Impact of using rule algorithms on designers' behavior in a parametric design environment: Preliminary result from a pilot study.

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Abstract. This paper presents preliminary results from a pilot protocol study of the cognitive behavior differences of designers in a parametric design environment and a traditional geometry modeling environment. The aim is to explore the impact of the rule algorithm feature in parametric design by comparing designers' behavior in these two design environments. Three architects participated in the experiment in which each of them was required to complete two design sessions, one in each environment. The protocols are coded using the function-behavior-structure (FBS) coding scheme. Preliminary results show that the overall behavior is not significantly affected by the environment; however, there are significant differences at different design stages in the two design environments.

Keywords: parametric design environment, geometry modeling environment, design cognition, designer behavior, protocol analysis

1 INTRODUCTION

This paper presents the results of a pilot study of the cognitive differences of professional architects when using Rhino, a NURBS-based 3D modeling tool, and Grasshopper, a visual programming language inside Rhinoceros, that allows for the development of algorithms or rules to generate forms. The important distinction between Rhino and Grasshopper is in their underlying design and modeling paradigms that appear to require different cognitive understanding and approaches to use them. It is these differences in cognition that are the focus of this research. This research is part of a wider study on the educational implications of utilizing programming in design.

In order to gain an understanding of the cognitive differences when using these two approaches, a pilot study utilizing the protocol analysis method was carried out. The aim of this pilot study is to determine whether differences can be observed. Once differences can be observed and measured, a statistically significant cohort will be examined to determine whether the differences in the pilot study are confirmed to be more general. The paper commences with a brief introduction of the concept of parametric design, and the interpretation of FBS ontology in the context of parametric design. Then a pilot study is described. The preliminary results from comparing the designers' behavior in a parametric design environment (PDE) and a geometry modeling environment (GME) are presented and analyzed.

2 Background

2.1 Parametric design environment (PDE)

Parametric design is a dynamic, rule-based process controlled by parameters and their variations, in which multiple design solutions can be developed in parallel. According to Kolarevic [11], this change is characterized by an adoption of dynamic systems which have rendered design more flexibly and productively. According to Woodbury [17], 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 [11].

Parametric design has become increasingly popular in architectural design practices in the recent years. Previous studies show that parametric tools advance design processes in a variety of ways [7,12,14]. However, there is a lack of empirical evidence supporting the understanding of designers' behavior in a parametric design environment (PDE) compared to traditional geometry modeling environments (GME).

2.2 Protocol Studies

Protocol studies are a method for turning qualitative verbal and gestural utterances into data [4,6]. They have been used extensively in design research to develop an understanding of design cognition [2,9,15]. In protocol studies used in design research one common coding scheme is that based on the Function-Behavior-Structure (FBS) ontology [5], which has been applied to a variety of studies on designers' cognitive behavior [6,8,10,16]

The FBS ontology, Figure 1, contains three classes of concepts: 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; and structure represents the components that make up an artifact and their relationships. Figure 1 shows the eight numbered design processes that flow from this—formulation, analysis, evaluation, synthesis, reformulation-1, -2, and -3. This study adopts the FBS ontology as the theoretical framework, because it clearly distinguishes the eight types of design processes, which provides opportunities to look into design in detail. It is suggested that it able to capture the meaningful design processes [10]. Gero and Kan [8] applied the FBS ontology to study software designers' behavior. That study suggested that FBS was effective for encoding programming /rule based activities across different design disciplines. Considering that PDE enables scripting/programming activities, it is anticipated that FBS coding scheme will be able to encode both geometric modeling and rule algorithm activities effectively.

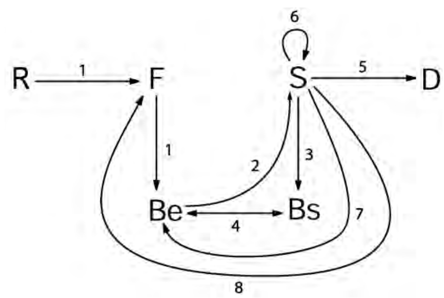

Fig. 1. FBS ontology [5]

3 Interpretation of FBS ontology for protocol analysis of designing in PDE

In design research, most of the environments that have been studied using the protocol analysis method have been either traditional sketch environments [6,10]or digital sketch/geometry modeling environment [16]. Parametric design is different from any traditional design method due to its rule algorithm feature. In addition to documentation and modeling, rule algorithm design activities in PDE assist designers by generating design paradigms and constructing data structures. [7]. The rule algorithm design in PDE has close relationship with designers' cognitive thinking process. In this study, we apply the FBS coding scheme to capture designers' behavior in PDE. This section interprets the FBS model in the context of designing in a PDE, specifically to capture the unique activities related to the use of rule algorithms.

