Theories and Models of Parametric Design Thinking

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Due to significant recent design-related technological developments, design theories and processes are undergoing re-formulation and an epistemological shift. The tools and practices of parametric design are beginning to impact new forms of Parametric Design Thinking (PDT). The present work is motivated by the need to explore and formulate the body of theoretical concepts of parametric design. It is built around the intersection of three areas of knowledge: cognitive models of design, digital models of design, and parametric tools and scripts. The work identifies forms of cognitive mechanisms in parametric design; types of logical flow of information that can be applied in digital processes for performance-based design; generative design and form finding. It explores the impact of parametric models and tools upon styles of design thinking from conception to production. These are presented as a body of knowledge in the search for thinking and process models of PDT in design.

Keywords: Parametric Design, Parametric Schema, Parametric Design Thinking, Generative Design, Performative Design

INTRODUCTION

Due to significant recent design-related technological developments, design theories and processes are undergoing re-formulation and an epistemological shift. Parametric design systems today can adapt to changing context (Woodbury 2010) under the influence of parametric languages and scripting techniques (Jabi 2013) and to diverse topological relationships and generative processes of design (Oxman 2006). Among its forms of influence parametric design has affected the topological and formal characteristics of designs produced in diverse design fields such as architecture, industrial design and fashion design. Current research has also shown that the development of new tools and scripting environments are also contributing to a distinctive design methodology and new epistemological bases of design knowledge resulting in new forms of design thinking (Oxman and Oxman 2014). We refer to these emerging phenomena as Parametric Design Thinking (PDT).

The work presented in this paper is motivated by the need to explore and characterize current theories and practices of parametric design and to reformulate the underlying concepts behind parametric design thinking. One of the bases for understanding these phenomena is the emergence of a body of cognitive and computational concepts that are expanding the role and overall design impact of parametric design. This body of concepts is rapidly becoming the nexus of theory and production in parametric design. Terms and concepts such as parametric
schema, algorithmic thinking and parametric reasoning are becoming an important body of new knowledge in the search for a general theory of PDT.

Following upon recent studies on parametric design methods and tools in academia and practice (Hernandez 2006; Iordanova 2009; Cellini and Vaz 2012) we focuses in this research upon theoretical and methodological issues, and the definition of concepts while exploring their relationships in order to expand current design theory and knowledge.

Our research is built around three areas of knowledge: cognitive models of design, digital models of design, and the examination of the impact of parametric tools and scripts. The research aims to explore their relationships and their mutual impact on PDT. In the following sections a body of design topics is introduced, discussed and presented with specific examples from architectural design.

PARAMETRIC DESIGN
Parametric design thinking can be defined as having three characteristics - thinking with abstraction; thinking mathematically; and thinking algorithmically (Woodbury, 2010). Thinking with abstraction is a base that enables parametric design as a generative approach for producing parallel alternatives and it also enables parts of the parametric model to be reused. Thinking mathematically refers to the theorems and constructions used to define the scripting language for design representation and generation. Thinking algorithmically means that the scripting language provides functions that can add, repeat, modify or remove parts in a parametric design.

Woodbury claims that in a parametric design environment designers need a different kind of knowledge that can "predict persistent effects to understand the diversity and structure of the mathematical toolbox, and to shuttle between the intended effect and mathematical invention that models it" (Woodbury 2010). That means that parametrically discriminating designers would need to know more than merely basic architectural knowledge. However, there should also be an informed balance between pure parametric tool manipulation and the utilization of a broad understanding of architectural knowledge in the parametric design process. For example, some designers who embrace what is referred to as Parametricism may tend to abandon fundamental architectural principles and concerns, having the tendency to avoid comprehensive critical judgment and aim instead for formal novelty through computing power without addressing other basics of architectural design such as social, historical and environmental concerns, functional and programmatic requirements, and user's psychological needs (Castellano, 2011).

The following three points are generally characteristic of the parametric design process:

- Designers design rules and define their logical relationships in the creation of 3D visualization models
- Designers can change and modify their design at any stage
- ...
Designers can change and modify their own rule-based representations in any stage of the design process. In processes of parametric design, the design system is differentiated and correlated. In the parametric model, all design procedures and activities are related to one another and clearly defined (Schumacher, 2008). Therefore, designers can return back in any stage and revise parameters or rules to modify their design or to pursue a different one. This allows them methodologically to keep the design process open and flexible.

- Design alternatives can be developed in parallel in any stage

Designers often consider a relatively limited number of alternative solutions (Woodbury & Burrow, 2006). In the parametric design process, once the rules are implemented, unlimited numbers of design alternatives can be generated in parallel. The possibility to use parallel design generation is changing modes of thinking and contributes to explorative processes (Hernandez, 2006; Holland, 2011; Karle & Kelly, 2011).

