Digital architecture as a challenge for design pedagogy: theory, knowledge, models and medium

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The paper introduces and discusses current developments in architectural discourse, design theory, digital design models and techniques and their relations to design pedagogy. The evolution of design knowledge in architectural theory and praxis is explicated and its implications for required changes in design education are presented. The theoretical influence of architectural concepts is presented through historical references in digital architecture. This structure of design concepts is proposed as a medium of design education. An experimental design studio on: 'Design as research: the exploration of digital architectural concepts' is presented as a pedagogical framework for educating the digital architect and a series of research and design programs carried out in an experimental design studio demonstrates this framework.

Keywords: digital architecture, digital design theory, digital design media, digital design knowledge, education and pedagogy

Among the significance of digital design is the way that this form of mediated design is beginning to evolve not only unique formal content, but also a unique body of architectural concepts. This structure of design concepts, their link to theories, models, technologies and techniques currently employed in digital design research and digital praxis, is proposed as a medium of design education. Any new framework for design pedagogy must be responsive to conditions in which digital concepts are integrated as a unique body of knowledge consisting of the relationship between digital architectural knowledge and digital design skill.

The search for new educational frameworks is due to the pedagogically unique impacts of digital design. Various researchers and educators have begun to address the need to integrate digital design in architectural design education investigating various forms of pedagogical agenda. Design computation and digital design had an influence on the development of theoretical; computational and cognitive approaches by various researchers as a foundation for design education and pedagogy (Knight, 1999; Oxman, 1999, 2001, 2004, 2006a,b,c; Cuff, 2001; Knight and Stiny, 2001; Özkar, 2007). Others considered the

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role of data architecture and visualization as a foundation for education (Bermudez and Agutter, 2005), as well as developing a basis for curriculum construction (Mark et al., 2003; Kvan et al., 2004).

In general, the pioneering of new approaches to a 'digital architectural educational agenda' has been the many new graduate programmes throughout the world that have developed over the last decade. However, any detailed investigation of these educational developments as they have emerged at Columbia, Harvard, MIT, Penn, UCLA, the AA, University of Applied Arts in Vienna, and elsewhere have been usually strongly motivated by important *individual* digital practitioners as compared to the influence of a comprehensive pedagogical agenda.

This first wave of practice-driven educational models has brought professional education in architecture to a new frontier. This condition now demands a process of redefinition of the intellectual and cultural frameworks of architecture as well as the theoretical foundations for architectural and design education. The need to accommodate the scale of change in professional practice with its new demands of requisite knowledge and skills presents this generation of design pioneers with a new challenge: to create a theory of architectural education and design pedagogy that acknowledges the scale and qualities of theoretical, professional, and technological changes that digitally mediated architecture is beginning to exert. In the case of such a broad cultural shift there is a need, first of all, to re-consider the theoretical basis, its related knowledge and its design methods in relation to emergent digital technologies.

Following this basic assumption that change in the professional culture of architecture is substantive in that it transcends stylistic agenda, it has now become important to re-consider certain of the existing theories of design and education. Concepts such as *design thinking* (Rowe, 1987) have in the recent past been part of a powerful cognitive model of design. The term '*designerly ways of knowing*' (Cross, 1982, 2007) is particularly significant, since it also introduces the notion of knowledge in design and what this might imply with respect to new approaches of digital design education. How can designerly ways of knowing, a concept so strongly derived from a paper-based culture of design, be adapted to the new situations of digital models and mediated design processes? Is it reasonable to assume that we can now theorize the forms of 'digital design thinking'? How do we conceptualize the 'paperless studio'; what is its knowledge content and what is its expected educational contribution?

If digital design knowledge constitutes among other things a new set of conceptualizations, including ideas related to the meaning of form, the nature of functional and formal knowledge, and the models of generative processes,

there is a need for an encompassing theory of digital design pedagogy that accommodates this modified knowledge base.

1 Obstacles to change

In the following work we propose to formulate a theoretical framework and didactic principles for digital design education. In the following sections, we analyze certain obstacles to change as they are encountered today in traditional design teaching. These problems of adaptability and inertia of the educational system are typically of three classes of influence: the influence of the *design medium*, the influence of *knowledge and theory*, and the influence of *models and methodologies*.

1.1 Changes in design media

Theories regarding the characterization of paper-based design thinking as a foundation of design education became broadly accepted. By the early 1980s new layers of cognitive research began to be introduced by Schön and his collaborators (Schön, 1983; Schön and Wiggins, 1988) who placed the main focus on the designer himself, as compared, for example, to domain knowledge (Oxman and Oxman, 1994), and on the study of design thinking. These works began to be suggestive of cognitive properties that were capable of capturing the complex nature of 'what goes on in the designer's head' (Lawson, 1997). These studies are also generally related to traditional paper-based sketches as medium of the conceptual and explorative process. Frequently referred to as 'reflection in action', these models emphasize the interaction of the designer with the problem representation and characterize design as a process of reception (perception), reflection (interpretation), and reaction (transformation). Up until today these theories have been a significant topic in design research (Lawson, 1980, 1997; Cross, 2001).

