MFD: Material-based Design Informed by Digital Fabrication

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Keywords: *Informed Computational Processes, Digital Tectonics, Digital Materiality, Performance Based Design, Generative Design*

ABSTRACT

Recent development of digital fabrication and materialization technologies is enhancing change within design processes. In this work we formulate a new conceptual schema termed Material-Fabrication-Design (MFD). MFD's are defined as **computational informing processes that enhance tectonic relationships between form, structure, and material within the logic of fabrication technologies.** ***By undertaking systematic approach,*** **MFD models** ***are identified representing knowledge of innovative digital material-based design. The work explores, formulates and explains the impact of these developments on theories, knowledge and processes of design. We demonstrate through comparative analysis of various selected representatives of precedents and case studies, emerging design models, principles, processes and techniques.***

1. INTRODUCTION

Beyond the first classical integrations of CAD/CAM, the continued evolution of digital fabrication media has produced a new symbiosis between technology and design. This symbiosis has now driven the emergence of broad changes in the coming into existence of material praxis as a dominant phenomenon of the last two decades. The revolution of digital material has provided new forms of design affordances that have transformed design culture in all of the diverse fields of the design discipline. The evolution of the field of Material-Fabrication-Design *(MFD) is the result of the rapid development of new fabrication media, the growth of the general acceptance of digital materiality as an important emphasis of design and the consequent impetus to new theories and methods.*

The growing convergence of design and materialization technologies is today creating an intense level of professional, academic, and research involvement with material praxis in design, *with the resultant evolution of a range of media-related design practices (R. Oxman & R. Oxman, 2010). Based upon advances in computational technology, design can currently be* informed by *materialization processes. Digital media are extending possibilities of the relationship between form generation and material production, and designers are beginning to make decisions related to choice of material and production method* from the stage of conceptual design. *Within design disciplines such as architectural and engineering design, these developments are breeding a broad theoretical shift in both design generative processes and materialization methods.*

2. BACKGROUND

By undertaking systematic study into the chronological development of the relationship between manufacturing and fabrication technologies (Kieran & Timberlake, 2004; Iwamoto, 2009) it was possible to define the first relationships *between fabrication technologies and design. The effect of this profound shift of technological influence within the design disciplines was referred to as the* culture of making *(Mori, 2002; Anderson, 2012). Today, the current shift is influencing a growth of experimental material-based design research in both academia and practice: R. Oxman & R. Oxman, 2014; Carpo, 2013; Dunn, 2012; Beorkrem, 2013; Sheil & Glynn, 2011; Gramazio et al., 2014. Through analysis of recent experimental and pioneering works we are beginning to conceptualize a series of unique* MFD models *that are exemplified by leading case studies.*

The following section begins to define the concepts and principles of design and materialization technologies.

2.1 Rapid-Prototyping

Technologies of Rapid Prototyping *(RP) were defined as a group of techniques used to* quickly fabricate a scale model, part, or assembly *by Computer-Aided Manufacturing (CAM) using three-dimensional Computer Aided Design (CAD) data. The concept of rapid prototyping of models to provide feed-back* during the process of design *was an early rationale for the relationship between design and fabrication. Important in manufacturing, rapid* *prototyping by fabrication technologies was also soon recognized as a potentially significant technology for design (Kieran & Timberlake, 2004).*

2.2 Fab Labs: The Emergence of Design Fabrication Laboratories

Today, digital modeling techniques support the linkage between the digital and the physical model *in design by creating information that is translated directly into the control data that drives the digital fabrication and integrates design, fabrication and manufacturing in a single process (Sass & R. Oxman, 2006; Kolarevic & Malkawi, 2005; Kolarevic & Klinger, 2008). The rapid growth of this relationship between the physical and the material has contributed to the rise of the concept of the* Fab Lab.

A fabrication laboratory, or Fab Lab *(Gershenfeld, 2007), is a multi-tool center for rapid prototyping and manufacturing. Fab Labs usually include a suite of technologies for additive and subtractive strategies such as: laser-cutters, 3D printers; CNC (Computer Numerically Controlled) cutting, sectioning, contouring, and milling machines. Fab Labs can also include robotic potential for the mounting and maneuvering of fabrication devices.*

A unique kind of Fab Lab has been developed by the Mediated Matter Group, at MIT Media-Lab *(N. Oxman, Oritz, Gramazio, & Kohler, 2015) where architects, designers and biologists collaborate, developing and testing novel tools, to support new design processes and products across-scales exploring new types of form generation such as growing materials, using top-down additive manufacturing and bottom-up biological growth. The lab of the Mediated Matter Group is become a medium for exploring the relationship between digital and biological fabrication, enabling design and production at nature's scales.*

