and so forth. During these stages, design exploration expanded from surface level analysis of the effects of applying specific construction principles to also incorporating actual building dimensions and construction details (Fig. 13). The data structure linking elements across Rhino and Revit environments served as an essential backbone for quick and iterative analysis and exchange of building data during these stages; this proved crucial for enabling both centralised and de-central exchange within the wider team of collaborators by establishing a shared and live frame of reference as the project evolved (Fig. 12).

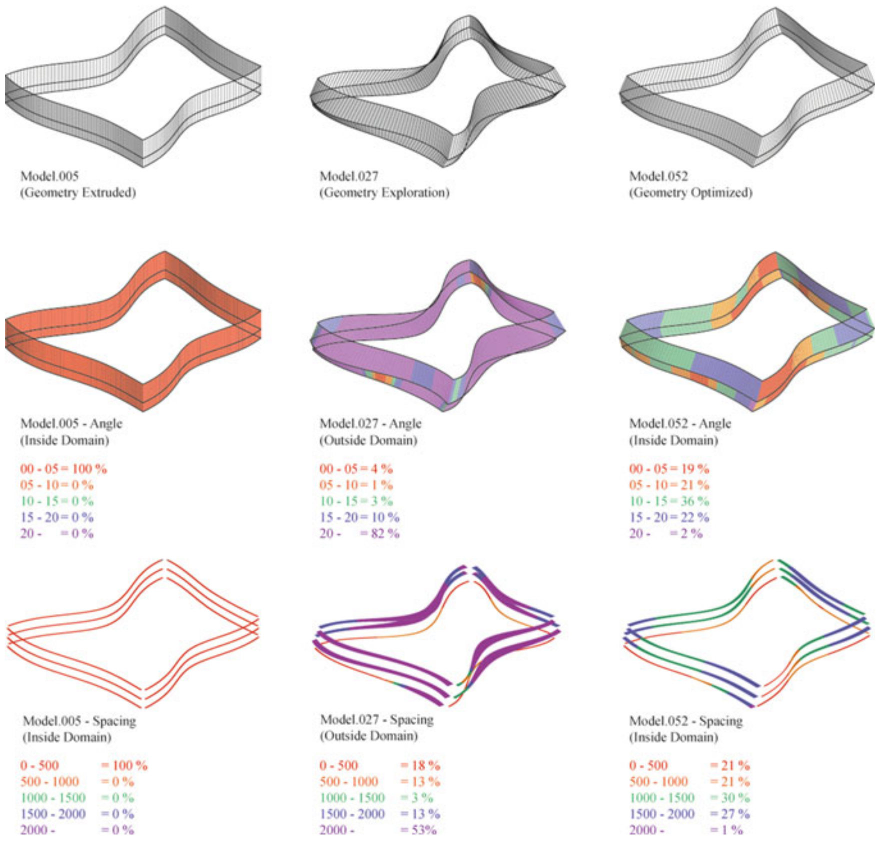


Fig. 11. Iterative design research into form (*top row*), angle (*middle*) and spacing (*bottom*) domains. Comparative analysis across these domains allowed the modelling team to evaluate performance and aesthetics across a large number of design iterations to find the best integration meeting structural criteria while maintaining a dynamic design expression

Discussion: Collaborative Workflow and Cognitive Ecology

Architects Menges and Ahlquist (2011, p. 16) propose that computational design thinking requires a deep understanding of how design models operate as form and as mathematical ordering constructs. In this, the position of the designer is changing as work moves from relative free-form design exploration to rule-based discovery within computational environments (cf. Simon 1996, p. 124; Cross 2006, p. 32). This raises interesting questions about the structuring of creative work within these highly rule bound environments. Combining modelling practice and the framework of cognitive ecology brings to light the co-constitutive relationship between design thinking, model and workflow as they co-evolve, increasing capacity for creative collaboration. We argue that the IOC model and workflow established a cognitive ecology for technical and aesthetic design exploration by coupling the distinct areas of expertise of designers,

