Oublier Domino

On the Evolution of Architectural Theory from Spatial to Performance-based Programming

Neri Oxman
PhD Candidate, Design Computation Group
Massachusetts Institute of Technology, Cambridge, MA, USA
neri@mit.edu

Abstract

The conception of the architect as form-giver has since historical times dominated the field of architecture. It is precisely this image which has devalued material practice in the distinction between form and matter consistently inherent in architectural discourse. Recent technological developments in the field of design computation, coupled with environmental concerns and philosophical debates have contributed to the shift in focus from form, as the exclusive object of design practice to matter and materials as an alternative approach to the conception of form. Such a shift calls for a reorientation of existing protocols for design generation. Design based upon performance appears to justify and make sensible computational design processes that integrate material properties with structural and environmental constraints. These processes, as demonstrated here, contribute to the elimination of traditional architectural typologies replaced with spatial organization driven by need and comfort. This paper proposes a new approach in design where processes of form-generation supporting sustainable design solutions are directly informed by structural and environmental constraints. Computational models are developed and implemented that incorporate data-driven form generation. Fabrication tools and technologies are customized to include material properties and behavior. The projects illustrated in this paper are currently on display at the Museum of Modern Art.

1. Modernism: Forgive and Forget

1.1. From Spatial Canons to Material Practice

From the early writings of modern theoreticians such as Giedeon, theories of form have dominated the discourse of architectural modernism[1]. Form rather than performance has been the central locus of practice and theoretical discussion. Performance has been significant in its influence upon form, but only as an agency at its service, rather than acting as the origin of creation. This cultural election of form as an indicator of architectural content has not been exclusive. There have been design experimentalists such as Gaudi, Fuller, Prouvé, and Otto for whom research in material and experimentation has been a legitimate field of design activity[2]. However, form has been such a dominant factor in the culture of modern architecture that it has also affected related fields in design and architectural research. We currently appear to be in a period in which the contribution of material experimentation is emerging as a new locus of theory and research in architecture.

Formal knowledge and the theoretical dominance of spatial typologies have long promoted a mono-functional approach to architectural design as manifested in the early 20's with the establishment of the Modern Movement. Le Corbusier's canonical essay, *Five Points for a*

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[1] Giedion, S. Space, Time and Architecture: The Growth of a New Tradition, Cambridge, MA: Harvard University Press, Fifth Edition, 1941

[2] Drew, P., Otto, F. Form and Structure, Boulder, Colo.: Westview Press, 1976.

New Architecture, formulated in 1926, established the formal content for pre-subscribed functional and spatial canons[3]. Homogeneous distribution of structure and matter were made to serve pre-determined functions in their generic spatial arrangements. These theoretical formulations of generic spatial relationships and of the dominance of spatial over material, or performance conceptions, have long become emblematic of modern architecture.

1.2. Functional Hierarchies: A Pathology

The non-bearing curtain wall façade stands out as a classical illustration of functional and hierarchical separation of the elements of architecture: formal and material attributes are assigned to the structural and non-bearing components. Through the demonstration of several design explorations which promote the distribution of properties in light of their performance, this paper questions the relevance and authority of such canons in the digital age. In doing so, the paper offers a new approach to design based upon performance where material properties and behavior are utilized as integrated formal organizations corresponding to a multitude of structural and environmental conditions.

1.3. Organization

The paper is organized in three sections: In the following section theoretical foundations are presented and discussed. In the third section – a series of relevant design experiments is presented. In the fourth and final section, design implications are presented which speculate upon the outcome of such new foundations of theory and practice.

2.0. Material Based Design

2.1. Performance Based Design, Condition Based Programming

Design based upon performance seeks to promote a multi-functional approach to design whereby matter is distributed where needed responding to its structural, environmental and indeed, social performance[4]. In fostering material integration of architectural elements across various scales, structure and façade are no longer divorced in function and/or in behavior, but rather negotiated through the informed distribution of matter. One significant consequence of design that is informed by performance is the incorporation of material variation: gradients of structural and material effects emerge modulating their thickness, transparency, porosity and thermal absorption according to their assigned function or desired conditions of stability (structure) and habitation (program).

Currently such technologies that support gradient material distributions are analytical rather than synthetic and therefore their generative potential is questionable. However given the possibility to formulate and formalize models enabling these two modes combined, it is possible to conceive of simulation models that integrate performance simulation with design generation[5]. Such an integrated approach would support *performance-based design*.