3.1 Two types of design spaces in PDE

Parametric design "requires a deeper understanding of how it can support our intentions as architects" [13, p. 47]. Compared to traditional design environments, in PDE designers not only design by applying design knowledge, but also by defining rules and their logical relationships using parameters. Therefore, in a typical parametric design process, there are two types of design spaces: *design knowledge space* and *rule algorithm space*. In the design knowledge space, architects make use of their design knowledge, such as those to address how to make a building adapted to the site, how people use the building, and how to satisfy the requirements of clients. In the rule algorithm space, designers apply design knowledge through the operations of parametric design tools, such as defining the rules and their logical relationships, choosing the components suitable for a particular purpose, and importing external data into the proposed rules. The relationship between the two design spaces is shown in Figure 2: during designing using a PDE designers always progress by applying design knowledge and in some parts they apply design knowledge indirectly by defining rules and their logical relationships, known as parameterization.

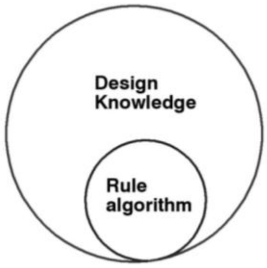

Fig. 2. Two types of design spaces in PDE

3.2 Framework of applying FBS coding scheme to study designing in PDE

In order to capture designing in PDE, the main class of variables---R, F, Be, Bs, S---are decomposed based on the two types of design spaces---design knowledge space, denoted by the superscript K, and rule algorithm space, denoted by the superscript R, Figure 3. The structure variables in the rule algorithm space (S^R) can have more subclasses of the specific rule algorithm activities in PDE, allowing for the representation of how parametric tools facilitate design processes. The design knowledge space is similar to traditional design environments which complies with the original FBS ontology; while the rule algorithm space is an articulation of the FBS ontology for PDEs that uses multiple instances of the FBS variables.

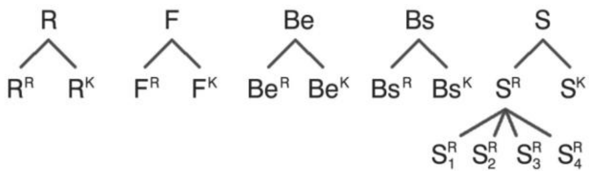

Fig. 3. Applying FBS ontology for PDE

4 Experiment design

In the experiment, each designer was required to complete two different design tasks of similar complexity in the selected PDE and GME. The pilot study was carried out with 3 designers, who are professional architects with an average of 7 years of experience in architectural design, and no less than 2 years of experience in using parametric design.

During the experiment, both designers' activities and their verbalization were video-recorded by a screen capture program and the recorded data used for the protocol analysis. There were two design sessions: one session used Rhino (GME) and the other session used Rhino and Grasshopper (PDE). Designers were given 40 minutes for each design session. Task 1 is a community center and Task 2 is a shopping center, both containing specific function requirements. A pre-modeled site was provided to the designers. The design sessions and tasks were randomly matched among different designers. During the experiment, designers were not allowed to sketch manually so that almost all their actions happened on the computer to ensure that the design environment is purely within PDEs and GMEs. The aim is to minimize other variables except for the two different design environments, to allow for comparative analyses.

5 Results

5.1 General design issue and process analysis

With only three participants no statistical analysis is carried out and the results are preliminary and are presented without standard deviations. This study focuses on designers' cognitive behavior during the design process; an analysis of the design outcomes is beyond the scope of this paper. In order to increase coding robustness two rounds of segmentation and coding were conducted with an interval of over two weeks between them. Then an arbitration session was carried out to produce the final protocol. The agreement between the two rounds of coding was 83.2%, and between the individual rounds and the final arbitrated results was 90.2%. This high agreement is indicative of the reliability of the coding results. Information on coding coverage is provided in Table 1. The numbers shown in Table 1 are the average of the three protocols. The average overall numbers of segments are respectively 249 in PDE and 214 in GME. On average designers spent more time in PDE sessions than in GME sessions. The design speed is similar in the two design environments. Over 90.6% segments can be coded as FBS codes. Non-coded segments include those concerned with communication, software management, etc.