This paradigm of design, strongly predicated upon visual reasoning has provided a strong influence upon design research and pedagogy for the last two decades. Schön's classic characterization of visual reasoning in design as a 'dialogue with the materials of the problem' and the process of 'backtalk' from visual images (Schön and Wiggins, 1988) has been consistently associated with paper-based media. It is still a dominant model for explicating thought and reasoning in many of the design studios. Whether or not particular theories of design education are explicitly influenced by such cognitive theories of designing, the general characterization of design as reflection supported by representational processes has had an almost universal influence on architectural design education.

If the characterization of design as reasoning through the exploration and manipulation of graphical symbols has become less relevant as a description of design with digital media, how can we characterize digital models of design? Today, it has become important to re-consider the significance of digital media

and what they might imply with respect to a different characterization of the design processes. If indeed, contemporary phenomena of digital media are different from traditional design media, how can we characterize digital models of design?

Are we encountering the same cognitive phenomena of known processes of design in the new digital media? Or are we encountering new forms of knowledge, new scientific foundations, and new models of design? A basic assumption presented here is that we are, in fact, facing new terrain in design thinking and that there is a need to formulate a rationale for digital design didactics. We describe below how it is possible to explore the role of digital media in relation to the way knowledge, concepts, design models, digital processes and methodologies are related in digital design.

1.2 Changes in the architectural knowledge base

Regardless of what might be the particular formal vocabulary, *syntactical and formal knowledge* is strongly accepted as a foundation of design pedagogy in architecture.

Beyond the exploitation of digital media as tools, *the relation between digital design and digital design models as a form of architectural knowledge* has begun to emerge as a significant ideational resource for design and design education. Theoreticians have attempted to define paradigmatic approaches in architecture based on the ideational impact of digital technology (Lynn, 1998, 1999; Kwinter et al., 2004).

As a result of the growth of a new knowledge base beyond the skill set of the digital designer, architecture as a design discipline has became rich in ideas, changing methodologies (Liu, 2006; Oxman, 2006b) and a unique body of conceptual content (Reiser and Umemoto, 2006; Aranda and Lasch, 2006). A recent research reported on the cultural process of the emergence, migration, and crystallization of new conceptual structure over the past decade under the influence of digital design (Oxman and Rotenstreich, 2005) demonstrating how concepts whose theoretical source is digital design are beginning to occupy a central role in current architectural language and discourse. The explication and ideation of this conceptual content of digital design is another import agenda for digital design education in architecture. Certain of these concepts are in direct contradiction with formalist approaches of syntactical and formal knowledge.

1.3 Changes in processes

An understanding of digital design as a unique set of design logic demands a formulation of the symbiosis between the product of design and the way it is now conceived, generated and materialized in digital media. Digital methodologies today are enhancing certain capabilities of generative and performative

processes that were never before available in conventional, paper-based methods. In doing so they are also changing the traditional processes and sequence of conventional design (Oxman, 2006a,b,c). Among such changes in digital design verses conventional processes are the relationship between conceptionalization and materialization (Sass and Oxman, 2006), form and material (Oxman and Rosenberg, 2007).

Following these developments, our objective in the pedagogical experimental work has been to take first steps through a process of re-thinking many of the root assumptions of design theory underlying architectural education. The experiments demonstrate a search for understanding of design models of digital design employing didactic principles that emphasized the integration of conceptual content, experimental methodologies and digital skill.

2 *Background: the emergence and coming of age of digital design*

During the last decade emerging technologies have begun to influence central issues in design theory. Architectural design has become engaged with the exploration of complex geometries, 'free forms' (Zellner, 1999) as well as related materialization processes of fabrication and manufacturing technologies (Schodek, 2000; Kieran and Timberlake, 2004; Schodek et al., 2005; Sass and Oxman, 2006). These developments have begun to exert significant influence on the theoretical, conceptual and methodological contents of design.

These characteristics emerged in various designs that were realized before and after the millennium. In architecture, the Guggenheim Museum, Bilbao by Frank Gehry was the most prominent catalyst of theorizing new formal directions and postulating new design, materialization and manufacturing methods. Beyond the post-modern sensibility of complexity through 'heterotopia', or complex hybrids, the Guggenheim, Walt Disney Concert Hall in Los Angeles, and other projects by Gehry introduced new geometric approaches freed from *a priori* formalisms, such as linguistic formalisms. Furthermore, the Gehry office was deeply committed to researching the potential role of digital technologies (Lindsey, 2001). Praxis and theory evolved simultaneously. Innovative experimental precedents have emerged from design practice and academic design experimentation. Furthermore, recent works of Zaha Hadid presented in the Guggenheim Museum (The Solomon R. Guggenheim Foundation, 2007) are also demonstrating current 'evolving', heterogeneously parametric themes that are preoccupying digital praxis today.

The characteristics of topological form, transformational evolution of spatial structure, non-hierarchical organization, and complex, hyper-connective spatial conditions became more prominent in later works. Among these, the Yokahama International Port Terminal designed by FOA (Kwinter et al.,

2004) is a case study in forms of complexity including the emphasis upon what might be termed, 'hyper-continuity', or complex topographical models that were difficult, in representation as well as in fabrication, in pre-digital design.

