

## EXPLORING DESIGN STRATEGY IN PARAMETRIC DESIGN TO SUPPORT CREATIVITY

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**Abstract.** This paper deals with the generative and evolutionary aspects of parametric design. We aim to provide a better understanding of individual design strategies to support creativity in parametric design via protocol analysis. An in-depth analysis conceptualises subjects' creative strategies into two models: problem-driven strategy and solution-driven strategy. The solution-driven strategy progress design in the solution space resulted in the highest value in the level of creativity. This is one of potential aspects of parametric design. Exploring design strategies in parametric design contributes to its effective use.

**Keywords.** Design strategy; parametric design; creativity; protocol analysis.

### 1. Introduction

Parametric design has become an emerging research issue. It refers to the use of the parameter, which allows for quick searches for alternative solutions (Madkour et al., 2009). Parametric design here focuses on the formative and generative design using 'advanced parametric applications (Holzer et al., 2007)' viz., Grasshopper™, CATIA™ and Generative Components™. The scripting activities (Qian et al., 2007) based on the parameter and rules in parametric design – algorithmic activities (Lee et al., 2012) – allow for different design approaches and variations from conventional design strategies. Nonetheless, our understanding of the generative and algorithmic features of parametric design and the role of creativity is limited.

We have aimed to bridge this knowledge gap. Our previous research (Lee et al., 2011; Lee et al., 2012) has presented both process and product-based evaluation of creativity, while this paper specifically addresses designers' strategies in parametric design.

We hypothesise that the design strategy applied may enhance/hinder creativity in the early conceptual design stage. Designers choose their own strategies in problem-solving processes (Weth, 1999; Ho, 2001; Kruger and Cross, 2006). This is related to an individual design thinking process identified by Analysis-Synthesis-Evaluation (Jones, 1992; Mc Neill et al., 1998). This paper applies the above thinking process to interpret the designer's problem/solution driven strategies. An understanding of the design strategy's relationship to parametric design, not yet understood, but is considered critical for its effective use.

To explore the design strategy applied by an individual during design thinking, this research utilises protocol studies (Suwa et al., 1998; Mc Neill et al., 1998), to develop an understanding of design strategies used in parametric design. This protocol study provides empirical evidence to support the understanding of individuals' design strategies, as they relate to creativity in parametric design.

This paper is divided into four parts. Section 2 explores the related literature and then presents a framework for exploring design strategies in parametric design. A protocol study investigating three designers' strategies is presented in Section 3. Finally, Section 4 concludes with a discussion and outlines the directions for future work.

## **2. Related Research**

### **2.1. DESIGN STRATEGY**

Creativity is a natural component of design process (Hasirci and Demirkan, 2007). Kim and Kang (2003) developed five creative-related tests: a personal creativity mode test, a brain bias test, Torrance Test of Creative Thinking (TTCT), a brainstorming test, and a visual reasoning test. Though the application of these tests is capable of identify the personal characteristics and performances of a designer, there is a limitation in exploring individual preference and habit in design problem solving.

Kruger and Cross (2006) argue that design strategies employed by designers are related to both design quality and creativity. Weth (1999) relates that strategies contain information relating to how the final goal is achieved. Design strategies define sub-goals which limit the possible operation. That is, design strategy is closely related to personal preference and habit and largely contributes to defining designs' thinking processes.

Evidence is presented (Weth, 1999; Ho, 2001; Kruger and Cross, 2006) which considers design strategy as the problem-solving process. Ho (2001), through the application of protocol analysis, identified problem decomposition strategy and working-forward/backward strategy can be used to differentiate between expert and novice designers. Ahmed et al. (2003) indicate that experts use particular

design strategies, whilst novices tend to use trial and error as their design method (backward reasoning). Kruger and Cross (2006) support the concept of a problem or solution driven design strategy. Their findings identified that the use of a solution driven strategy produces lower solution quality but higher creativity. A problem driven design strategy results in the best balance between quality and creativity. These studies identify the relationship that the design strategy has on design quality, efficiency and creativity.