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[3] Le Corbusier. Vers une Architecture, France: Getty Research Institute, 1923

[4] Kolarevic, B., Towards the Performative in Architecture", in *Performative Architecture: Beyond Instrumentality*, Kolarevic, B. (ed.) New York: Spon Press, 2005, pp.203-214

[5] Oxman N. "Get Real: Towards Performance Driven Computational Geometry" International Journal of Architectural Computing, vol. 5 2008, p.663-684

We introduce arguments for the transformation of architectural design rationale from theories of universal space and programs based on typology to theories of condition-based programming. Such processes allow for the generation of spatial organization based on conditions of habitation, contrary to the traditional typology based approach. It is proposed here that digital design, as it is now evolving, should serve as a catalyst of this transition with unique implications for architectural design. A key characteristic of this process of change is the prioritization of the non-standard over repetition, homogenization and standardization.

2.2. The Function of Effect: Towards Material Based Design

Architectural discourse of the last two decades, supported by digital design technologies and coupled with a renewed interest in sustainability, is now offering an alternative to the dominancy of mono-functional architectural solutions implicit in the modern tradition. Contrary to a design approach which has promoted *divisions of function* between the architectural elements (structure, façade, etc), design based upon performance and conditions of habitation postulates *divisions of effect* (structural, environmental, etc.)[6] Our ability to quantify structural and environmental performance in a building's envelope assumes that differences of use and behavior must be accounted for. Given such ability to predict and respond to performance criteria and desired effects this paper aims at shifting the practice from design typologies dominated by presubscribed mono-functional programs to condition- (or performance) based programming.

2.3. Making Difference: Towards Material Based Fabrication

Traditional CAD (Computer-Aided Design) packages assist architects and engineers in tasks of representation (drafting, modeling etc). As such – these computational methods offer geometry authoring tools that range from 2-D vector based drafting systems to 3-D solid and surface modelers. CAE (Computer-Aided Engineering) packages, parallel to the domain of CAD are used to evaluate the structural behavior of components and assemblies through simulation and optimization processes such as FEM (Finite Element Method) analysis. CAM (Computer-Aided Manufacturing) includes a range of applications to assist in the manufacturing and/or prototyping of product components. CAM functions such as CNC (Computer Numerically Controlled) code generated to drive machine tools are expanding to become more fully integrated with CAD/CAE solutions. Most advanced CAD/CAE/CAM software packages incorporate associative modeling features providing the designer with a method of linking dimensions and variables to geometry such that any transformation in a given variable propagates throughout the entire model. Combined, CAD/CAE/CAM technologies offer a wide range of visualization, simulation and optimization tools. When initiated and informed by pre-determined variables brought about by process or product constraints, the design process carries potential for becoming generative: the designer defines a network of constraints parametrically linked to geometrical features in order to generate multiple options for generation.

Rooted within a design culture inspired and evaluated by formal manifestation, computational geometry has become and still remains an elevated science for architectural production. Triggered by computational developments in the fields of digital design and fabrication, we are now witnessing a shift in method questioning the profession's value

[6] Oxman N. "Material-based Design Computation" International Journal of Architectural Computing, vol. 5, 2007, p.26-44

system. While computational geometry is still central to design practice, computational techniques and technologies enable shift from form-based design to performance-based design[7]. Design processes based on performance rather than pure form, have promoted design protocols integrating form, material, structure and environment. From here, the emerging significance of the physical over the virtual is inevitable. In search for both the theory and practice of performance based design, we are preparing to value distribution over assembly and difference over standardization. Material properties and effects, such as transparency, elasticity, porosity and relative strength are slowly catching up with Cartesian descriptions of space as we know it. Could we hypothesize that in design, form is to geometry what effect is to material practice? And given that such an assumption occupies a legitimate place in the contemporary discourse, what does it entail in terms of the tools and techniques that govern the intensions and processes behind our designs?

Recent initiatives in design computation capitalize upon optimization-based routines using ESO (Evolutionary Structural Optimization). Such methods are based on finite element analysis methods (FEA) capable of optimizing the formal geometry of an object to obtain minimum volume through an iterative design processes under even stress-distribution. However, such analytical methods have rarely been used as generative tools allowing the designer to shift freely between representations and allow, by means of optimization, for difference in kind to occur in addition to difference in degree.