Beyond the stylistic qualities that are frequently associated with digital architecture, it is the institutional developments in such areas as professional collaboration between architects and engineers (Franken, 2002; Bollinger and Grohmann, 2004; Rahim, 2005; Reiser and Umemoto, 2006; etc.) emerging techniques (e.g., parametric techniques) project management (BIM), and fabrication, that have exerted an influence upon the professional culture of architecture.

2.1 Theoretical change

Critical writings are also one of the theoretical milestones of the digital design period. Much of the important theoretical writing of the last decade has been in the area of digital architecture which has become a focal area of modern design theory. Like much of the writing of the period, the emphasis is upon theoretical discourse as related to design, and less upon technical, or systematic, exegesis of methods and design techniques.

As is characteristic of a period of cultural transformation, much significant theoretical writing (Kipnis, 1993; Lynn, 1993, 1999; Kwinter, 1998, 2001; Somol, 1999) attempted to re-address key theoretical issues (such as 'formal knowledge'; 'models'; 'representation', etc.) that preoccupied the theoretical discourse of the last generation. An important threshold was achieved with the Folding in Architecture (Lynn, 1993). Accompanying theoretically important early pieces by Lynn (1993) and Kipnis (1993) are introductions to philosophical sources, studies of technological innovations and their relevance to design, and descriptions of experimental projects. This combination of diverse theoretical, philosophical, methodological, technical and professional sources was to characterize the discourse of digital design in its first decade.

Among theoretically significant monographs are Lynn (1999), Van Berkel and Bos (1999), Rashid and Couture (2002), Oosterhuis (2002), Zaero-Polo and Moussavi (2003), and Spuybroek (2004) each of which are important works by and on leading digital design practices. Zellner (1999) and Rosa (2003) are characteristics of numerous volumes on digital designs that are collections of short descriptive monographs on selected digital practices. Kolarevic (2003) and Kolarevic and Malkawi (2005) are providing more methodological and technological contents on recent developments in digital design.

2.2 New concepts: transcending the linguistic/formal/ syntactic paradigms

Rather than providing a comprehensive survey of these developments which is beyond the scope of this present paper, an attempt was made to characterize

this body of work, in order to introduce and define the transitions that have occurred in 'architectural theory' and in 'design theory'.

The characteristics of this transition in architectural theory demonstrate that they attempt to be the antithesis of the formal paradigms of the post-modern era. New theories appear to be influenced by digital technologies that support different types of form generation relative to complex and topological geometries. The impetus toward formal diversity and differentiation may be seen in part as a rejection of the compositional strategies that had become characteristic of the 1980s. Rather than architectural strategies of hybridization, combination and transformation, the architecture of the 1990s favored material and performative investigation that was capable of producing topologically complex geometries and formal differentiation over the continuity of the architectural object. Evolutionary form and space were related to design concepts such as *hyper-continuities* and *connectivity*; concepts of the mediated topological continuity and diversity of digital architecture began to replace the complexity and contradiction of an earlier generation. The new interest in tectonics, topological geometry and material expression reflects an implied critique of the formally motivated complexity of the previous generation.

In *design theory*, the decline and transformation of root concepts such as *representation*, *precedent-based design*, *typologies*, and other principles of the past generation are in the process of being replaced today by a new body of design concepts related to models of *generation*, *animation, performance-based design* and *materialization*. These are design concepts deriving from the synergy between emergent technologies, design and architectural theories.

3 *Models of digital design and the relationship to digital architecture*

Any comprehensive theory of digital architecture must begin to acknowledge the relationships between theory and praxis. The instances of praxis are related to the theory of digital architecture. Rather than claiming some causal basis for this relationship of design theory to architectural theory, we claim that technology becomes the mediating factor between design theory and architectural theory. A recent publication, focusing on the relations between architecture and technology, offers an interesting collection of essays related to the effects of technological innovation on architectural theory and design (Braham and Hale, 2007).

3.1 *Models of design process*

One way in which the clarification of the uniqueness of digital design media can be established is to define taxonomy for digital design models. In doing so, existing models can be modified and adapted when considering design with digital media. A framework that identifies digital design models and their associated digital techniques may assist in understanding the relations among

design concepts and terminologies such as models, technologies and techniques. Basic framework and classification of digital models were introduced by Oxman (2006a,b,c). Selected models that support the characterization of major design tendencies in digital design today, including formation models, generative models, and performance models are re-introduced below.

3.1.1 Introduction

Today there is a need to make the distinction between *CAD* (computer-aided design) and *DAD* (digital architectural design). The distinction between *CAD* and *DAD* is much more than simply terminological. While principles, theories and methods of CAD (Kalay, 2004), have been basically based on imitating paper-based design, the novel concepts of digital design models are re-introducing a different medium of conceptualization, replacing paper-based media. The new relations between digital form and digital processes are contributing today to the emergence of new conceptual vocabulary, and domain knowledge. It characterizes what might legitimately be considered the early formative stages of a paradigm shift.