## 2.2. RESEARCH FRAMEWORK

For the purpose of better understanding an individual's design strategies, protocol analysis (Mc Neill et al., 1998; Ho, 2001; Kruger and Cross, 2006) was utilised. In protocol analysis, a coding scheme is essential and should be devised specifically for the purpose and the design environment. The coding scheme developed in our previous studies (Lee et al., 2012) was enhanced for the purpose of better exploring design strategies. There is considerable literature reporting on research that adopts 'Analysis–Synthesis–Evaluation' as a design method (Jones, 1992). Mc Neill et al. (1998), for example, employed this method as the micro strategy coding scheme: analysis of the problem; synthesis of a candidate solution, evaluation of a candidate solution, and other activities. The study, reported here, based its coding scheme on this model. Our coding scheme consists of three categories: analysis, synthesis, and evaluation.

'*Analysis*' decomposes a problem into sub problems (Jones, 1992; Ho, 2001). The coding scheme in Table 1 enables us to identify introducing new ideas (SF-Initial Goal), new geometric ideas (SF-Geometry SubGoal), and new algorithmic ideas extended from a previous idea (SF-Algorithm SubGoal). These cognitive activities belong to the conceptual level of Suwa's work (Suwa et al., 1998).

'*Synthesis*' refers to the re-composition of sub problems in different ways (Jones, 1992; Ho, 2001). We deal with two sub-levels which differentiate between 'physical' and 'conceptual'. The distinction between the two sub-levels allows for capturing the generative aspect of parametric design, which is different from common synthesis of a solution. Adopting an idea also belongs to the conceptual level of '*Synthesis*'. This enabled us to distinguish physical depiction from conceptual synthesis which better supports creativity in parametric design.

'*Evaluation*' refers to the test of the performance of new structures (Jones, 1992; Ho, 2001). One code (SE-Geometry) – evaluating primitives or existing geometries – identifies the geometric cognitive activity. Two codes in the algorithm level reveal the algorithmic activities, which are related to evaluating existing parameters and rules as specific activities in parametric design. The algorithm level may refer to evaluating the problem (Purcell et al., 1996), which

Table 1. Coding scheme for design strategy in parametric design.

| Category                        | Code | Description                                                   | Sub-code             |
|---------------------------------|------|---------------------------------------------------------------|----------------------|
| Analysis                        | An_p | Introduce new ideas (or goals) based on a given design brief  | SF-Initial Goal      |
|                                 |      | Introduce new geometric ideas extended from a previous idea   | SF-Geometry SubGoal  |
|                                 |      | Introduce new algorithmic ideas extended from a previous idea | SF-Algorithm SubGoal |
| Synthesis<br>(Physical level)   | Sy_p | Create directly geometries                                    | RG-Geometry          |
|                                 |      | Change existing geometries                                    | RG-Change            |
|                                 |      | Create initial parameters                                     | RA-Parameter         |
|                                 |      | Change existing parameters                                    | RA-Change Parameter  |
|                                 |      | Create initial rules                                          | RA-Rule              |
| Synthesis<br>(Conceptual level) | Sy_c | Change existing rules                                         | RA-ChangeRule        |
|                                 |      | Make generation (or variation)                                | R-Generation         |
|                                 |      | Adopt new ideas to geometries                                 | SA-Geometry          |
|                                 |      | Adopt new ideas to parameters                                 | SA-Parameter         |
|                                 |      | Adopt new ideas to rules                                      | SA-Rule              |
| Evaluation<br>(Geometry level)  | Ev_g | Evaluate primitives or existing geometries                    | SE-Geometry          |
| Evaluation<br>(Algorithm level) | Ev_a | Evaluate existing parameters                                  | SE-Parameter         |
|                                 |      | Evaluate existing rules                                       | SE-Rule              |

belongs to ‘*Analysis*’. That is, the algorithm level can be regarded as the activities of evaluating both a problem and a solution space of parametric designing.

