

COGNITIVE EFFECTS OF USING PARAMETRIC MODELING BY PRACTICING ARCHITECTS: A PRELIMINARY STUDY

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Abstract. This paper presents the results of a protocol study which explores the cognitive behaviour of eight practicing architects while they used a geometric modeller (Rhino) with a parametric modeller (Grasshopper) as they designed. The protocol videos collected were transcribed, segmented and coded using the FBS ontology as the coding scheme. This resulted in each protocol being transformed from a qualitative video into a sequence of symbols from the FBS ontology and further divided into design knowledge and rule algorithm classes. The sequence of symbols forms the foundation on which quantitative representations of cognitive behaviour can be constructed and compared. Results of the relative cognitive effort expended on design knowledge and rule algorithm classes, through an articulation of the cognitive design issues, have been compared and discussed. These results provide insight into the use of parametric modellers by architects.

Keywords. Design cognition; parametric modelling; protocol studies.

1. Introduction

Design media have a significant effect on designers' thinking processes (Chen 2001; Mitchell 2003). With the increasing use of parametric modelling by practicing architects it is useful to determine what effects the use of such tools have on their cognitive behaviour. According to Kolarevic (2003), the change in designing associated with parametricism is characterized by a

rejection of the static solutions offered in conventional design systems and the adoption of intelligent systems. Previous studies potentially support this view, arguing that parametric tools can advance design processes in a variety of ways (Qian, Chen et al. 2007; Schnabel 2007; Abdelmohsen and Do 2009; Iordanova, Tidafi et al. 2009). However, there is a lack of empirical evidence supporting an understanding of designers' behaviour in the parametric design environment (PDE).

In order to examine the way designers think and act in a PDE, this paper presents the results of a cognitive study in which designers were asked to complete an architectural design task using parametric modelling tools. Protocol analysis (Ericsson and Simon 1993; Gero and Mc Neill 1998) was then employed to study the designers' behaviour. From the analysis, the relative cognitive effort expended on two classes of design activities – design knowledge and rule algorithm – through an articulation of the cognitive design issues is presented and discussed.

2. Background

Parametric design is a dynamic, rule-based process controlled by variations and parameters 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 the parameters of an object, particular instances can be altered or created from a potentially infinite range of possibilities (Kolarevic 2003). The term "parameters" means factors which determine a series of variations. In architecture, parameters are usually defined as building parameters or environmental factors.

Previous studies on designers' behaviours in PDEs suggest that parametric tools advance design processes in a variety of ways. For instance, there is evidence that the generation of ideas is positively influenced in a PDE. 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. Schnabel (2007) showed that PDEs are beneficial for generating unpredicted events and for accommodating changes. However, researchers have typically studied design behaviour in PDEs by observing students' actions within PDEs in design studios or workshops rather than practicing architects. This empirical gap is addressed in the present study by adopting the method of protocol analysis in studying practicing architects. Protocol analysis is a method used for in-depth or detailed analysis of designers' cognitive activities. Lee et al (2012) have demonstrated the use of protocol analysis to evaluate creativity in the PDE. Using the same method, Chien and Yeh (2012) explored "unexpected outcomes" in the PDE. Results

of these studies both confirm the viability of the method, and also suggest that in some conditions PDEs can potentially enhance creativity.

2.1. PROTOCOL STUDIES USING FBS ONTOLOGY

Protocol analysis is a method for turning qualitative verbal and gestural utterances into data (Ericsson and Simon 1993; Gero and Mc Neill 1998). It has been used extensively in design research to develop an understanding of design cognition (Suwa and Tversky 1997; Atman, Chimka et al. 1999; Kan and Gero 2008). In design research a common coding scheme is the one based on the Function-Behaviour-Structure (FBS) ontology (Gero 1990).

The FBS ontology, Figure 1, contains three classes of ontological concepts: Function (F), Behaviour (B) and Structure (S). Function represents the design intentions or purposes; behaviour represents how the structure of an artefact achieves its functions; and structure represents the components that make up an artefact and their relationships. Figure 1 shows the eight numbered design processes that flow from this—formulation, analysis, evaluation, synthesis, documentation, reformulation-1, -2, and -3.