3.1.2 Formation models

According to Zaero-Polo, processes are becoming far more interesting than ideas. Processes of generation are synthesized as a kind of accelerated motion, adding information integrally to the construction. This sequential, integrative addition produces more ambiguous effects, more capable of resonating on different levels than straightforward ideological statements, metaphors, allegories, or reproductions (Zaero-Polo, 2001). As a result, traditional concepts of (paper-based) representation today lose their centrality as a conceptual basis for explicating the processes and knowledge associated with digital design. Digital design theory has transformed the concept of *form* into the concept of *formation*. Again this is another paradigmatic distinction. Beyond the generation of complex free forms, the concept of digital *formation* models are becoming a medium of conceptualization. Formation, therefore, constitutes a radical and even antithetical departure from graphical manipulation of formal and syntactic representations. This conception of formation processes is related to the dynamics and heterogeneity of topological versioning that goes beyond dimensional variation. Two digital techniques are associated with this model: animation and parametric design. In both, topology is playing a major role. 'Formations by animation' have introduced the concept of 'dynamic design'. Parametric formations have introduced the concept of topological variations. In parametric formations parameters of particular design are declared, not its shape; different configurations can be created assigning values to parameters. Parametric exploits associative geometry describing relationships between objects, establishing interdependencies and defining transformational behavior of these objects.

3.1.3 Generative models

Generative models of digital design are characterized by the provision of computational mechanisms of generative processes. Here, as compared to formation

models, shapes and forms are considered to be a result of pre-formulated generative processes. Two of the known examples in architecture are evolutionary models (Frazer, 2002) and Shape Grammars (Stiny, 1980, 2006; Knight and Stiny, 2001). Evolutionary models are based on mimicking rules of natural growth such as mutation and reproduction and Shape Grammars provide a computational approach to formulize generative systems of designs. A unique formalism of Shape Grammar is the 'parametric Shape Grammar'. Here, the shape rule is defined by parameters which are related to specific context and predefined shapes. Applications of Shape Grammars were widely explored in typological studies of architectural design and structural design.

3.1.4 Performance model

Performance-based models are driven by simulations. Today, there exist a wide range of digital tools for simulation, analysis and evaluation of performance aspects (Chaszar et al., 2006). However, none of them currently also provide generative and modification capabilities. Current theories and technologies of digital design suggest a shift from analytical simulation to simulation for synthesis and generation. These approaches identify generative processes with performance. This distinction is very significant. Instead of analyzing the performance of a design, and modifying it according to results, performance-based simulations can directly modify designs. In such approaches the desired performance can be activated as a performative mechanism to generate and modify designs digitally (Oxman and Rosenberg, 2007; Oxman et al., 2007). Performance here is defined as the ability to directly act upon the physical performance properties of specific design. In addition to quantitative properties, these classes of properties could eventually be broadened to include qualitative aspects such as spatial factors in addition to technical simulations such as structural and acoustical performance.

Figure 1 presents the difference between a conventional cyclic process (upper part) typically known as an iterative 'analysis–synthesis–evaluation' process and performance model (bottom part) (Oxman et al., 2007).

Architectural design shifts from pure modeling to the understanding of organizational principles and systems with a specific behavior. The actual form emerges from a process seeking for optimal performance. Solutions derived from this process do not necessarily match conventional structural systems but gain performance by self-organization of its members (Bollinger and Grohmann, 2004).

Forces such as physical forces, e.g., wind forces on building structures, in a given context are fundamental to form-making in performance-based design. External forces may be considered as environmental forces including structural loads, acoustics, transportation, site, program, etc. Information itself is

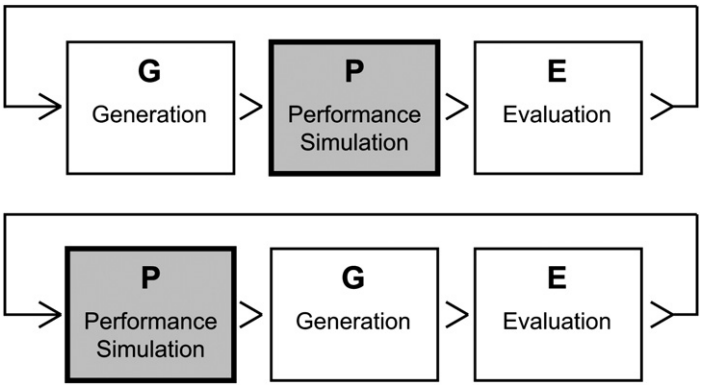

Figure 1 Models of performance: (upper part) conventional CAD simulation model and (bottom part) performance model

also considered as an external 'force' that can manipulate the design (Oxman and Rosenberg, 2007).

4 The challenge of a pedagogical framework for digital design didactics

Today, existing models of architectural education are in the process of adjustment to new cultural and technological conditions of the digital age. This situation can be seen as analogous to the crystallization of Modernism as a pedagogical model during the period of the Bauhaus. The Bauhaus is perhaps relevant, since this model of education evolved in a period of a similar major shift in theory and design. Among the distinctive pedagogical ideas was to support design as exploration within the integration of new domains, particularly those of craft and the fine arts. The 'working materials' (glass, clay, stone, wood, metal, fabric and color) were interpreted as contributing key properties to be manipulated in design.

The Bauhaus (1919–1933), and later the HfG Ulm (1955–1968), emerged in periods of conceptual change in both content and tools (from craft to mechanization). The Bauhaus provided a theoretical orientation to modern design through the integration of art and design in order to introduce new forms, new materials, and a new orientation to design in an age of industrialization (Wingler, 1969; Naylor, 1985). Learning based upon materials and tools and the study of nature, material science, space–color–composition, construction and representation were integrated in that pioneering program.