2.3 The Concept of Computational Informing Processes

Understanding design as a synthesis of explicit and externalized information processes such as presentation, generation, performance, and evaluation was explicated and formulated as a computational operative process of digital design (R. Oxman, 2006). The emergence of informed computational design processes, *combining new developments of parametric modeling environments, e.g., Generative Components and Rhino Grasshopper, algorithmic generative languages, visual scripting and coding possibilities is also beginning to enable the* integration of the materialization processes *in conceptual design (R. Oxman, 2012).*

2.4 The Concept of Informed Tectonics

Due to the emergence of computational informing processes enabling the mediation between form, structure and material properties *in processes of design, tectonics is again becoming a seminal and operative concept of digital design. Tectonic relationships are now capable of being* informed *and thus mediated by digital media through each of the stages of design from conception to production. The multi-stage continuously informed mediation of the tectonic content of designs is an essential component of material-based design that is defined by the term* informed tectonics *(R. Oxman, 2012). The diverse classes of informed tectonics are denoted by the characteristic relationships of form, structure, and material in fabrication design. It is these classes of informed tectonics in fabrication design that constitute the basis for defining and classifying the diverse* Materialization Models of Design.

2.5 Materialization Models of Design

Experimentation with new materials and materialization principles is becoming integrated within the rationale of emerging digital design processes thus enriching the integration of new strategies of design and production (Gramazio, Kohler, & Oesterle, 2010; Schodek, Bechthold, Griggs, Kao, & Steinbur, 2004; N. Oxman, 2010, 2011; Menges, 2012; N. Oxman et al., 2015). In order to characterize the processes and types of relationships between fab technologies and design, research has been undertaken into the definition of the Materialization Models of Design. *These are models of design in which the potential of material design and fabrication is a major factor in the design concept.*

3. MFD: MATERIAL-FABRICATION-DESIGN

Material Fabrication Design is defined as a computational informing process that enhances the tectonic relationships between form, structure and material within the logic of fabrication and robotic technologies (N. Oxman, 2011; R. Oxman, 2012; Menges, 2012). The formulation of terms and definitions of concepts and principles in MFD have been derived from theoretical studies and critical analysis of selected case studies. The examples presented below demonstrate different MFD models (Figures 1-4, p. 54, 55, 57) that are integrating in diverse ways the three components of Material, Fabrication, and Design. These three components of MFD are briefly described as follows:

3.1 Material

The convergence of digital design, materialization processes, and fabrication technologies is breeding an expansion of material design research and practices in architecture as well as traditionally more industrial and craft-oriented design fields such as industrial design, fashion design and jewelry design.

Contemporary material design originated in the technological extension of traditional models of design based on well-understood traditional materials (Addington & Schodek, 2005) such as wood, steel, etc., and their relationships with form, structure and construction. The extended use of digital techniques in material-based design is becoming a dominant design model among experimental design practices (Barkow, 2010). The current discourse on materials includes such advanced concepts as smart materials, responsive materials, etc. In architecture, material experimentation relates to a great extent to the design of the building envelope and to fabrication-derived structural systems (Shröpfer, 2011).

3.2 Material-Fabrication and Material Systems (Across Scales)

The origin of current fabrication technologies can be traced back to the evolution of computer technologies associated with the automation and production of the final stages of design and to the first CAD/CAM systems (Schodek et al., 2004).

Due to the impact of informed computational processes on design, beyond the traditional use of the term 'material', understanding the concept of Material Systems *and its relation to fabrication is central to this field. This novel concept exploits the logic and principles of material systems of physical, natural, and digital materials. A material system represents the formal logic and integration of material properties, structural behavior, and their relationships to the environment and its impacts on physical and digital form-finding processes. Digital design and fabrication inspired by nature is a new research field termed Material Ecology. This new research field developed by Neri Oxman, explores processes of shape generation of classes of various material systems such as weaving, folding, and layering in micro and macro scales.*

3.3 Fabrication-based Design (Building Scale)

The forms and processes of fabrication have become a source for the generation of new design concepts in architectural design (Gramazio & Kohler, 2008). We not only design within the potential of fabrication, but buildings are frequently designed within the design rationale *of fabrication (Mayer, 2011; Scheurer, 2010).*

The fabrication of material systems reflects the relationships of material properties, material performance, material behavior, and materialization strategies and techniques. The type of fabrication-based design of material systems *is a key concept in the MFD approach. To understand the MFD models there is a need to appreciate the desired relationships between the material system, performance strategies, and the fabrication technique of the selected technology in each model.*

4. MFD MODELS

4.1 Introduction and Objectives

The design world of MFD is approximately two decades old. Within that brief span of design history, the field is rich in new technologies as well as a bountiful selection of important examples of experimental design. Despite the characteristic of a strong technological presence, much of the work is rich in innovative thinking and lyrical quality in the designs. MFD is a wave of change that is creating a profound influence upon all fields of the design discipline.

