USING SITUATED FBS ONTOLOGY TO EXPLORE DESIGNERS' PATTERNS OF BEHAVIOR IN PARAMETRIC ENVIRONMENTS

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Abstract. Current literature suggests that there is limited empirical evidence supporting the understanding of designers' behavior or processes in parametric design environments (PDEs). This on-going study explores designers' patterns of behavior in PDEs and its relationship with design creativity. To achieve this, we introduce the situated function-behavior-structure (FBS) model to develop a customized coding scheme for future protocol studies. This FBS ontological model has been adapted to reflect the characteristics of parametric design. We propose to apply the results of the protocol analysis in identifying three levels of design behavior patterns: behavior patterns derived from design processes, behavior patterns derived from the whole design life-cycle and those derived from the two levels of parametric design activities (design knowledge based activities and rule algorithm based activities). Future experiments and subsequent protocol analysis will apply the coding scheme to identify these behavioral patterns. The relationship with design creativity will then be explored by mapping the identified behavior patterns against the design outcome assessment.

1. Introduction

Parametric design has become increasingly popular in the architectural design industry in recent years. According to Kolarevic (2003), this change is characterized by a rejection of static solutions in conventional design systems and the adoption of intelligent systems which have rendered design processes more flexible and productive. As argued by Woodbury (2010), design processes in parametric design environments (PDEs) are different from those in other design environments due to the unique characteristics of PDEs. Analysis of literature further shows that there is a lack of empirical evidence supporting the understanding of designers' behavior in PDEs. The overarching question therefore is, what are the typical design activities in a parametric design process? For instance, in PDEs, what are the characteristic patterns of a designer's behavior? What methodology best favors design process and knowledge transfer? What kind of design behavior patterns lead to more creative design solutions? Aiming to answer these questions, this study starts by exploring design behavior patterns in PDEs using protocol analysis.

To prepare for the protocol analysis, we adopt Gero's and Kannengiesser's (2004) situated FBS ontology model to form a customized coding scheme in order to reflect the characteristics of designing in PDEs. The model has been applied in a variety of cognitive design studies and is potentially capable of capturing 92% of meaningful design processes (Kan and Gero, 2009). Moreover, as reported by these authors, the situated FBS ontology model indicates clear transitions between design events. Therefore, the situated FBS ontology provides a reasonable foundation for developing an appropriate coding scheme for our research. Moreover, in protocol studies, the coding scheme has to be suitable for the design environment being studied; this means it should reflect the characteristics of parametric design in this particular study. Based on related works in parametric design such as those by de Boissieu et al., (2011) and Woodbury (2010), there are two levels of typical activities in parametric design process: activities based on design knowledge and activities based on rule algorithms. It is also possible to suggest that designers' behavior in PDEs shifts between these two levels. Therefore, these two levels of parametric design activities have been combined with the FBS ontology for developing our coding scheme.

2. Background

2.1. PARAMETRIC DESIGN

Parametric design is a dynamic, rule-based process controlled by variations and constraints, in which multiple design solutions can be developed in parallel. According to Woodbury (2010), it supports the creation, management and organization of complex digital design models. By changing parameters of an object, particular instances can be altered or created from a potentially infinite range of possibilities (Kolarevic, 2003). In the architecture design industry, parametric design tools are utilized mainly on complex building form generation, multiple design solution optimization, as well as structural and sustainability control.

Previous studies on designers' behaviors in PDEs show that parametric tools advance design processes in a variety of ways. For instance, evidence shows that the generation of ideas is positively influenced in PDEs. Particularly, in

Iordanova et al.'s (2009) experiment on generative methods, ideas were shown to be generated rapidly while they also emerge simultaneously as variations. Moreover, Schnabel (2007) shows that PDEs are beneficial for generating unpredicted events and can be responsible for accommodating changes. However, researchers have typically studied design behavior in PDEs mostly by observing students interactions with PDEs in design studios or workshops. Arguably, this approach can hardly provide an in-depth understanding of designers' behaviors in PDEs. This empirical gap will be addressed in the present study by adopting the method of protocol analysis.