The 'Vorkurs' – the foundation course – was created as a framework in which the elementary study of form and material was introduced. This exposure was conducted largely in the workshop through hands-on activity of doing and making, drawing upon craft as the medium that was materially founded. Thus among the educational distinctions of the program was the meeting of the conceptual and the material in the format of problem related learning. This bi-polarity of new formal concepts integrated with material imperatives

was part of the experimental heritage of the Bauhaus as an educational model. In order to support this new curriculum, a new generation of teachers had to be educated. The example of the Bauhaus and its pioneer teachers (Marcel Breuer was himself a graduate) demonstrated a strategy that integrated skill (craft techniques, making) with new conceptual content.

Similar to these educational principles, a new pedagogical framework may be based on such a bi-polarity in which digital design media create new forms of integration between the theoretical (architectural theory) and the models (design theory). Digital design education spread across the architectural curriculum will have many manifestations.

What is, in fact, the distinctiveness of the digital studio as contrasted with conventional paper-based studios? Does the nature of digital design affect design processes to the extent that studio educational formats must accommodate new processes and conceptual structures? Can the experimentation with such new conceptual structures become an objective of design education? Has the praxis of digital architectural design come of age to the extent that we can define such emerging conceptual vocabularies?

One of the pedagogical responsibilities of academic institutions is to provide the basis for theoretical discourse that would consider such intellectual content and would explicate its design implications.

4.1 The impact of conceptual content

Many of the conceptual terms that have been applied in the experimental studio are attempts to explore the concepts related to digital design.

Beyond the mere transformation of design media, the new design paradigm also has contributed to the emergence of new concepts, such as continuous versus discrete, intricate versus hierarchical, topological versus typological, material versus space, structure versus form, formation processes versus representation, etc.

Parametric design (Burry and Murray, 1997) has become medium of experimentation in itself. The parametric design process is formational rather than compositional and formal. For example, in parametric design, the manipulation of associative geometrical relations of complex structural patterns can be further mapped to organizational and spatial concepts of the complexity of heterogeneous structures.

Lynn (2002, 2003) has defined this shift away from the spatial, formal and compositional terminology of the post-modern. 'Wherever two or more of the words ''form'', ''space'', ''design'', ''order'', or ''structure'' are found in company, one can be sure that one is in the world of modernist discourse'

(Forty, 2000). For example, the attributes of hyper-connectivity and non-hierarchical structures of organization have influenced the creation of spatial design concepts involving new forms of continuity and new concepts of indeterminate and non-homogeneous environments.

Given that a rigorous formulation of such concepts does not yet exists, any work based upon as yet unformulated body of theory must, by necessity, be in itself experimental.

4.2 Beyond formal representational design

We have seen that this process of formal–graphical evolution in design representation has been well-formulated by various design theoreticians. Any approach at a new pedagogy predicated on new forms of digital design thinking must necessarily move beyond the formal syndrome of representation, formal language and compositional collage aesthetics. Today, the departure from paper-based design concepts and sketch-based design attempts to create counter-theories of digital models in place of the representation and modification of images and the use of visual precedent.

4.3 Matter and material

Another goal of any new digital pedagogy is to define an understanding of 'matter and material'. The interpretation of sketching as design thinking through iterative stages of visual formal discovery is the antithesis of the digital 'matter and material' approach. In the latter, digital design introduces a unique design ontology. This fundamental change has been postulated by Reiser and Umemoto (2006) as follows: 'Mies' constraint of matter by ideal geometry is based on an essentialist notion: that matter is formless and that geometry regulates it, that geometry is transcendental and in some sense indifferent to the material that substantiates it. When freed from such essentializing conceptions, matter proves to have its own capacity for self-organization'.

4.4 Didactic implications

The conventional educational model in the design studio has generally employed accepted knowledge and a simulation of praxis as a didactic model. That is, most studios still employ well accepted knowledge-bases and typologies in architectural design. Furthermore, the didactic stages are usually driven by a theoretical interpretation of program, site, and conditions carried through stages of conceptualization, schematic design and design development. If indeed, digital design constitutes a novel set of conceptualization as well as a novel set of design methodologies, how do the new medium and the new knowledge base influence the content and practice of the design studio?

4.4.1 Transforming the typological definition of design problems

Typological knowledge is one of the foundational principles of modern architectural education. According to Colquhoun (1989) it is precisely through the

persistence of earlier forms that the system can convey meaning. These forms, or types, interact with the tasks presented to architecture, in any moment of history, to form the entire system.

Models and processes of digital design may provide a different orientation to design exploration and creativity. Instead of a conventional holistic typological problem definition including context and explicit functional programs, definitions of digital models such as 'formation by animation' or 'parametric design' can serve as a starting point for design exploration. Such orientations are explicitly anti-typological.

4.4.2 Transforming the design process

The exploration of new conceptual vocabularies may require different stages of exploration. This orientation can be achieved only by freeing the student from expectations related to conventionalized design studio-approach. Instead of following the traditional sequence, for example, the analysis of a given site, definition of functional programs, followed by conceptual design, the generation of architectural space, to visual representation, etc. a didactic principle that transcends the conventionalized design methodological sequence can be explored.