Our previous research (Lee et al., 2012), evaluating creativity in parametric design, was based on a two-pronged approach: a protocol analysis procedure (process-based evaluation), and a selective criteria-based assessment method (product-based evaluation). This paper reveals that designers’ parametric design strategy is a component of our overall framework, which enables us to investigate three perspectives of creativity in parametric design: person (interpreted as individual design strategies in our study), process and products.

The hypothesis of the overall framework is that the sequence of coded segments will (i) identify cognitive patterns that reveal insights into creativity in parametric designing; these findings will (ii) relate to the results of expert panel assessments evaluating the design outcomes; so as to then derive relationships between these results with (iii) the designer’s strategy and/or preference. This paper focuses on the third stage of the framework.

### 3. A Protocol Study

To collect protocol data, participants were given one hour to undertake a given design task using parametric modelling tools of their choice, whilst adopting think-aloud protocols, the design sessions were video-recorded. The study involved three participants (a lecturer and two postgraduate students). The brief, presented verbally to by the researcher, concerned the conceptual design of a high-rise building as an ill-defined design problem.

The protocols of each recorded video were directly transcribed using NVivo 9 software and automatically segmented into smaller episodes. The average value of the number of segments was 263.5 (Session 1: 142, Session 2: 286, Session 3: 368). Over 90% of each protocol was encoded using our adopted coding scheme, regardless of the use of the parametric design environments (Grasshopper, Maya Script Editor, and Python). This implies that our coding scheme enables the effective encoding of the protocol data.

#### 3.1. OVERALL FINDINGS

Table 2 shows the results of the coding process which describes the percentage of the frequency weighted by time span (calculated by time duration of each code). This allowed us to determine the time devoted to each component of the design strategy as well as main levels of individual design thinking of each participant. On average the coverage of '*Synthesis*' accounts for 53.7%, '*Evaluation*' accounts for 30.2%, and '*Analysis*' accounts for 9.6%, which is the smallest component.

The representation activities of S2 are highest, while '*analysis*' of S2 is relatively low. This participant, a postgraduate student, had a tendency to solve the problem by first goal search. This may indicate the procedure of novice's problem-solving. Literature (Ho, 2001; Coley et al., 2007) indicates that a novice designer may lack problem analysis or scoping skills or strategies. S2 also struggled with

Table 2. The percentage of coding result of each protocol.

| Category                     | S1   | S2   | S3   | Mean | SD  |
|------------------------------|------|------|------|------|-----|
| Analysis                     | 17.5 | 4.2  | 7.0  | 9.6  | 7.0 |
| Synthesis (Physical level)   | 45.0 | 56.2 | 38.6 | 46.6 | 8.9 |
| Synthesis (Conceptual level) | 4.3  | 3.4  | 13.5 | 7.1  | 5.6 |
| Evaluation (Geometry level)  | 18.6 | 8.7  | 16.2 | 14.5 | 5.2 |
| Evaluation (Algorithm level) | 11.2 | 17.0 | 19.0 | 15.7 | 4.1 |
| Sum                          | 96.6 | 89.5 | 94.5 | 93.5 | 3.6 |

trial and error (novice's backward reasoning by Ahmed et al. (2003)). By contrast, the 'analysis' identified that S1 achieved the highest mean value of 'synthesis (physical level)'. This Subject, considered an expert (lecturer) in parametric modelling tools, applied strategic rules from the initial states of the problem, which is called the working-forward search strategy (Ho, 2001).