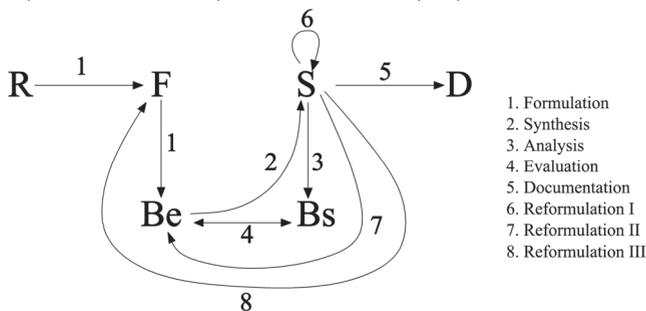


Figure 1. FBS ontology (after Gero and Kannengiesser 2004)

2.2. TWO CLASSES OF DESIGN ACTIVITIES

The ways in which parametric design is used by architects are not well understood which is why Sanguinetti and Kraus argue that parametric design "requires a deeper understanding of how it can support our intentions as architects" (Sanguinetti and Kraus 2011, p. 47). Compared to traditional design environments, in a PDE designers not only design by applying design knowledge, but they also define rules and their logical relationships, using parameters. Thus, in a typical parametric design process, there are two classes of cognitive design activities: the design knowledge and the rule algorithm. In the design knowledge class, architects make use of their design knowledge including, for example, how to adapt a building to the site, how

to shape the way people use the building, and how to satisfy the requirements of their clients. In the rule algorithm class, they apply design knowledge through the operations of the parametric design tools, including defining the rules and their logical relationships, choosing the parameters suitable for a particular purpose and importing external data into the proposed rules. During the design process, designers progress by applying design knowledge directly and in some parts they apply design knowledge indirectly by defining rules and their logical relationships, and this is known as parameterization. In order to capture the processes involved in designing in PDEs, the main class of variables from the original FBS ontology that have been used are R, F, Be, Bs, and S. Each variable is then further decomposed into the two classes of design activities: the design knowledge class, denoted by the superscript K, and the rule algorithm class, denoted by the superscript R, Figure 2. For instance, when designers set up algorithm goals or think about the way to achieve those goals in the rule algorithm space, the segments will be coded as Be^R .

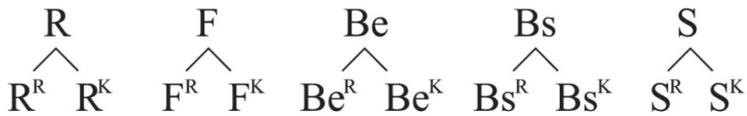


Figure 2. Applying FBS ontology in the PDE.

3. Experiment Setting

The study reported in this paper is focused on the work of eight designers, who are all professional architects with an average of eight years of experience, and with no less than two years of experience using Rhino and Grasshopper. In the experiment, each designer was required to complete a defined architectural design task using a parametric modeller.

During the experiment, both designers' activities and their verbalization were video-recorded by a screen capture program and the recorded data subsequently used for protocol analysis. The design environment is Rhino and Grasshopper, a typical PDE. Designers were given 40 minutes for the design session, although most needed slightly more time to complete the design. The design task was a conceptual design for a commercial building containing certain specific functions and located on a pre-modelled site which was provided to each designer. During the experiment, designers were not allowed to sketch manually so that almost all their actions occurred on the computer to ensure that the design environment was purely within the PDE. All of these controls were put in place to ensure that any variables which

could potentially bias the study were minimized. This design environment is close to a real-world design environment at this stage of the design.

4. Results

4.1. GENERAL RESULTS

In order to increase the robustness of the protocol coding process, two rounds of segmentation and coding were conducted with an interval of two weeks between them. Thereafter an arbitration session was carried out to produce the final protocol from the combination of the two rounds. The percentage of agreement between the two rounds was 83.4% [SD=5.7%], and between the individual rounds and the final arbitrated results was 91.5% [SD=3.1%]. These percentages are indicative of the methodological reliability of the coding process and results. From analysing the eight protocols, the average overall numbers of segments—a segment is the division of a protocol into individual units, in the current research, the division was based on FBS meaning—were 244 [SD=29.7]. The mean time spent on the design session was 48.4 mins [SD=7.4] and over 92.2% of all segments were coded using the FBS model. Non-coded segments include those concerned with communication, software management, etc. The quantitative analysis of FBS design issue occurrences are shown in Table 1. The occurrences of design issues were normalized by turning them into percentages of the total number of design issues in each protocol. The results indicate that designers spent most of their cognitive effort on the structure-related design issues which consist of S^K (21.56%), S^R (20.49%), Bs^K (23.55%) and Bs^R (5.18%). Although designers show individual differences in their design strategies and habits, by exploring the repeated patterns across their behaviours, characteristics of parametric design will be identified.

Table 1. Design issue analysis

	R ^K (%)	F ^K (%)	Be ^K (%)	Be ^R (%)	Bs ^K (%)	Bs ^R (%)	S ^K (%)	S ^R (%)
Mean	1.52	5.09	11.08	11.59	23.55	5.18	21.56	20.49
SD	0.72	2.81	7.96	6.12	5.09	2.80	9.37	10.18

4.2. RELATIVE EFFORT ON THE TWO CLASSES

The protocol’s coding scheme codes six ontological design issues, where a design issue maps onto a cognitive activation. Since the length of each design session varies the number of segments in session is first normalized to be 100. This then makes each design session the same length of 100 normal-

ized segments. In order to be able to compare the relative cognitive efforts, the cognitive activations associated with design knowledge and those associated with rule algorithm are separated and aggregated across all eight designers.

