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Making Digital Architecture: Historical, Formal, and Structural Implications of Computer Controlled Fabrication and Expressive Form

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Digital output from computer modeling represents a significant new method for visualization and fabrication of architecture. The ability to move directly from three-dimensional modeling to real three-dimensional output challenges the need for traditional means of representation such as plan, section, etc. Moreover, the necessity for conversion of architectural intentions into a code (construction documents, shop drawings, etc.) to be translated by the contractor will also be tested with these new potentials in fabrication. This subjugation of traditional forms of representation and fabrication has serious implications for architectural design process and production.

The intention of this paper is to scrutinize underlying issues inherent in a design process of developing architectural solutions using the computer both as a tool for three-dimensional visualization as well as for guiding three-dimensional fabrication. Precedent of historic expressive architectural form (seen through the lens of fabrication) will be presented to lay the foundation for the examination of new fabrication techniques and structural concerns for computer generated expressive forms. A series of rapid prototype studies from a digital architecture seminar will also be analyzed to outline the need for developing visualization/fabrication process ideas and research into methods for making digital architecture.

Keywords: *expressive form, digital visualization, digital fabrication, rapid prototyping, five-axis milling*

"…Architecture depends upon its time. It is the crystallization of its inner structure, the slow unfolding of its form. That is the reason why technology and architecture are so closely related. Our real hope is that they will grow together, that some day the one will be the expression of the other. Only then will we have an architecture worthy of its name: architecture as a true symbol of our time"

(Mies van der Rohe, 1950).

Making digital things

Handcrafting of objects leads to creation of unique individual things. Tools of craft historically were extensions of the hand, and skilled craftspersons developed good hand/eye/mind coordination. The industrial revolution extended these tools of craft with a mechanized extrusion of mass-produced repetitive units. New tools of mechanistic technology encouraged efficiency through standardization and repetition. The skilled craftsperson in the industrial

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age was able to employ the processes of industry resulting from new methods in fabrication.

What exactly is a tool? Malcolm McCullough offers a comprehensive definition that a “tool is a moving entity whose use is initiated and actively guided by a human being, for whom it acts as an extension, towards a specific purpose” (1996). The computer, as a tool, is more akin to an extension of the mind. Further, in terms of making things, or physical output, the computer may be situated as the mind of other tools. It encourages a repetition and variation that affects the making of many distinct things (most noticeable today in industrial design “objects” and rapid prototyping). This mind-tool can be integrated into a critical process between the designer, the visualization software, and the fabrication processes. Even still, the computer in concert with fabrication processes has its own inherent techniques for making things. What constitutes hand/eye/mind coordination when the computer governs the process of fabrication? What makes a skilled craftsperson in the age of information technology? Certainly, the software programmer plays a growing role in the relationship of form generation and direct translation to fabrication techniques.

The synthesis of design conception and fabrication has always been integral to the process of creating architecture. As Le Corbusier reminded us, “almost every period of architecture has been linked to research in construction” (1931). Further, “the architect should have construction at least as much at his fingers’ ends as a thinker his grammar” (Le Corbusier, 1931). For groundwork in the discussion of expressive form in computer visualization and fabrication, it is useful to consider historical expressive forms aligned with processes of fabrication.

Expressive form

Expressive form challenges prevailing ideas of architecture, as well the limits of understanding in engineering by encouraging the development of innovative fabrication solutions. William Mitchell points out that “as buildings evolve in directions represented by new ideas and pioneering experiments, construction materials, products, and processes will change” (1999). Further, Branko Kolarevic continues this point by acknowledging that today, “building construction is being transformed into production of the differentiated components and their assembly on site, instead of conventional manual techniques” (2000). Manufacturing processes employed in the physical realization of expressive form will continue to evolve as a direct result of the influence of the computer. Therefore, a complete discussion and definition of principles of expressive form in contemporary computer generated physical architecture must include the synthesis of innovative fabrication processes with creative, aesthetic, and formal aims.

Expressive medieval form: mastered craft

The medieval master builder was a master of stone. The design of the cathedral evolved from an exhaustive knowledge of this specific material. The medieval master builder was, in fact “an imaginative and creative designer on the one hand,” who was “comprehensively and intimately familiar, at the same time, with the means by which his design could be brought to realization in actual stone and mortar” (Fitchen, 1961). The master builder was a skilled craftsperson rising out the stonemason craft with a thorough knowledge of the material and the tools with which to manipulate this material. The stonemason tools were extensions of the builder’s hand. The precision of the craft depended upon the knowledge and skill of the craftsman, and the ability to translate ideas into built form given the tools of the craft. A master builder architect deeply understood this relationship between tool, material, structure, and form.