PARAMETRIC DESIGN THINKING (PDT)
Beyond any particular formal style or design tool, parametric design thinking is emerging as a theoretical topic (Oxman and Gu, 2013) and a key model of digital design. With the emergence of new languages and tools, and in comparison to traditional models of the parametric, the generic formulation of a Parametric Design Schema should be formulated and explored as a comprehensive theoretical framework to support design.

Karle & Kelly, 2011 describe this process as "a new way of relating tangible and intangible systems into a design proposal removed from digital tool specificity and establishes relationships between properties within a system. It asks architects to start with the design parameters and not preconceived or predetermined design solutions." (Karle & Kelly, 2011) Beyond being merely a new digital technique, parametric design thinking is more about an understanding of parametric structures of design knowledge that can be formulated and represented as generic parametric schema. The adoption of design patterns in certain domains is a phenomenon that has been observed by a number of researchers in both traditional architectural design (Alexander et al., 1977) and in parametric design (Woodbury et al., 2007).

According to Brett Steele, parametric design knowledge is a model of design thinking that integrates topological patterns within generic typologies. This cognitive capability has been termed, the "serial sensibility" (Brett Steele, in Lee and Jacoby, 2007).

The Role of the Cognitive Parametric Schema
The cognitive role and the logic of a generic knowledge schema as a basis for understanding process of schema adaptation and refinement by re-representation can be demonstrated through examples of prior research (Oxman, 1992; 1997). The emergence of a new schema is a fundamental cognitive capability of creativity in the human designer. In the process of design, engineering, and construction the schema can be modified and adapted. To summarize, the role of the parametric schema:

- Providing an explorative mechanism
- Providing a medium for generating variation
- Providing a medium for transformational processes

The cognitive roles and the logic of a generic schema (referring in this case to architectural knowledge of basic classical temple types) can be demonstrated through the example of the Classical Greek Temple, reflecting the different styles, geometrical series and proportions (see figure 1). The cognitive role and the logic of a generic schema (referring in this case to architectural knowledge of column types and variables) can also be demonstrated by examples of the Classical Greek columns (see figure 2).

These two examples represent the distinction between generic typological-schema referring to typological design of different types versus a
topological-schema referring to topological formation by changing the value of parametric variants of the Greek Columns. Please also write your "reply to the reviews" directly in the paper, using notes such as this one to point out where you have reacted to the inputs given.

The Role of the Visual Representation in Parametric Schema
Traditional representations in design are focused upon visual and geometrical representation of the design object. Visual representations are generally non-explicit with respect to presenting the structural logic behind form making and the development of the object under design.

In visual parametric schema the designer interacts with parametric modeling using visual code symbols. The image of the design is generated by the 3D Rhino modeling component of the system. The parametric capability of a Grasshopper system enables generation and modification of the design by changing the parameters rather than rewriting the code (or 3D re-modeling by Rhino). This presents a typical process of visual reasoning in which a parametric modification process of the script maintains the parametric relationships that have been defined and generated.

Tools, Scripting and Coding of Parametric Design Process
Understanding and developing methods of programming such as parametric scripting and coding for various process-based models of digital design are providing a foundation for the characterization and conceptual definition of parametric design thinking.

In order to represent processes of parametric design there is a need to explicate the flow of information and the logic that is embedded in process models of design focusing on the explication of knowledge structures and the order of flow of information; the constructive logic should become explicit. In parametric modeling of digital models of design (for example: Grasshopper) there are two types of visual display. An interactive display of the visual image is generated in parallel to interactive programming by visual scripting code. Parametric variations of the image can be updated and generated simultaneously in a visual display in parallel to code modification. The following figure illustrates the linked dual provision of the visual interface for interactive code input and the resultant 3D graphical representation (Oxman 2016) (see figures 3-6).

Understanding how a parametric schema supports the logic of a digital process model in design (Oxman, 2006) requires skill and knowledge that includes parametric design, theories of topological structures and their relations, mathematics, and associative geometry.
Conclusions
We have introduced and explored a range of research issues in the characterization and definition of PDT in architectural design. Certain basic terms and concepts have been discussed in order to provide a theoretical framework for defining PDT. The clarification of the taxonomic, epistemological, and theoretical issues in PDT has been outlined. Further development of a comprehensive theory of PDT in parametric design in architecture is a comprehensive and important undertaking.

Such a comprehensive theory would be based upon the distinctive concepts and models of parametric design thinking and their impact on the formalization of distinctive forms of information flow in parametric models of design. This would include a comprehensive formulation of the generic cognitive and computational reasoning models that are applied in processes of parametric design.

It appears to have now become important to understand the role of parametric tools on design thinking. We have here made a first attempt to contribute to the definition of PDT, its dominant concepts, theories, models, and its emerging research agenda. Given the rapid development and the broad acceptance of parametric design tools, the further extension of this research agenda as well as the definition of its intellectual resources appears to be a high priority agenda for design research and the digital design community.

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