Table 1. General coding coverage

Design environments	Time (mins)	Number of Segments	FBS coded segments (%)	Speed (segments/min)
GME	37.7	214	93.4	5.6
PDE	46.7	249	90.6	5.3

In the following data analysis, the design issues and design processes are normalized as percentages. All the values are the average of the three sets of protocols. The distribution of FBS design issues is shown in Figure 4. The two design environments produce qualitatively similar design issues distributions. More cognitive effort is expended on the structure design issue than any others in both environments. This is followed by behavior from structure (Bs), expected behavior (Be), function (F), and the least effort is expended on requirements (R). From the results it can be inferred that the overall distribution of design issues are not significantly affected by the method used.

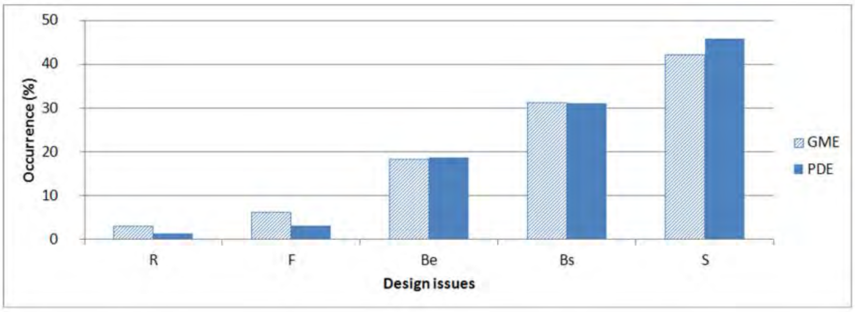

Fig. 4. Design issue distributions in GME and PDE

The syntactic design processes in the two design environments are plotted in Figure 5. In this pilot study there are no significant differences in design processes between GME and PDE: the three types of reformulation processes and evaluation process are very similar between GME and PDE. When the results from a statistically significant sample become available it will be possible to determine whether there are significant differences between these two environments that may be masked by the small sample size in the pilot study.

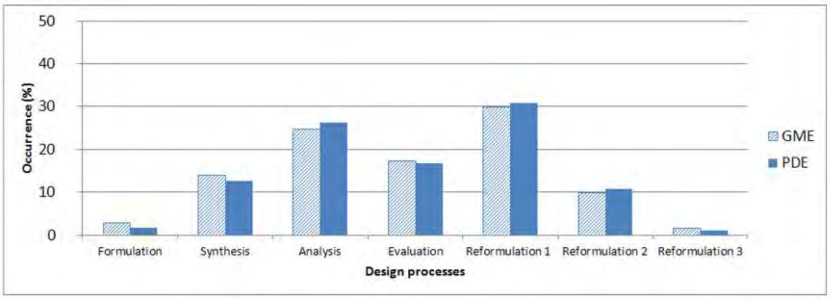

Fig. 5. Syntactic design processes in GME and PDE

5.2 Impact of rule algorithm in PDE

The design issue distribution in the knowledge space for both GME and PDE is shown in Figure 6. Qualitatively, large differences between the two design environments can be observed: there is significantly more cognitive effort expended on design knowledge issues in GME than in PDE. Figure 7 presents the design issues distribution in both knowledge and rule spaces. A comparison of the results in Figures 4 and 7 shows that although the total distribution of design issues in both environments is similar, the make-up of the design issues is different. Some of the knowledge related design issues are substituted by rule algorithm design issue in PDE. This applies particularly for the design issues of expected behavior (Be) and structure (S). The high contribution of the rule algorithm to the expected behavior (Be^R) may be because designers often consider ways to achieve algorithm goals in PDE; while the significant impact of rule algorithm on Structure (S^R) may be because when designers consider geometry modeling, they put more effort into the structure of rule relationships.

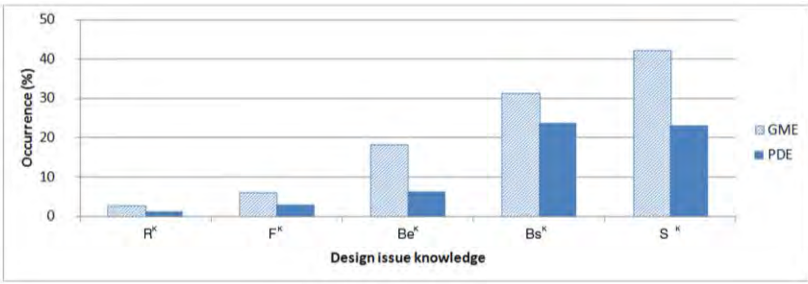

Fig. 6. Design issue distribution in the knowledge space in GME and PDE

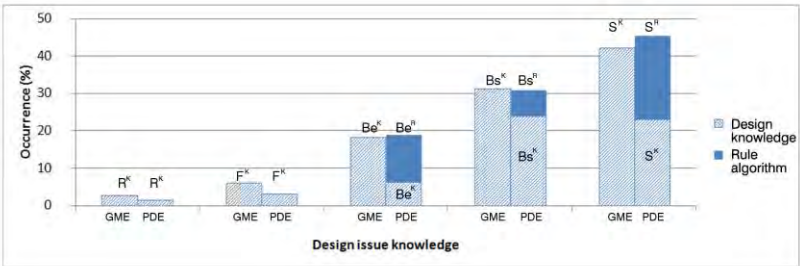

Fig. 7. Design issue distribution in both the knowledge and rule spaces in GME and PDE