The educational process need not necessarily be 'project-oriented' in the conventional understanding of the term. No program or specific site need be presented at the inception of design, assuming that design is an exploratory and research-based activity. Teaching may in turn be 'model oriented'. The investigation of digital models and processes along with an orientation to 'material exploration first' are significantly different from many of the existing pedagogical traditions of the design studio.

Again, this is a substantive change in the logic of design. Theory is expressed as method, and method becomes the model of design process that is integrated in the studio.

4.4.3 The digital medium and the design process

One of a major aims of the studio is to demonstrate the methodological relevance of the concept of digital models in relation to digital design processes. The following points enhance design exploration through digital processes:

- Formation, generation and performance are the motivating forces of digital design.
- The coupling of these three processes with the new material sensibility is the frontier of design research.
- First material, then selecting a digital design model, is suggested to be the methodological sequence of digital architectural design.

In the following section we present an experimental design studio and illustrate selected projects. Given that the orientation is toward exploration and research rather than the production of a final product in the form of a one-off finished design, each student can be assigned a digital research task, concept set, and methodology appropriate to his own interests and aptitudes.

5 *Exploration of digital models, methods and design concepts*

The digital design studio is experimental in the sense that it encourages research-oriented study. This is treated as a bottom-up process – one can explore processes that can organize a set of ideas and rules that can than modify the process by selecting alternative methods and techniques of exploration. Each of the following projects was developed by exploiting digital models and techniques that suited the theoretical and conceptual content of the project. In each a conceptualization of 'digital material' and a unique digital model or digital technique appropriate to the material concept was employed.

The didactic process consists of the following four basic steps:

- Conceptualize and define a specific type of 'digital material'. Digital material can be defined as an organizational structure, or pattern, of a certain material.
- Define a specific digital design model related to formation, generation, or performance, or relationships of such models.
- Select a context that can best demonstrate the behavior and applicability of the 'design material' in relation to principles related to formation, generation or performance.
- Develop and present a taxonomy (related to digital architecture) that can be used to describe the digital architectural design thinking processes.

All work is in the form of multiple short exercises which are finally produced by each student as a research report including the conceptual vocabulary. These experimental projects explore the intersections between methodologies techniques, representational modes, etc. underlying the integration between digital media and the conceptual. They also explore resulting new geometries related to particular forms such as topological surfaces and responsive network structures that are related to the given materials.

5.1 *Continuously evolving topological vocabularies*

The following research explored the concept of hypercontinuity as an expression, a linear evolving topological vocabulary of form. It accommodates the complexity of topology (Emmer, 2005) and attempts to apply topology that maintains the same relations along a linear development. The application involves the study of such design methods and techniques in order to develop

a national boundary. In this case, the boundary is conceived of a continuous set of diverse functional spaces for collaborative activities of the neighboring countries. Changing requirements along the boundary create a constantly changing condition of context and program along the otherwise continuous design of the boundary.

Acting together, both performance-based technique and the definition of programmatic parameters produced a concept: a 'functional boundary', that is, hypercontinuity of surfaces and volumes, and heterogeneity. This approach relates to the generic problem of complex program and changing conditions. Heterogeneity has replaced the instantiation of a particular standardized, modular structure as is currently routinely applied irrespective of complex changes of program and conditions (see Figure 2).

5.2 A Mobius model of continuity

In comparison to the digital model of topological geometry studied in the first research, the following design project explored a topology of the Mobius Ring; named after August Fernando Mobius (1790–1868). It is characterized as an infinite spatial topology; without definition of inside and outside. In this project these characteristics are employed in order to create a blurring of the conditions of inside and outside, horizontal and vertical employed as an architectural space. These studies were then utilized to be explored in an architectural project (see Figure 3).

5.3 Generative design based on morphological principles

The conceptualization here is based on a study and analysis of the morphological principles of woven textiles. This woven material created an indeterminate range of heterogeneous folded profiles that were versions of folding and weaving principles. The formation principles of the woven materials were exploited to generate the structure. These profiles evolved to enable spatial, structural and environmental envelope functions within the woven matrix. The design transformations are defined by a set of syntactic rules related to morphological principles. The diverse matrices were transformed with respect to their solar protective (sun-shading) potential (see Figure 4).

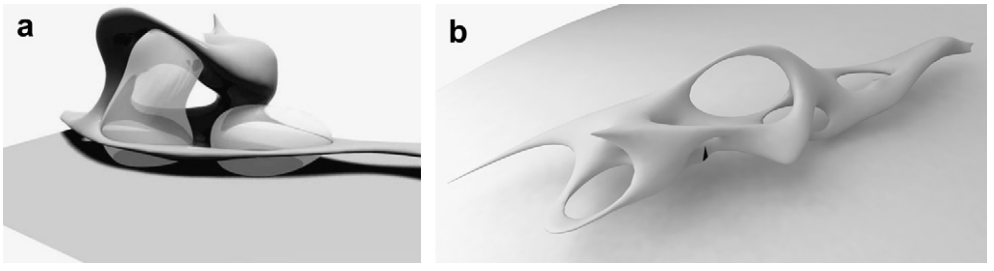

Figure 2 Topological design of a continuously evolving boundary (Farah Farah, Technion IIT)