Function (F) and Requirement (R) in the rule algorithm class were coded as zero in this study. The three ontological design issues of expected behaviour (Be), structure (S) and behaviour from structure (Bs) are the most frequently occurring issues and measurements are made using those three. At each normalized segment the relative percentages of cognitive effort on two classes of design activities – design knowledge and rule algorithm – are calculated and plotted. The resulting graphs provide a qualitative overview of the locus of cognitive effort distribution between design knowledge and rule algorithm, in addition to the quantitative values used to produce the graphs.

4.2.1. Overall relative effort on the two classes

The overall relative effort on two classes of designers' cognitive activities – design knowledge and rule algorithm is illustrated in Figure 3. The vertical axis represents the average value of relative effort of eight protocols. The horizontal axis is the normalized segment numbers.

From the overall distribution of cognitive effort shown in Figure 3, we can see that initially the cognitive effort on design knowledge dominates that on rule algorithm. However, as the design session proceeds, the cognitive effort on design knowledge drops from 100% to approximately 60% of the total in a shape that looks like a decay curve. In parallel, as the design session proceeds, the cognitive effort on rule algorithm increases from 0% to approximately 40% of the total in a shape that looks like an excitation curve. Therefore, we can infer that in parametric design process, designers still expend most effort on design knowledge; parametric scripting is mainly used to support their intention of generating models. Designers started with con-

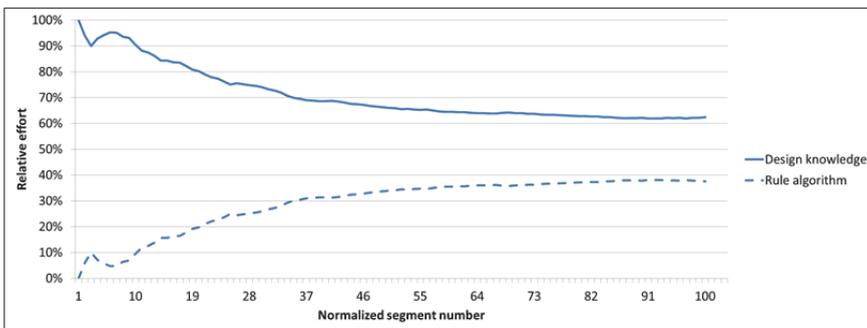


Figure 3. Overall relative cognitive effort

sidering design knowledge-related issues, such as building functions; as the design proceeded, they gradually spent more of their cognitive effort on parametric scripting. In the following sections, we articulate these results with further detail about the cognitive behaviour related to Bs, S and Be, and draw implications from them.

4.2.2. Relative effort on Be

Expected behaviour (Be) means that "designers use theory or experience to speculate what effect could fulfil a purpose before a specific structure is proposed" (Jiang 2012, p 36-37). Applying it in rule algorithm related activities (Be^R) it means that designers set up algorithm goals or think about the way to achieve those goals.

The relative cognitive effort expended on expected behaviour (Be) of the two classes during the parametric design process is presented in Figure 4. In terms of expected behaviour (Be), the relative effort expended on design knowledge class (Be^K) is higher at the beginning and then decreases across the design session; while that on rule algorithm class (Be^R) rises toward the end of design session. At the end of the design session, designers' cognitive effort expended on the rule algorithm exceeds that of design knowledge. From this we can infer that later design in the design session, designers tend to focus more on setting rule algorithm goals and exploring ways to achieve those goals.

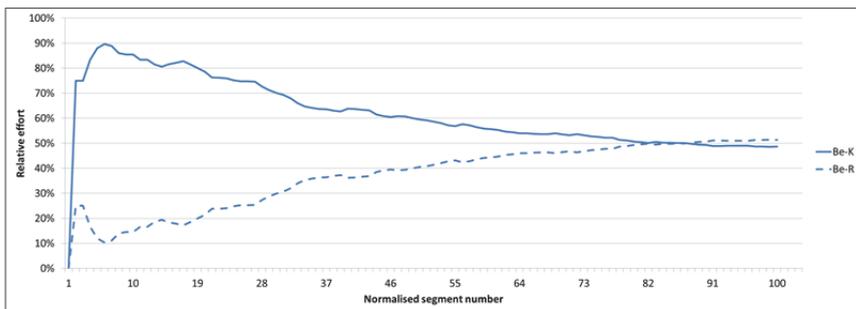


Figure 4. Relative cognitive effort expended on Be

4.2.3. Relative effort on Bs

Structure behaviour (Bs) refers to the behaviour derived from the structure: for the design knowledge class, Bs^K represents evaluation of existing geometry/structure; while for the rule algorithm class, Bs^R means evaluating the structure of the rule algorithm.