5.3 Design behavior across different design stages

In order to explore designers' cognitive behavior across a design session, each design session is divided into three equal parts based on the coded segments: labeled early design stage, mid design stage and end design stage. Their design issue distributions are presented in Figure 8. The design issues of requirements, function and expected behavior decrease towards the end of the design sessions in both GME and PDE. There are noticeable differences at the early design stage of F, Bs, and S, as well as the end design stage of Bs between GME and PDE. For Be, the rule algorithm occupies a larger percentage towards the end of the design session. While for Bs, this percentage decreases. For the rule algorithm S decreases at the middle of design session and then rises significantly at the end. From these results some preliminary inferences are made: that rule algorithm plays an important role in the design issues of expected behavior (Be) and structure (S) in PDE, and its impact increases towards the end of design session. The reason possibly is that designers focus frequently on the structuring of the rule relationship in the end of PDE session.

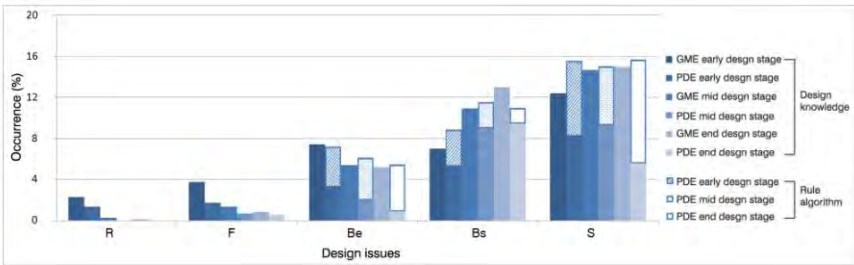

Fig. 8. Design issue distributions for the early, mid and end design stages in GME and PDE

The syntactic design process distributions at the three different design stages in GME and PDE are presented in Figure 9. Some preliminary inferences can be made: in both design environments, formulation and reformulation 3 rarely happen at the end of design stage; analysis occurs towards the end of design session; formulation and reformulation 2 decrease toward the end. There is more reformulation 1 at the end of design session in PDEs than GMEs; meanwhile, there are significant differences in all the design stages of synthesis, as well as at the early design stage of reformulation 2 and formulation process.

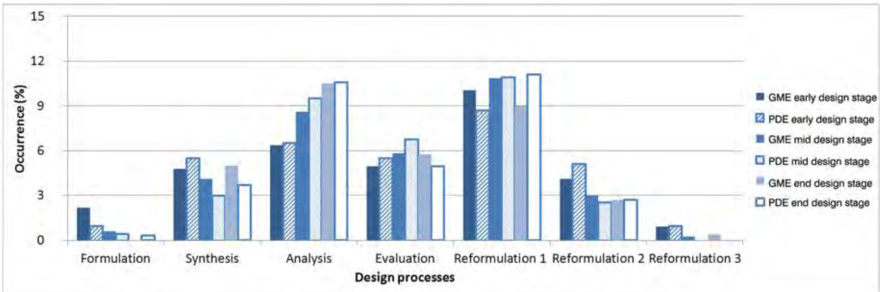

Fig. 9. Syntactic design process for the early, mid and end design stages in GME vs. PDE

6 Discussion and Conclusion

Results of this pilot study show that the hierarchical FBS framework is useful for coding designers' behavior in GME and PDE, and consequently can be used to explore the differences between geometric and parametric modeling activities. The preliminary results from this pilot study imply that there are potentially significant differences between the two design environments. The overall distribution of design issues and design processes are not significantly affected by the method used. When the design sessions are divided into different design stages, a number of differences both in design issue and design process are found, which indicates that the different design environments affect the designer's behavior at different design stages. The use of the rule algorithm feature in PDE significantly affects designers' cognitive behavior.