3. Demonstrating Material Based Design

The projects below demonstrate the notion of condition-based programming and *material-based design*[8] through the integration of structural and environmental performance data into form-generating processes. Each project explores unique relationships between material organization and behavior, inherent in their form and attributed to the ways and methods in which these objects have been fabricated. It is precisely this interaction between material organization and environmental pressures that is a novel approach to the genesis of form.

Combined with this aspiration, the projects postulate our ability as designers to exploit digital fabrication technologies as a generative domain for material production[9]. Making is not secondary to from-generation and directly ties to it, beyond its being an agency for production[10].

3.1. Monocoque

Monocoque (French for "single shell") stands for a construction technique that supports structural load using an object's external skin. This stands in contrast with using

[7] Oxman N. “Get Real: Towards Performance Driven Computational Geometry” International Journal of Architectural Computing, vol. 5 2008, p.663-684

[8] Oxman N. “Material-based Design Computation” International Journal of Architectural Computing, vol. 5, 2007, p.26-44

[9] Oxman N. “Fab Finding” Proceedings for eCAADe, Predicting the Future, Frankfurt am Main, 2007, p.785-792

[10] Oxman N. “Rapid Craft: Machine Immanence and Naïve Materialization” Proceedings for IASS 2007, Shell and Spatial Structures: Structural Architecture: Towards the Future Looking to the Past, Venice, Italy, 2007, p.269-276

an internal framework (posts and beams) that is then covered with a non-load-bearing skin. The project demonstrates the notion of a structural skin using a voronoi pattern, the density of which corresponds to multi-scalar loading conditions. The distribution of shear-stress lines and surface pressure is embodied in the allocation and relative thickness of the vein-like elements built into the skin. The composite prototype models represent three strategies for the design and fabrication of single shell structures.

Figure 1. *Monocoque*: illustrated are three fabrication approaches

3.2. Raycounting

Raycounting is a method for originating form by registering the intensity and orientation of light rays. 3-D surfaces of double curvature are the result of assigning light parameters to flat planes. The algorithm calculates the intensity, position and direction of one or multiple light sources placed in a given environment and assigns local curvature values to each point in space corresponding to the reference plane and the light dimension. The models explore the relation between geometry and light performance from a computational-geometry perspective. Light performance analysis tools are reconstructed programmatically to allow for morphological synthesis based on intensity, frequency and polarization of light parameters as defined by the user. The project is inspired by one of the first rapid prototyping technologies from the 1860’s known as photo sculpting. The method was developed with the aim of regenerating accurate 3-D replicas of a given object by projecting multiple prints of different angles and carving them relative to the reference artifact. Photo sculpting employs 2-D projections to regenerate 3-D objects; Raycounting employs 2-D planes as they are informed by light to generate form.

Figure 2. *Raycounting*: SLS nylon models (top) and printed resin composites including structural pockets (bottom).

3.3. Subterrain

The physical features of a terrain represent the distribution and magnitude of the forces that have brought it about. These elements embody the complex relations between physical matter in its given environment and denote its subterranean force field.

The work explores the notion of material organization as it is informed by structural load and environmental conditions. 2-D micro structural tissues are visualized, analyzed and reconstructed in 3-D macro scale prototypes. Computational analysis is used to determine material behavior according to assigned properties and performance such as force, stress, strain, deformation, heat flux and energy such that the tensor properties in atomic scale are kept isomorphic to the morphological pattern. The tissue is then reconstructed using a CNC mill and multiple types of wood composites. Anisotropic in nature, grain directionality and layering are informed by the analysis resulting in a laminated structure which corresponds to a range of loading conditions. Three micro scale biological tissues (a leaf section, a butterfly wing and a scorpion paw) are reconstructed using this generative digital protocol.