One interesting outcome relating to S3's performance was that both 'synthesis (conceptual level)' and 'evaluation (algorithm level)' – evaluating the problem (Purcell et al., 1996) – were very high. These approaches may have advantages for evolving and generating creative design variations, because these are related to both the co-evolution process of the problem and solution spaces (Dorst and Cross, 2001; Maher, 2010). S3's design also received the highest score from the judges in our product-based evaluation (Lee et al., 2012). That is, design strategy weighting of both the problem and solution spaces plays a significant role in creativity in parametric design.

### 3.2. DESIGN STRATEGY IN PARAMETRIC DESIGN

The encoded data was visualised to facilitate the exploration of design strategies over time. Figure 1 illustrates the five levels of design thinking – Ev\_a: Evaluation (algorithm level), Ev\_g: Evaluation (geometry level), Sy\_c: Synthesis (conceptual level), Sy\_p: Synthesis (physical level), and An: Analysis – in sequence and to compare the changes over time.

While Sy\_p and Ev\_g can be seen to be dominant activities over time, occurrences of both the An and Sy\_c codes differ more significantly between all three

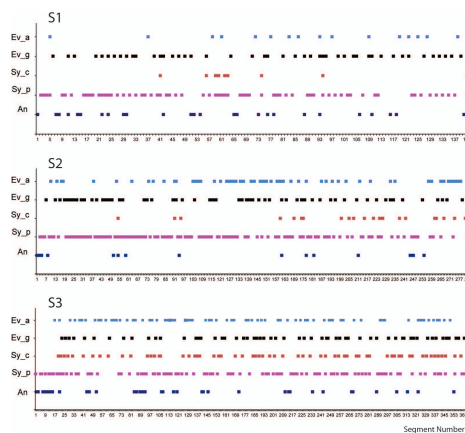


Figure 1. Patterns of design thinking (Ev\_a: Evaluation (Algorithm), Ev\_g: Evaluation (Geometry), Sy\_c: Synthesis (Conceptual), Sy\_p: Synthesis (Physical), and An: Analysis).

designers. The Sy\_c – synthesis (conceptual level) – within the protocol of S3 occurred at regular intervals throughout the time period. The analysis also happened regularly in the protocols of S1 and S3. The problem space in our coding scheme is based on ‘analysis’, whilst the solution space highlights ‘synthesis (conceptual level)’. That is, S3 used design strategy highlighting both the problem and the solution. These features of the S3’s design strategy, which are consistent with the results of Table 1, may enhance creativity in parametric design.

The An and Sy\_c codes did not happen regularly in the protocol of S2, which may be the feature of the novice’s problem-solving in parametric design. The Sy\_c (conceptual level) appeared towards the end of the protocol. He repeated the procedure highlighting the representation (Sy\_p) and the evaluation of algorithms (Ev\_a). These features may have disadvantages in creativity. S1 showed the regular occurrences of ‘analysis’ but a small number of activities encoded by making generation (Sy\_c). The problem space is based on ‘analysis’, while the solution space weights the generative aspects of parametric design. These features imply that he adopted a problem-driven strategy rather than a solution-driven strategy to produce his design product.

Figure 2 shows the occurrences of three cognitive activities of ‘analysis’ over time. It enables the investigation of problem decomposition strategies in detail. ‘SF-Initial Goal’ refers to explicitly introducing main problem, while two codes introducing sub goals deal with sub problems.

A closer examination of Figure 2 it reveals that only S1 produces ‘SF-Initial Goal’ at the beginning, middle and end of the protocol. S1 also sequentially decomposed the problem into geometric sub problems and then algorithmic sub problems. This is similar to ‘the explicit problem-decomposing strategy’ (Ho, 2001). Figure 1 also supports that S1 adopted a problem-driven strategy. Kruger and Cross (2006) argued that a problem driven design strategy produces the good