Expressive medieval form was as expressive as the stone structural system allowed it to be. In reference to the flying buttress at Chartres, Viollet-le-Duc submits that the flying buttress “is a completely oblique construction intended to resist weight that also pushes obliquely” (1876). The application of the flying buttress supported the evolution of gothic cathedral form, as this innovative structural solution set a new standard. Thus, “the development of the structure of churches set out with a new vigor in a new direction” (Viollett-le-Duc, 1876).

Expressive modernist form: the craft of industry

The industrial revolution led to a separation of traditional forms of craft from the actual process of building through a mechanized off-site extrusion of repetitive units, pre-manufactured and shipped to sites ready to assemble. The universal impact of industrialization on architecture led to efficiencies through industrial processes in manufacturing. Architects aligned with the spirit of this time took advantage of the new developments in structural systems available through mechanization. The realization of expressive form in modern architecture, however, challenged the building industry to develop special solutions on a per project basis. These innovative architects were able to explore an industry-wide craft in the fabrication of architecture, unlike medieval stonemasons, by governing the processes in industry resulting from developments in materials, structure, fabrication, and manufacturing.

The use of reinforced concrete employed by Eric Mendelsohn in the Einstein Tower was a direct translation of the potential use of innovative material developments into an expressive form of architecture. Eric Mendelsohn demanded, “new methods of construction be translated into design” (Stephan, 1999). Later, modernists experimenting with expressive form, such as Eero Saarinen and Jorn Utzon, remained consistent with the structural necessity for the realization of these forms. Eero Saarinen argued for the integration of expressive form (or as he refers to it, plastic form) with fabrication processes. He states: “plastic form uncontrolled by structure rings a hollow note” (1962). Likewise, the philosophical position of Ove Arup, structural engineers and collaborators with Jorn Utzon for the Sydney Opera House, explains “the willingness of the engineers to expand the limits of problem-solving by moving towards the principle of ‘total design,’ that is to say, the integration of all design and construction processes for the sake of the project as a whole” (Sommer, Stocher, Weiber, 1994). As craft evolved with technological developments and industrial manufacturing processes, design aims and realization of innovative expressive forms in architecture were clearly aligned with intentions for fabrication.

Detached skin and bones

The minimization of structural systems suggested by pushing the limits of stone in medieval times and fully realized in the manufacturing processes of the industrial age has facilitated the ability to freely express form as surfaces. When façades were freed from the structural system and hung from the building as envelopes, the two systems (skeleton and skin) were allowed to evolve independently from one another. Façade was free, plan was free, and thus simultaneously, form (as skin) was “free” from structure. Corbusier tested the implications of this separation of skin and bones at Ronchamp with the application of new methods of fabrication available with malleable concrete, which was sprayed onto a mesh to create the skin of the building. The columns that bear the weight of the curved roof form are hidden in a wrapped non-structural concrete skin (although the skin still serves to stiffen the total structure). In Daniele Pauly’s analysis, “one can imagine this building as a skeleton with a skin stretched over it, both inside and outside” (1997). At Ronchamp, expressive form was articulated independently of structure, thus suggesting the evolution of expressive form created by surface articulation. This separation of skin and bones is no more apparent than in architecture today with the proliferation of expressive forms in an image-saturated society. Software tools add to the propagation of image based surface articulation by supporting rapid digital visualization of expressive form.

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Digital visualization: surfaceness and image

Indeed, with digital visualization software, it is possible to develop architecture entirely on the basis of its surfaceness. This kind of expressive skin form may be generated with the assistance of algorithmical calculations of the computer based upon input variables established in negotiation between the designer and the visualization software. This new surface architecture has raised significant issues about evaluation criteria for innovative formal expressions. Do we evaluate the form/surfaceness or the input parameters? Do we abandon traditional formal principles in a search of new principles for expressive surfaceness? Which responsibilities in form generation lie with the architect and which with the software developer? The current critique of surfaceness leans toward an evaluation of the image of the architecture. Architecture considered as image, or even brand identity, then becomes akin to image-based output of industrial design products, such as the iMac computer, Nokia telephone, or Volkswagon Bug. Thus, the proliferation of an image-based surface architecture could potentially lead to a family of architectural flavors based on the image power of the expressive form.