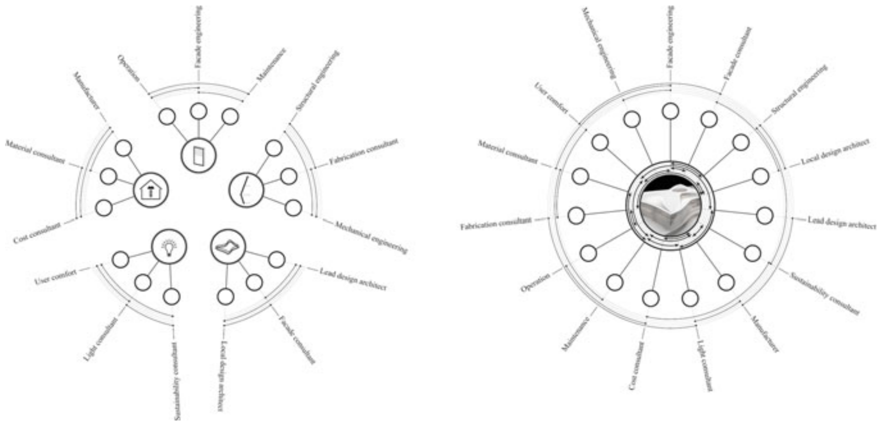


Fig. 12. Contrary to decoupled workflows freezing geometry to distribute subsets of the model (*left*), modelling workflow on the IOC façade, created a coupled system where all elements and data remained online for collaborators via access to a central model during design development and construction documentation (*right*)

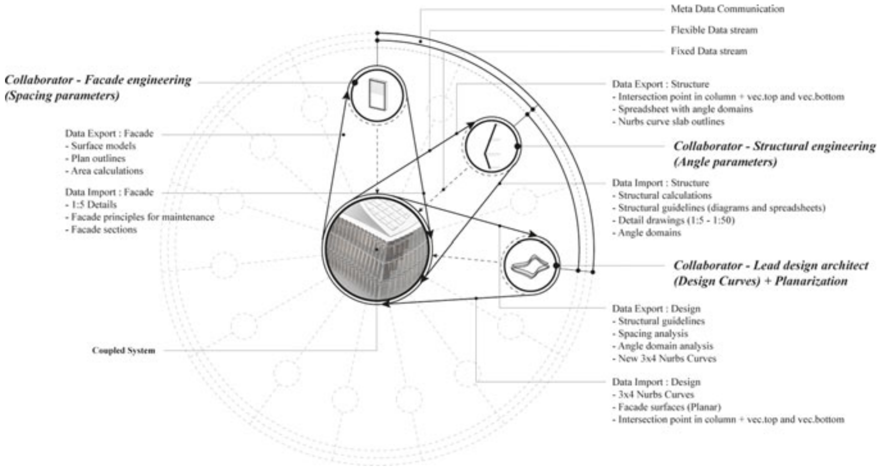


Fig. 13. Iterative computational modelling and evaluation of construction principles around inside and outside angling domain for the interior and exterior skin and spacing between them. This was one area amongst many that was managed and solved via the coupled workflow established by the model

façade engineers, and structural engineers (amongst others) and leveraging the different affordances and possibilities of Rhino and Revit software environments (Fig. 12). This dynamic coupling is integral to computational design thinking and deeply reliant on the simultaneous modelling of form and workflow.

Anthropologist Hutchins (2005, 1995) has shown how the solution of complex problems involving input and expertise from a variety of fields often come to rely on external environments for selective combination and manipulation of these fields. These environments serve as anchors; two or more input spaces are selectively projected into a separate, blended space anchored in materials or technics, which thereby develops emergent cognitive properties not available from the individual inputs. These cognitive ecologies permit collaborators to selectively access, combine and process specific aspects within them while ignoring others and this greatly enhances the emergent possibilities for creative problem solving (cf. Vallée-Tourangeau and Villejoubert 2013). These process often come to rely on material and technical environments that are: "sufficiently immutable to hold the conceptual relationships fixed while other operations are performed," but supple enough to allow continuous manipulation (Hutchins 2005, p. 1562). Modelling and workflow on the IOC project established such a cognitive ecology, allowing for the projection and selective blending of expertise, principles and calculations from designers, structural engineers, and façade engineers amongst others. This relied in part on the establishment of a clear and explicit data structure that acted as a notation system; it set out rules, classes and relations between them, and became integral to structuring collaboration on the complex design project by allowing several collaborators to work within well-established and 'sufficiently immutable' boundaries. However, the linked modelling environment also allowed the manipulation of data as geometry and a more open-ended exploration of how different computational problems and solutions would affect the overall design expression. This helped recast complex mathematical optimisation problems into visually coded on-screen geometry, that could be compared and manipulated on the fly by the design team who thereby maintained control of form and design expression throughout the complex project. The simultaneous rigidity of data driven notation systems and fluidity inherent in the linked modelling environment meant that design exploration and collaboration on the IOC project could move between two poles: at one end was aesthetic interpretation with rich scope for dynamic iteration and change, at the other, the data structure serving as notation system in which the structural options were comprehensively coded. The efficacy of the resulting model and workflow lay in its possibilities for functional simplification, the way it allowed both design team and collaborators to selectively zoom in on, mix and process specific aspects of local and global design development while ignoring others. This permitted research into highly complex and dynamic systems at a human scale allowing the design team to continuously manipulate the model and input of collaborators to find the best fit between optimal performance and design aesthetics.