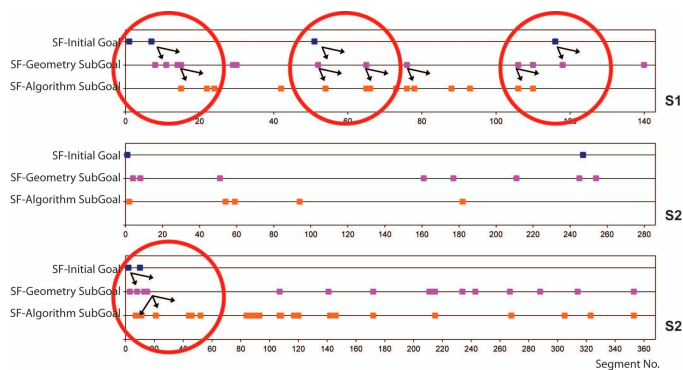


Figure 2. Three cognitive activities of ‘analysis’ over time.

results of both overall solution quality and creativity. Our observation and product-based evaluation consistently show that the level of usefulness of S1's model has an equivalent score of S3's model. S2's is the lowest, and S1's and S3's values are similarly higher in novelty and complexity. That is, both the problem-decomposing strategy and the problem-driven strategy may enhance creativity in parametric design. Based on these results, this paper illustrates the conceptual procedures of a problem-driven strategy model in Figure 3.

Figure 2 shows that S2 and S3 tend to use an implicit problem-decomposing strategy, which is often used by novices. S2 produces 'SF-Initial Goal' at the beginning and end of the protocol but rarely sub problems. This implies that he performs unsystematically and adopts the working backward search strategy. By contrast, S3 was keen to decompose the problem into geometric and algorithmic sub problems. Figure 1 reveals that S3 regularly used the conceptual level of synthesis (Sy\_c). S3 used design strategy highlighting both the problem and the solution, but his sub problems implicitly followed the generating solutions in Figure 1 (see also sequential sub problems in Figure 2). These features imply that S3 adopted a solution-driven strategy to produce his final design product.

As a result, this paper presents two models enhancing creativity in parametric design: problem-driven strategy and solution-driven strategy in Figure 3. The solution-driven strategy is specific to parametric design. S3's design (using solution-driven strategy) received the highest score from the judges in the level of creativity. This is consistent with the Kruger and Cross's results (2006) that a solution-driven strategy produced higher creativity scores. The strategy also is related to iterative design activities providing the restructuring of components (Verstijnen et al., 1998) and the regulation of elements into comprehensive solutions (Akin and Moustapha, 2004).

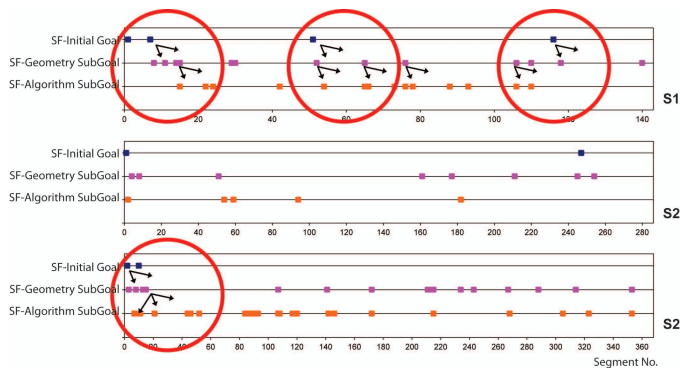


Figure 3. Two models of parametric design strategies to support creativity.

#### 4. Discussion and Conclusion

This paper reports on the exploration of the subjects' design strategies in parametric designing based on the three design levels: 'Analysis', 'Synthesis', and 'Evaluation'. The study presents a formal framework for evaluating creativity in parametric design in terms of the personal aspects of creativity.

The results indicate that the coding scheme used allows for the effective descriptions of design strategies that problem and solution co-evolve. Considering the rating results of the design product in the previous research, these results imply that 'analysis' and 'synthesis (conceptual level)' may support creativity in parametric designing. The authors also summarised subjects' creative strategies into two models: problem-driven strategy and solution-driven strategy. Even though S3 had the features of both novices' and experts' behaviour, his solution-driven strategy making generation in the solution space resulted in the highest value in the level of creativity. This is one of potentials of parametric design.