2.2. SITUATED FBS ONTOLOGY

Since its publication, Gero's (1990) original FBS model has been widely used as a theoretical foundation to study designers' behavior in cognitive design studies. The FBS model contains three classes of variables: Function (F), Behavior (B) and Structure (S). Function represents the design intentions or purposes; behavior represents how the structure of an artifact achieves its functions; structure represents the components that make up an artifact and their relationships. There have been many design cognitive studies that develop and apply coding schemes based on the FBS model to study design cognition in different environments. These include collaboration in virtual environments and in face-to-face design settings (Kan and Gero, 2009) as well as in digital and traditional sketching environments (Tang et al., 2011). Like any research method, coding schemes based on the original FBS model have their limitations as they focus more on designers' intentions and on "thinking aloud", both of which are criticized as overtly influencing participants' perceptions (Suwa and Tversky, 1997).

Gero and Kannengiesser (2004) further developed the FBS model by introducing interaction in three worlds the external world, interpreted world and expected world (Figure 1). This development divides the variables into 10 classes and establishes 20 design processes. This situated FBS ontology is allegedly capable of capturing 92% of meaningful design process compared to only 66% in the original FBS model. Furthermore, it is claimed to be a universal coding scheme which can be adapted for a variety of design processes (Kan and Gero, 2009).

There are eight processes in this revised situated FBS ontology: Formulation process: processes 1,2,3,10; Analysis process: process 14; Synthesis process: process 11; Evaluation process: process 15; Documentation process: processes 12,17,18; Reformulation process: processes 6,9.13; Reformulation process: processes 5,8,19; Reformulation process: processes 4,7,16,20. In terms of the eight design processes in the FBS ontology, the reformulation processes have been suggested to be of benefit for evoking design creativity by introducing new variables (including new variables of function, behavior and structure) or new directions (Gero, 1990).

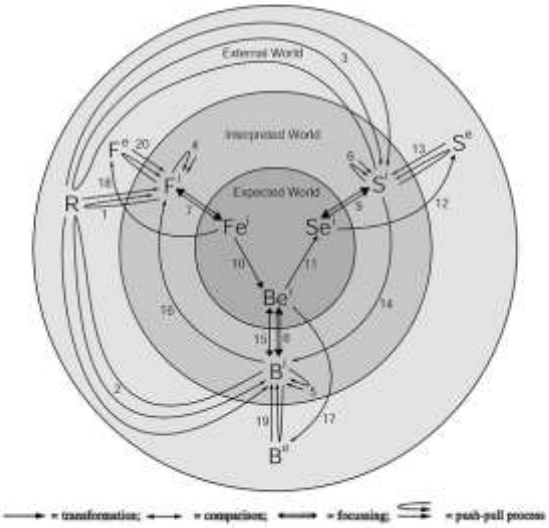

Figure 1. Situated FBS ontology (Gero and Kannengiesser, 2004).

3. Coding Scheme Development

Protocol analysis is a method widely used for cognitive studies into designers' behavior during design processes (Cross, 2001, Cross et al., 1996, Ericsson and Simon, 1980). After collecting protocol data from such design experiments, a particular coding scheme will be applied to categorise the collected data, enabling a detailed study of the design process in the chosen design environment(s). In this section, we present a coding scheme based on the situated FBS ontology and for the purpose of encoding design processes in PDEs.

3.1. DESIGN BEHAVIOR IN PARAMETRIC DESIGN

In comparison with traditional design environments, in PDEs designers are not only modeling geometries, but also defining the rules and their logical relationships. Parametric design "requires a deeper understanding of how it can support our intentions as architects" (Sanguinetti and Kraus, 2011, p. 47). In this design process, PDEs play an important role in calculating, evolving and generating design solutions using computational algorithms to support the process. Meanwhile, the architect "is still ultimately responsible for design intention and needs to be able to look at the big picture to decide which factors to parameterize to give limits to the parameters, assign a weight to each factor and determine method of the information modeling process" (Ottchen, 2009, p. 23). Therefore, we believe that in the typical parametric design process, there are two levels of design activities: design knowledge based activities and rule algorithm based activities. As shown in Figure 2, designers' activities will be transferred between these two levels throughout the parametric design process.