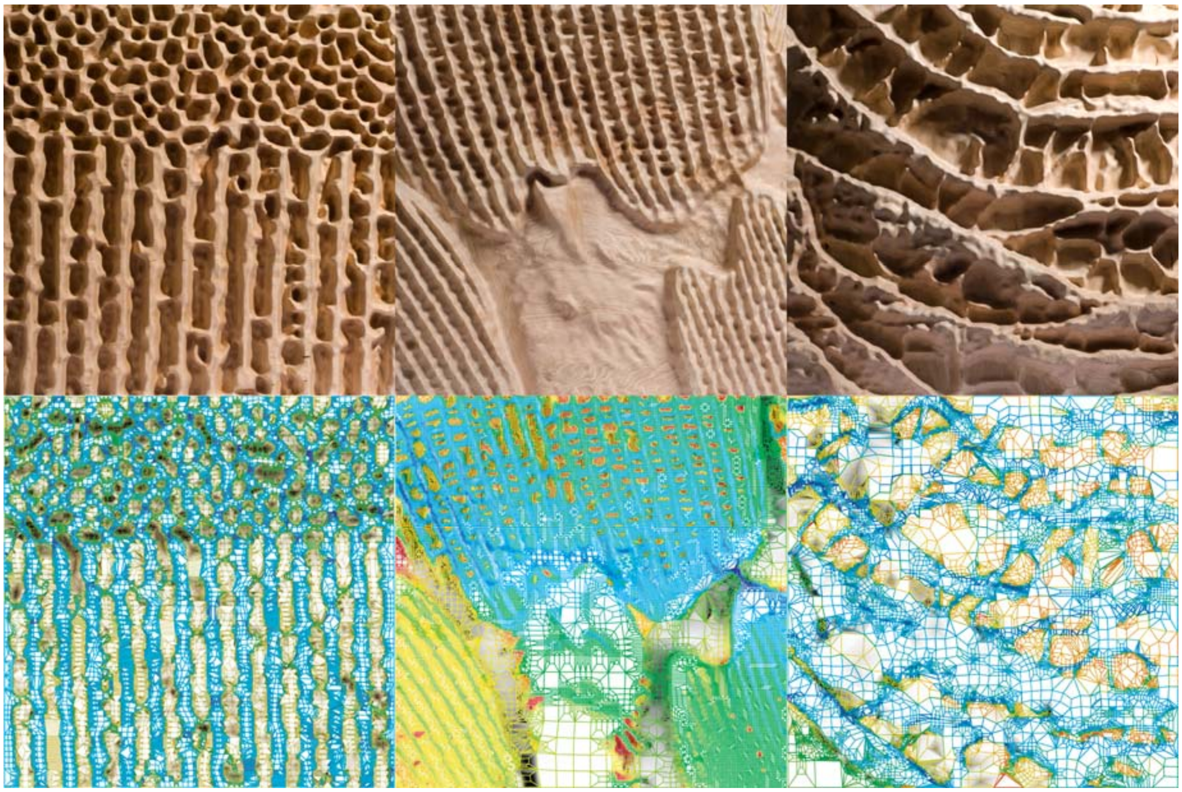

Figure 3: *Subterrain*: Micro structural biological tissues structural compost (top) and perofrmance analysis (bottom).

3.4. Cartesian Wax

The project explores the notion of material organization as it is informed by structural and environmental performance: a continuous tiling system is differentiated across its entire surface area to accommodate for a range of conditions accommodating for light transmission, heat flux, and structural support. The surface is thickened locally where it is structurally required to support itself, and modulates its transparency according to the light conditions of its hosting environment. 20 tiles are assembled as a continuum comprised of multiple resin types - rigid and/or flexible. Each tile is designed as a structural composite representing the local performance criteria as manifested in the mixtures of resin.

The work is inspired by the Cartesian Wax thesis, as elucidated by Descartes in the 1640's. The thesis relates to the construction of self knowledge and the way in which it is informed by and reports about an individual's experience of the physical world. According to Descartes, the knowledge of the wax is whatever survives the various changes in the wax's physical form. That is, the form of the wax embodies the processes that have generated its final features. Replace the notion of knowledge with that of performance and the wax's physical form represents the force fields that grant its birth.