The objective of this preliminary study is to begin to systematically review the brief history of the field, and to define the major concepts, issues and intellectual resources. In this section, we present a brief review of selected content of the field and briefly present certain key concepts and precedents.

4.2 Classes of MFD Models

In order to be able to understand what might be considered 'models' of MFD design orientation, we briefly present certain terms and concepts of the approach.

4.2.1 Tectonic Order

Tectonic order *is the relationship of influence between the design of form, structure, and material. One of the important recent developments in tectonic order has been the ability to advance materialization processes to the early conceptual phases of design. In the traditional model of architectural design materialization, processes frequently follow design conceptualization phases that can be represented as:*

from Form - to Structure - to Material

Today, with the rapid development of new fabrication technologies, the selection of material and fabrication techniques may be done at an early design stage; materialization design and fabrication technologies can in this case act as an *input in the conceptual phase of design. This tectonic order can be represented as:*

from Material - to Structure - to Form

In MFD, there is generally a radical reversal of information flow in tectonic order in design, in which fabrication techniques and their affects upon the formal and behavioral content of materials becomes a dominant part of the content of conceptualization, thus creating an architecture of digital materiality.

4.2.2 Technologies and Techniques

Novel technologies are enabling design and production at product and building scale; these include pioneering fabrication technologies such as Laser Cutter, 3-D printing, Water Jet, CNC Milling/Routing, and Robotics. These technologies continue to innovate rapidly. For example, recently research experiments at MIT have developed new techniques of additive fabrication demonstrating how 3D printing can be used in the design process, producing homogeneous material design (cp. component parts design) through manipulating multi-property materiality as in natural design (N. Oxman et al., 2015).

5. MFD CASE STUDIES

It may be generally stated that the increasing prominence and performance of fabrication technologies have elevated the design of material systems *into a seminal problem of design in architecture, and one that has become formative in the generation of design concepts. In the selected case studies that are illustrated it is possible to observe that the increasing centrality of the design of material systems has frequently become the foundation for the* partis *in much experimental architecture, as well as an important source of architectural innovation.*

The following sample of principles and types of material systems represents the formal logic of various classes of formal types that can be characterized by their selected material and structural behavior. We compare below form to fabrication *processes versus* fabrication to form *processes.*

The Metropol Parasol in Seville, Spain, designed by Jürgen Mayer (Figure 1, p. 54) is a large-free-form urban spatial grid structure fabricated in wood. While the origin of the concept was not conventionalized in the fabrication technology, the realization of the design was dependent upon its total involvement with the potential of fabrication technologies to act as a construction solution.

Similarly with Shigeru Ban's and Designtoproduction's Golf Club (Figure 2, p. 55), again fabricated in wood, the origin of the concept is not necessarily in the fabrication process. However, the elegance, lightness and complexity of the form are totally dependent upon the potential of fabrication.

With respect to the influence of fabrication in design, we can contrast the above designs with the pavilion of Menges and Knippers at the University of Stuttgart (Figure 3, p. 57). In this case, it is the integration between design rationale, structural concept and unique fabrication of two-dimensional elements that have been employed to create a woven fabric-like structural form.

In the work of Gramazio and Kohler (Figure 4, p. 57), encoding digital materiality and assembly using industrial and Flying Robots *has become their central field of research and the foundation of their design processes.*

Finally, we have selected to present work of Neri Oxman at the MIT Media Lab (Figure 5, p. 58) as an example of a new world of design potential and architectural richness that innovates functionally and artistically within the potential of an emerging Material Ecology *founded upon* Mediated Matter. *The examples present a body of design resulting from a direct relationship to the fabrication technology; the advancement of which is one of the important objectives of the design development process.*

6. CONCLUSIONS: DIGITAL MATERIALITY: THE DESIGN WORLD OF MFD

MFD opens a field of broad and innovative potential for architecture and design. We are now in the process of advancing our work on MFD models and we strongly believe that as the field becomes more prominent in architecture and design, the potential for important contributions shows great promise. Part of this promise for architecture and design derives from the rich body of contributions that have been mvade in the last two decades to the concept of Digital Materiality in general and to the definition and explication of the field of Material Fabrication Design as a new world of design discovery.

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