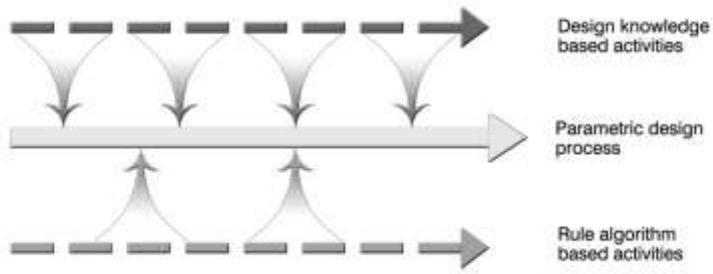

Figure 2. Two levels of parametric design activities

In the design knowledge based activities level, architects make use of their innate professional knowledge, such as how to make the building adapt to the environment, how people will use the building, how to satisfy the requirements of clients, etc. While in the rule algorithm based activities level, designers focus on the operation of parametric design tools. At this level, their design behavior includes defining the rules and their logical relationships, choosing the toolbox suitable for a particular purpose, importing external data into the proposed rules, etc.

3.2. PROPOSED CODING SCHEME

Based on an analysis of design activities in PDEs, the following coding scheme is proposed. Designers' behavior includes their design intentions and design actions. Intentions inspire design actions, while actions are reflections of design intentions. According to the situated FBS ontology, most of the transformation process come from design actions (Gero and Kannengiesser, 2004). Additionally, we interpret some particular parametric design actions into the following categories.

Variables in the function category describe "what the design is for", which is mostly from the design knowledge based level. Table 1 is the function category of our coding scheme.

TABLE 1. Function category

Category	Subcategory	Name	ID	Description

R	Design knowledge based	Intention	R-KI	Considering or revisiting the requirement
F^i	Design knowledge based	Intention	F^i-KI	Initial definition of basic function of building from the requirement
F^e	Design Knowledge based	Intention	F^e-KI	External representation of function, usually from designers' experience or knowledge
F_e^i	Design knowledge based	Intention	F_e^i-KI	Definition of the expected function from the interpreted function

Variables in the behavior category describe "what it does". The rule algorithm based activities consist of intension, constraints and relationships, documented related actions and external data; while design knowledge based activities consist of design intention and perception. The rule algorithm category in interpreted behavior (B^i) represents design actions based on a consideration of how the algorithm rules achieve certain behavior interpreted from requirements or structures. In this context, relationship means the connection between different variables, external data, as well as constraints. Table 2 is the behavior category of out coding scheme.

TABLE 2. Behavior category

Category	**Subcategory**	**Name**	**ID**	**Description**
B^i	Design knowledge based	Intention	B^i-KI	Defining behavior interpreted from requirements or structures
	Rule algorithm based	Intention	B^i-RI	Intention to achieve certain purpose from the rule algorithm view
		Constraints	B^i-RC	Setting constraints
		Constraints change	B^i-RCc	Changing constraints
		Relationship	B^i-RR	Setting initial relationship
		Relationship change	B^i-RRc	Changing relationship
		Document related action	B^i-RS	Hiding, Baking, saving file, reducing duplicate line
B^e	Design knowledge based	Intention	B^e-KI	External representation of behavior derived from knowledge

	Rule algorithm based	External data	B^e-RE	Importing external data or use of designers' own toolbox
B_e^i	Design knowledge based	Intention	B_e^i-KI	Defining expected behavior Traffic Route, direction of building/entrance, etc.
		Perception	B_e^i-KP	Looking at and examining the model