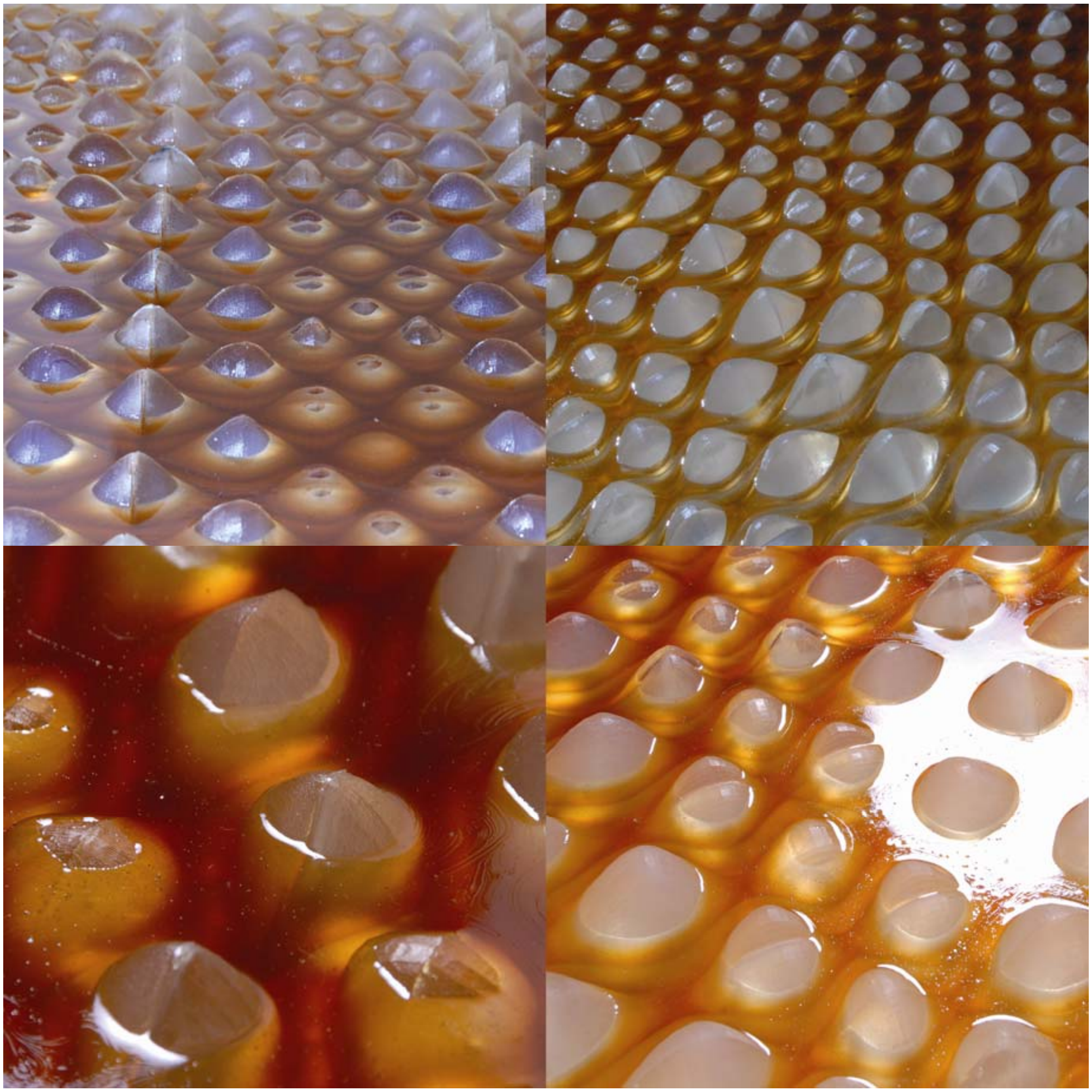

Figure 4. *Cartesian Wax*: full scale and details composite image of final installation

4. Discussion and Contribution

The distinction between form and matter in architectural design has historically valued the formal over the material. As a result, the discourse of architecture has tended to concern itself with formal questions, establishing the role of the architect as form-giver rather then form-finder or form-maker. This privileging of form over matter is profoundly embedded into our practices and methods of working.

Performance-based design processes carry significant potential to rethink traditional classifications of function. This paper calls for a reconsideration of functional integration on the level of the building skin: rather than considering structural and material partitions between structure and surface (or: column and façade) we consider the strategic distribution of matter as assigned to performance. Through the medium of various experiments in performance based design, the projects presented have demonstrated the significance and potential of such a transformation of design theory.

The experiments demonstrate the notion of *material based design* formulated here to facilitate informed material distributions and structures at the building scale. Particular emphasis was placed on innovative applications of computation and fabrication technologies that can potentially contribute to the design generation of material organizations.

The use of computational geometry and a growing ability to author our own form-generation tools have contributed to processes of design engaged with performance. However, performance based design is still confined to geometry and form, while the consideration of *material based design* as a potential design generator has been limited and undefined. The paper has introduced some theoretical and technical foundations for *material based design*.

Finally, the paper has provoked and expressed a will to defy the very classical canons of modernist design production protocols: now that we can control material organization and behavior in construction scales, we can finally break away from typology. Oublier Domino.