Expressive contemporary skin-forms

Software tools facilitate the immediate visualization and manipulation of expressive skins as forms. In fact, in the virtual modeling environment, form can exist entirely as surface without structural considerations. It has become increasingly uncomplicated to visualize, manipulate, and generate complex geometries using new software technology. In its relatively short existence, software that encourages surface manipulations has led to the creation of inventive formal languages for architecture. Fundamental principles of design have been challenged and perhaps replaced. Digital visualization software tools can be used to create a number of "digital architectures," outlined by Branko Kolarevic, which "refer to the computationally based processes of form origination and transformations, such as topological space, isomorphic surfaces, motion kinematics and dynamics, keyshape animation, parametric design, and genetic algorithms" (2000). These new types of digital architectures represent a strong potential in defining significant new territory for architecture. Certainly, hybrid-architecture, information architecture, digital architecture, and similar categorizations can exist entirely in the virtual world. These new gravity-less virtual architectures have enlivened the debates within our discipline. Nonetheless, when we consider the translation of expressive skin-form into physical architecture, with structural systems and material properties, consideration of fabrication processes are essential in the realization of these forms. Thus, as new principles evolve for contemporary architecture as a direct result of the expressive skin-form manipulations of digital visualization software, these new principles should invariably include potentials for a digital craft.

A definitive discussion of expressive contemporary skin-forms in architecture would be incomplete without addressing the implications of fabrication and a synthesis of the direct digital output with form generation. In fact, the manufacture and fabrication process of components for a physical building could inform the design conception and development. If so, software developers will play a key role in facilitating these considerations of fabrication into a comprehensive modeling environment. Parameters for gravity, material properties, and manufacturing techniques could become testable components of design visualization software. Fabrication implications could then be tested from both within the virtual environment as well as through direct physical output. This design process would lead to "an exciting dance back and forth between modeling geometry in the computer and its transformation into a real product" (Pongratz, Perbellini, 2000).

A visualization/fabrication design process is more akin to a master architect programmer builder relationship. Perhaps then, the responsibility for an integrated visualization/fabrication design process lies equally with both architect and software developer. Nonetheless, a clear classification of fabrication processes in direct relationship with digital visualization potentials would provide a necessary outline for the development of new principles in the realization of expressive form into physical architecture.

Design visualization/fabrication process study

As an introductory pedagogical step in the integration of the concept of visualization/fabrication design process, a series of short iterative process studies employed the use a five-axis milling machine. The simple aim of these studies was a simultaneous consideration of digital visualization and fabrication, and an examination of the nature of the craft of a computer-controlled machine. The nature of the milling model fabrication is a reduction of form from a block of foam or clay, like a sculptor carving form from stone. All that is not necessary (void) is scraped away by the drill bit. Students were asked to develop not hand/eye coordination typical to the crafting of a real made object, but an eye/mind coordination of thinking through the design process and exploring potentials by considering the particularities of the milling machine tool, such as residue or traces left behind by the drill-bit. Students were encouraged to consider their three-dimensional study models as forms/spaces/fields/systems that could operate on a multitude of scales, ranging from the manufactured panel scale, reverse form work, or a study model of object, building, or urban scale. It became immediately clear that the initial level of study should require a rigorous study only at the scale of the building component in order to best examine visualization/fabrication design process implications. Additionally, this process of conception, fabrication, and back to conception relies upon a rigorous application of the design/visualization/fabrication feedback loop. Further, in this short exercise, it became evident that in order to best understand true potentials of visualization/fabrication processes, a comprehensive study of a wide range of fabrication processes and machines is necessary, as five-axis milling has its own inherent limitations in the nature of how the tool excavates form.

Summary: making digital architecture

The translation of a digital project into the physical world weighs heavily upon the consideration of gravity, and thus, recognition of structural and fabrication solutions in the conception of expressive form. The rapid evolution of surface considerations made available with digital visualization software, underscore the need to understand fabrication implications.

As the computer serves as the mind of the machines it controls in the fabrication of building components, it still cannot replace the critical thought process of the designer. Thus, the question remains: what constitutes a skilled digital craftsperson? Undoubtedly, A skilled craftsperson in the digital age must be skilled with strong design ideas, knowledge of a variety of software, and an understanding of fabrication processes. Equally, software developers become essential to the formula for an integrated digital craft. Parameters for gravity, material properties, and fabrication processes could be embedded into design visualization software providing immediate feedback during design visualization and development. Additionally, physical three-dimensional output studies facilitate a feedback loop with the process of architectural design conception and development. Either way, an architectural design process striving to realize expressive form in a physical building, and remaining consistent with historical considerations of fabrication processes, should necessarily include a rigorous research on the implications of fabrication techniques as guided by the computer. An exhaustive consolidation of research outlining the relationship between design visualization and fabrication processes would serve to better inform the evolution of new principles for a contemporary architecture as a true symbol of our time.

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