Properly linked, digital models centralise and decentralise at once. Drawing many diverse actors and expertise into a common infrastructure, they allow for decentralised communication and some autonomy at the edges while also standardising conditions of communication between them. The distributed perspective on cognition emphasise that the emergent properties of a cognitive ecology arise from the dynamic and continuous coupling of elements within it (Hutchins 2010; Varela et al. 1991); in emergent systems there is significant added value in keeping and managing a linked and dynamic ecology rather than a fully distributed one-way setup which lessens feedback flows. At the IOC project, recursive cycles of design exploration with additional data from collaborators

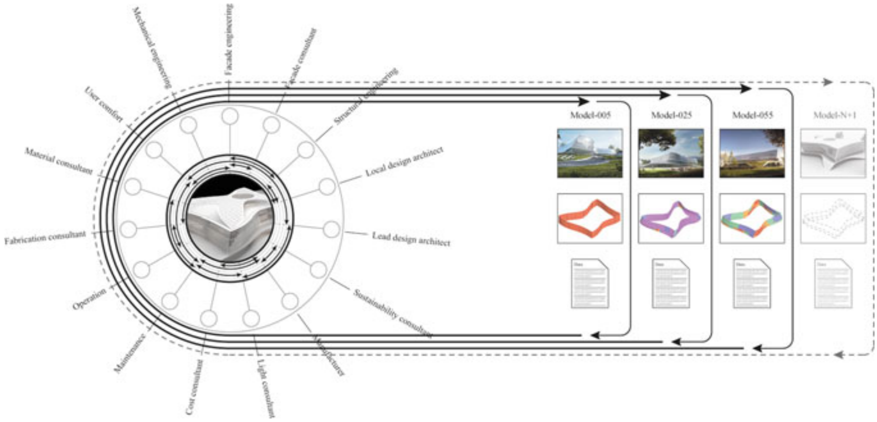


Fig. 14. The IOC model and data structure served as a robust environment for integrating design solutions while creating project documentation at different resolutions; each iteration permitting detailed visualisations, ongoing structural and aesthetic analysis, and updated data packages for servicing individual collaborators

informing each cycle, allowed the full team of architects, engineers and specialists to generate a wider number of explorative solutions for evaluation and selection as the design matured towards construction (Fig. 14). In this way, the dynamic flexibility of the original design intent found its counterpart in the iterative development of design model, workflow and collaborative processes.

Conclusion

As large-scale models mature and incorporates increasing levels of information, the scope and reach of modelling necessarily expands. The IOC model developed from a design tool for extensive shape research, to include additional factors and data as the project developed, including structural behaviour, maintenance conditions and fabrication constraints—all while facilitating creative design thinking and collaborative workflow on the project.

At 3XN architects and GXN innovation, models increasingly become essential nodes in studio practice around complex projects by creating a dynamic environment for ongoing computation of internal and external inputs while also performing as a medium for aesthetic collaboration and communication. To explore the meaning of this shift, we have introduced the framework of cognitive ecology, analysing the co-constitutive relationship between design thinking, modelling and workflow. In this perspective, modelling becomes a hybrid evolving system comprising computational, aesthetic, and structural factors dynamically interacting with each other. This combined approach opens new venues for the study of digital technology and practice within computational design modelling, and for thinking about the relationship between practice, innovation and change within the architectural professional community.

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