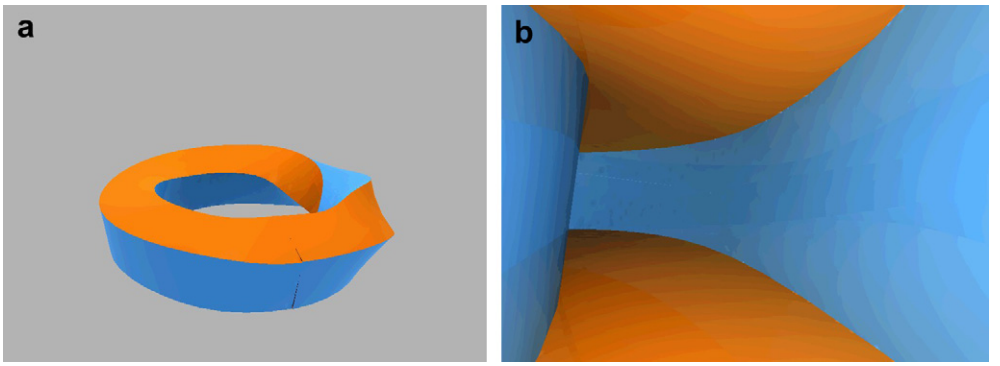

Figure 3 Spatial explorations of Mobius-based digital models (by Shaul Goldklang, Technion IIT)

5.4 Parametric models

The project is based on a parametric system that enables the local modulation of the structure in response to performative factors of the physical context. Here again, the analysis is based upon solar control. The design method employs parametric techniques which resulted in the production of parametric versioning of continuous structural cellular network morphology (see Figure 5).

5.5 Performance-based design

The responsive wall integrates a constructive skeleton that supports a system of a scale-structure. The skeleton has built-in sensors that can inform and simulate the dynamic motion of the scale system. The skin design itself has been generated by a performance-based simulation of wind force and light penetration (Oxman et al., 2007). These forces produce dynamic effects on the skin. The objective in this model is that the formation of the skin–structure assembly will be generated by multiple performative conditions, all of which are dynamic. This condition of design models, that support multiple performance-based analyses in their componentized assembly, is

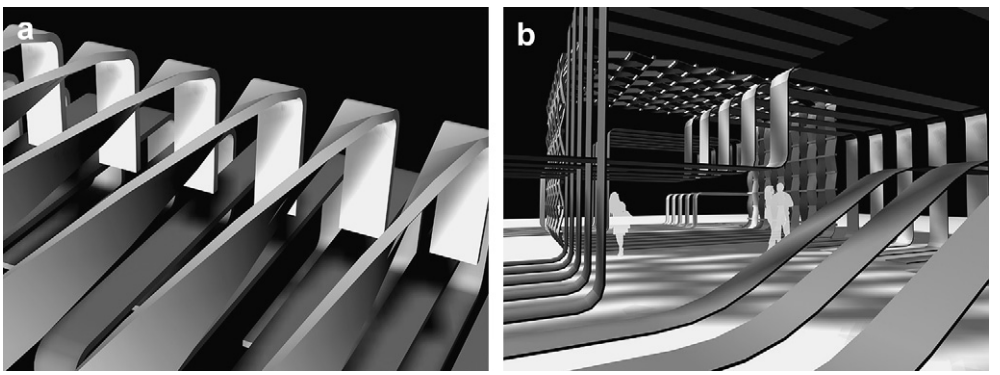

Figure 4 Generative design based on morphological principles (by Alex Eitan and Tal Kasten, Technion IIT)

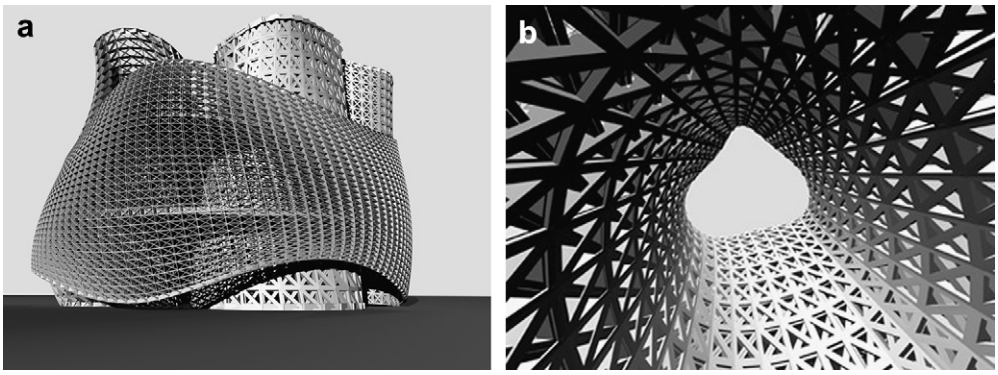

Figure 5 Parametric material models and their performative attributes (by Shoham Ben Ari, Technion IIT)

highly representative of complex wall assemblies. Animation studies were employed to model the formation process in which form generation was controlled according to types of simulations. The specific context in this case is the need to support the dynamic behavior in the various components in response to the dynamic nature of the wind and light loadings of the building surface. The skin is responsive to environmental performance and involved the design of responsive building skins that might protect a building from excessive wind loads, solar penetration and acoustical contextual problems such as urban noise (see Figure 6).