The relative cognitive effort expended on structure behaviour (Bs) of the two classes during the parametric design process is presented in Figure 5. Designers expended noticeably more cognitive effort on the design knowledge class than on rule algorithm class during the whole design session when focusing on Bs. Design knowledge-related activities decrease from 100% to approximately 70% during the first third of design sessions and then remain unchanged between 70%-80%; the rule algorithm-related activities increase from 0% to 30% during the first third of the design sessions and then remain unchanged between 20%-30%. From the results in Figure 5, we can see that in terms of Bs, rule algorithm related activities (Bs^R) do not commence at the beginning of the design sessions. One of the possible reasons is that designers only examine rule setting after their rule concepts achieve a certain degree of maturity.

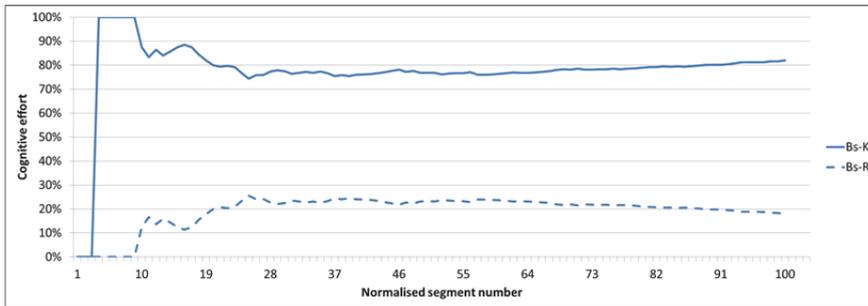


Figure 5. Relative cognitive effort expended on Bs

4.2.4. Relative effort on S

Structure (S) variables describe "the components of the object and their relationships, which mean "what it is"." (Gero and Kannengiesser 2004, p 374). In the design knowledge class, structure (S^K) refers to the elements or relationships of the geometries; while in the rule algorithm class (S^R), it is defined as the structure of the rule algorithm – the components of rules and their relationships for parameterization.

The relative cognitive effort expended on structure (S) for the two classes during parametric design process is shown in Figure 6. From the results in Figure 6, we can see that design knowledge-related activities dominate the design process during the early and mid-stages of the design sessions and then converge to a level similar to that of rule algorithm activities. The cognitive effort expended on S^K decreases from 100% at the beginning of the sessions to approximately 50%; while rule algorithm-related activities increase from 0% to approximately 50%.

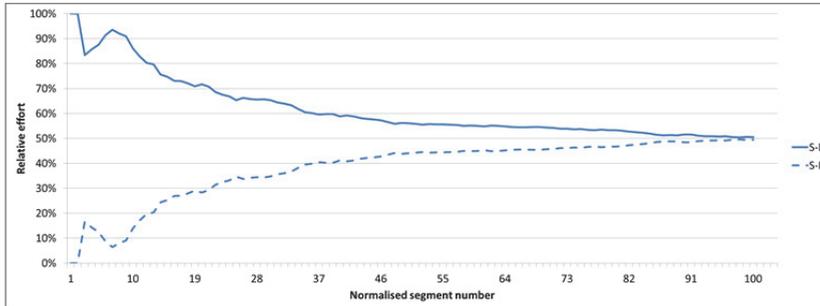


Figure 6. Relative cognitive effort expended on S

5. Conclusion

This paper presents the results of a cognitive study based on an experiment with eight professional architects using parametric design tools. From protocol analysis, designers' relative cognitive effort expended on design knowledge and rule algorithm class have been explored. Results of this study suggest that the division of these two design classes is useful in understanding designers' behaviour in the PDE. The results indicate that the design knowledge-related activities dominate the parametric design process for all cognitive issues.

The implications of these results, if they are found to be generalizable, is that practicing architects with experience in using parametric design tools make use of those tools very early in a design session and make increasing use of them as the design session proceeds. This implies that the designer is substituting rule algorithms for design knowledge.

These preliminary findings have implications for architectural education in the digital design age. Architectural education should include how design knowledge is captured in rule algorithms and in parametric design in general rather than focusing on the structure of rule algorithms only. This opens up ways of encoding design patterns that can form the basis of reusable rules that allow a designer to develop a style of designing and through the rule parameterization a style of designs. Each design generated through the use of these patterns but parameterized individually is unique and responds to each unique program but forms part of an overall style associated with an individual designer or design team.

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