From the designer's perspective, the nature of parametric tools provides architects opportunities of designing rules for their design, which opens a world with various possibilities: complex forms are able to be generated freely; mathematical calculation is embedded which could make the design of the form more rational. At the same time, challenges exist: the role of architects is changing, they have to be both architects and programmers. Using parametric tools, a designer's programming skill has an impact on the design. From qualitative observations, designers tended to use the programming method they are familiar with. This may restrict their concept development. However, if the designer has good programming skills, by designing the rules suitable for the requirement, novelty may be inspired by the method used. It was observed that in PDE designers tended to build a "correct" parametric relationship system rather than building a "correct" model, which is also reflected in the high percentage of rule algorithm structure (S^R) (see Figure 7). In PDE, The whole system concept seems to be determined at the beginning of design stage. Researchers have suggested that early solution conjectures is beneficial for solution exploration [3]. Designers in PDE were not sure about what will come out after they generated a piece of script: "Aha" moments [1] occur frequently in PDE. For instance, there are more utterances like "this looks good", "it starts to look interesting" which refer to the evaluation of current design situation in PDE. Designers tended to go back to examine the model after they changed a parameter or parametric relationship, or went back to check their previous definition using the script interface. This inspection of previous model or script definition can be defined as a kind of perceptual activity [15], which sometimes results in the generation of new intentions.

These preliminary results are based on three subjects from the pilot study, the next step of this research is to have a statistically significant number of protocols to provide statistically robust results. This pilot study has shown that there are differences to be studied potentially leading to important findings.

7 Reference

1. Akin, Ö., Necessary Conditions for Design Expertise and Creativity, Design Studies, 11, (2), 107-113 (1990)
2. Atman, C.J., Chimka, J.R., Bursic, K.M., Nachtmann, H.L., A Comparison of Freshman and Senior Engineering Design Processes, Design Studies, 20, (2), 131-152 (1999)
3. Cross, N., Expertise in Design: An Overview, Design Studies, 25, (5), 427-441 (2004)
4. Ericsson, K.A., Simon, H.A., Protocol Analysis : Verbal Reports as Data, MIT Press,

Mass. (1993)
5. Gero, J., Design Prototypes: A Knowledge Representation Schema for Design, AI Magazine, 11, (4), 26–36 (1990)
6. Gero, J., Mc Neill, T., An Approach to the Analysis of Design Protocols, Design Studies, 19, (1), 21-61 (1998)
7. Iordanova, I., Tidafi, T., Guité, M., De Paoli, G., Lachapelle, J., Parametric Methods of Exploration and Creativity During Architectural Design: A Case Study in the Design Studio, in The 13th International Conference on Computer Aided Architectural Design Futures, pp. 423-439 (2009)
8. Kan, J., Gero, J., Studing Software Design Cognition, in: M. Petre, A.V.d. Hoek (Eds.), Software Designers in Action: A Human-Centric Look at Design Work (2012)
9. Kan, J.W.T., Gero, J.S., Acquiring Information from Linkography in Protocol Studies of Designing, Design Studies, 29, (4), 315-337 (2008)
10. Kan, J.W.T., Gero, J.S., Using the Fbs Ontology to Capture Semantic Design Information in Design Protocol Studies, in: J. McDonnell, P. Lloyd (Eds.), About: Designing. Analysing Design Meetings, CRC Press, pp. 213-229 (2009)
11. Kolarevic, B., Architecture in the Digital Age : Design and Manufacturing, Spon Press, New York, NY (2003)
12. Lee, J.H., Gu, N., Jupp, J., Sherratt, S., Evaluating Creativity in Parametric Design Processes and Products: A Pilot Study, in The 5th international conference on design computing and cognition, pp., Texas (2012)
13. Sanguinetti, P., Kraus, C., Thinking in Parametric Phenomenology in Proceedings of ACADIA Regional 2011 Conference, pp. 39-48 University of Nebraska-Lincoln, Lincoln, USA (2011)
14. Schnabel, M.A., Parametric Designing in Architecture, in The 12th International Conference on Computer Aided Architectural Design Futures, pp. 237-250, Sydney, Australia (2007)
15. Suwa, M., Tversky, B., What Do Architects and Students Perceive in Their Design Sketches? A Protocol Analysis, Design Studies, 18, (4), 385-403 (1997)
16. Tang, H.H., Lee, Y.Y., Gero, J.S., Comparing Collaborative Co-Located and Distributed Design Processes in Digital and Traditional Sketching Environments: A protocol Study Using the Function-Behaviour-Structure Coding Scheme, Design Studies, 32, (1), 1-29 (2011)
17. Woodbury, R., Elements of Parametric Design, Taylor and Francis (2010)