5.6 *Physical model of digital material*

Physical modeling techniques were found to be extremely significant in that they provide a complementary technique for the study of digital material. As pointed out above by Reiser and Umemoto, they can also function as an 'analogue computer' providing an efficient medium for the testing and study of material behaviors. Since current descriptive geometrical modeling lacks intrinsic structural logic, the physical model provides a complementary medium.

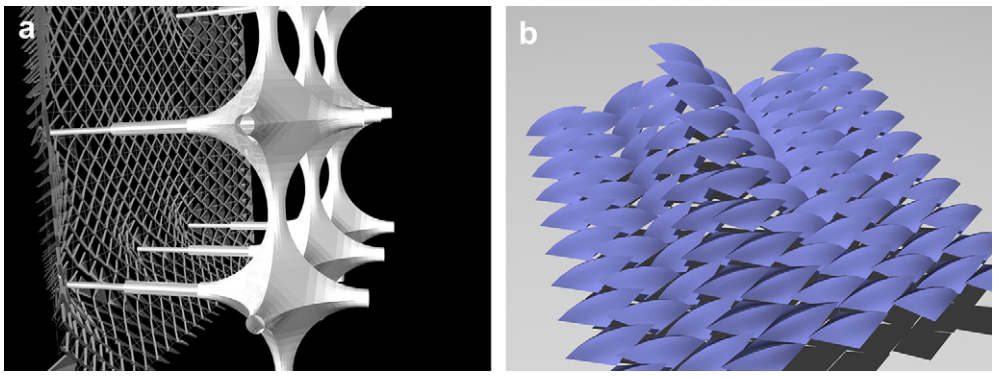

Figure 6 Performance-based design and dynamic attributes in 'Responsive Systems' (by Shoham Ben Ari and Roey Hammer, Technion IIT)

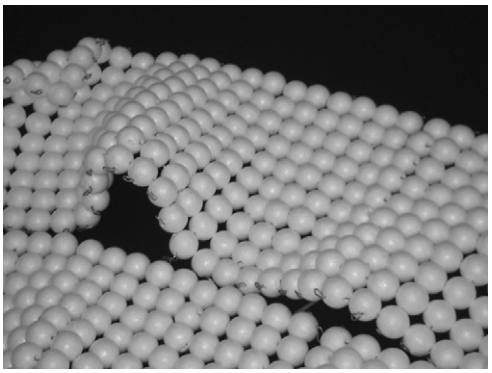

Figure 7 Physical model of digital material (by Sarit Weingarten, Technion IIT)

Physical studies can then be translated into digital models for transformation and versioning (see Figure 7).

6 *Digital architecture and the challenge of a new pedagogy*

As a result of these experiences we have encountered new orientations to the explication of the judgmental aspects of design as performative and generative factors. The student has become adept at juggling the multiple forms of data and images that are represented in digital design environments. Far beyond Schön's characterization of visual reasoning as a 'dialogue with the materials of the problem' and 'backtalk' from visual images, the digital and compound processes of formation, generation and performance of 'digital material' creates a completely novel view of design that may even justify the uniqueness of the term, digital design thinking.

Architectural thinking has been presented as non-typological and non-deterministic in supporting and preferring the differentiated over the generic and the typological. We have explored new forms and relationships between the designer, process and information establishing new approaches to design. Integration of techniques, such as parametric formation, etc. has provided novel venues for design exploration. These models have demonstrated the growing impact of digital design media as a mediator between content and skill.

With respect to certain of the root concepts of conventional design theories, the implications of these transformations of traditional didactic principles, as we believe, have demonstrated significant implications for the field of architecture and design education.

Root concepts in design theory such as representation, typologies, and other principles of the visual literacy school of design pedagogy are transformed. Instead concepts such as morphogenesis, generative and performance-based design, materialization and production are introduced. A schema of four

paradigmatic models presents an interpretation of digital design in which the methodological characteristics of these paradigms have been formulated relative to theoretical concepts of design and design thinking. These models include formation, generation, performance, and performance-base generation. These four processes become the underlying logic of digital architectural design in which digital models can be applied to architectural content and design tasks.

As digital design media become more complex and more demanding with respect to knowledge of multiple types of software, knowledge of scripting languages, and the manipulation and maintenance of complex data models, there will be a need to educate a new generation of digital design specialists. The thought of the designer as digital tool-maker reflects both the potential for customizing digital design media as it does the necessity for specialist knowledge needed to operate such media. So presently the idea of a class of 'digerati', or digital literati as advanced digital systems designers appears to be an accurate description of the contemporary situation.

Beyond any doubt digital design appears to be a mainstream phenomenon, and the theory of digital design appears to be one of the most active and significant subjects of theoretical discourse today. Our approach to fitting the digital and the theoretical has dealt with the problem of any new pedagogy: beginning with a new taxonomy for digital architectural theory. This has occurred in order to create the theoretical foundations of new processes of design that, in turn, are transforming our accepted traditional models and logic of design. Together with the accompanying technological and media developments, the foundations of architectural education appear to be in need of a make-over from the bottom-up.

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