TABLE 3. Structure category

Category	Subcategory	Name	ID	Description
S^i	Design Knowledge based	Geometry	S^i-KG	Modeling initial geometry
		Geometry change	S^i-KGc	Changing geometry
		Calculation	S^i-KC	Calculating
	Rule algorithm based	Parameter	S^i-RP	Setting parameters related to geometry
		Parameter change	S^i-RPc	Changing parameters related to geometry
		Constraint	S^i-RC	Setting constraints related to geometry
		Constraint change	S^i-RCc	Changing constraints related to geometry
		Relationship	S^i-RR	Setting constraints related to geometry
		Relationship change	S^i-RRc	Changing constraints related to geometry
S^e	Design knowledge based	Intention	S^e-KI	Depiction that indicate structure
	Rule based	Parameters setting	S^e-RP	Parameters setting from external knowledge or previous experience
S_e^i	Design knowledge based	Intention	S_e^i-KI	Expected structure/geometry

Variables in the structure category describe "what it is". This class of variables contains mostly design actions related to geometry making. Table 3 is the structure category of our coding scheme.

4. Identification of Designers' Behavior Patterns

Alexander et al.(1977, p.x) describes design patterns as "describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such way that you can use this solution a million times over". Generally, a design pattern consists of a design problem, its context and a specific solution which can be followed and reused. In this study, designers' behavioral patterns are defined as those operations or processes which a person repeats in a certain period/process of design. They will consist of a pattern name, a simple description and a specific transition pattern. Because in future data collection, there will be multiple designers undertaking a 60 minute design task in PDEs, the proposed behavior patterns will be extracted from the design activities that most participants repeat. In the future protocol analysis, there are three levels of behavior patterns being proposed: those derived from design processes, from the whole design life-cycle and from the two levels of parametric design activities. Once the design behavior patterns are identified, design outcomes produced from the experiments will be assessed by an expert panel. The relationship between the identified design behavior patterns and creativity will be explored by mapping the patterns with the assessment results.

4.1. BEHAVIOR PATTERNS DERIVED FROM DESIGN PROCESSES

In this level of the model, behavior patterns are derived from eight design processes in the situated FBS ontology: formulation, analysis, synthesis, evaluation, documentation, reformulation, reformulation and reformulation. In each of the design process patterns, transition frequency, time duration, and distribution in design processes will be analyzed. For instance, analysis process is defined as process 14, which means activities transfer from S^i to B^i. According to coding categories in Table 2 and 3, there are 63 transition possibilities from S^i to B^i. The proposed behavior patterns will be explored by looking into statistical analysis of these transitions. The pattern will help us understand what kind of transition appears most frequently, how much time each transition takes and when it appears.

4.2. BEHAVIOR PATTERNS DERIVED FROM THE WHOLE DESIGN LIFE-CYCLE

In this level, behavior patterns are explored from the perspective of the whole design life-cycle. The proposed pattern will help us understand how the transition between eight design processes happens during the whole design life-cycle; that is, what proportion does each class of variables take up; what is the typical pattern respectively in the early design stage, developing stage and final documentation stage. It may also assist to answer some detailed questions such as how often do designers update parameters, how often do they change constraints, and if they are setting all variations in the early design stage?

4.3. BEHAVIOR PATTERNS DERIVE FORM THE TWO LEVELS OF PARAMETRIC DESIGN ACTIVITIES

In this level, transitions between the two levels of parametric design activities - design knowledge and rule algorithm levels - will be explored. The proposed behavior pattern will help us understand how the designers' activities transfer between these two levels, what proportions does each level of activity take up and how do the two levels of activities distribute in the parametric design process.

5. Conclusion and Future Work

This study proposes a new coding scheme, based on the situated FBS ontology, and further adapted to the characteristics of parametric design. We then hypothesize three levels of behavioral patterns in PDEs which will be expected to be identified in future experiments research. The next stage of this work is to conduct a pilot study to collect data of designers' behavior in PDEs. Results of pilot study will help to test the validity of the proposed coding scheme and the associated levels of behavioral patterns.

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