In summary, this study presents results which provide a better understanding of individual design strategies. As a pilot study, whilst the authors acknowledge the small sample size, the results indicate some unique characteristics of design strategies to support creativity in parametric design. As a starting point, this study provides the potential of exploring design strategies in parametric design.

We continue to investigate other aspects of parametric design. One is the designers' algorithmic preferences. Subsequent research is needed which involves further analysis of algorithms, so called scripting or coding. Scripting activities are a means of representing ideas as well as a channel for creativity (Salim and Burry, 2010). The scripting activities will be categorised into the following algorithmic functions: (Qian et al., 2007): branching, incremental variation, filtering, goal seeking, and mapping and sampling.

Our coding scheme for design strategy in parametric design limits its exploration to exploring the other aspects of cognitive strategies. It needs the second coding scheme such as level of abstraction (Ho, 2001) and expertise model (Kruger and Cross, 2006). This will allow for further investigation and verification of the two models of parametric design strategies to support creativity. Future works also include an in-depth analysis for the purpose of identifying/evaluating the other cognitive design strategies.

#### References

- Ahmed, S., Wallace, K. M. and Blessing, L. M.: 2003, Understanding the differences between how novice and experienced designers approach design tasks, *Research in Engineering Design*, **14**(1), 1.

- Akin, O. and Moustapha, H.: 2004, Strategic use of representation in architectural massing, *Design Studies*, 25(1), 31–50.
- Coley, F., Houseman, O. and Roy, R.: 2007, An introduction to capturing and understanding the cognitive behaviour of design engineers, *Journal of Engineering Design*, 18(4), 311–325.
- Dorst, K. and Cross, N.: 2001, Creativity in the design process: co-evolution of problem-solution, *Design Studies*, 22(5), 425–437.
- Hasirci, D. and Demirkan, H.: 2007, Understanding the effects of cognition in creative decision making: A creativity model for enhancing the design studio process, *Creativity Research Journal*, 19(2-3), 259–271.
- Ho, C.-H.: 2001, Some phenomena of problem decomposition strategy for design thinking: differences between novices and experts, *Design Studies*, 22(1), 27–45.
- Holzer, D., Hough, R. and Burry, M.: 2007, Parametric Design and Structural Optimisation for Early Design Exploration, *International Journal of Architectural Computing*, 5(4), 625–643.
- Jones, J. C.: 1992, *Design methods*, 2nd ed., Van Nostrand Reinhold, New York.
- Kim, Y. S. and Kang, B. G.: 2003, Personal Characteristics and Design-Related Performances in a Creative Engineering Design Course, *Proceedings of the 6th Asian Design Conference*, Tsukuba, Japan.
- Kruger, C. and Cross, N.: 2006, Solution driven versus problem driven design: strategies and outcomes, *Design Studies*, 27(5), 527–548.
- Lee, J. H., Gu, N., Jupp, J. and Sherratt, S.: 2012, Evaluating Creativity in Parametric Design Processes and Products: A Pilot Study, *Design Computing and Cognition (DCC'12)*, College Station, TX.
- Lee, J. H., Gu, N. and Sherratt, S.: 2011, Developing a framework for evaluating creativity in parametric design, *45th ANZAScA*, Sydney, Australia, Abstracts Book, 17.
- Maher, M. L.: 2010, Evaluating Creativity in Humans, Computers, and Collectively Intelligent Systems, *DESIRE'10: Creativity and Innovation in Design*, Aarhus, Denmark, 22–28.
- Madkour, Y., Neumann, O. and Erhan, H.: 2009, Programmatic Formation: Practical Applications of Parametric Design, *International Journal of Architectural Computing*, 7(4), 587–604.
- Mc Neill, T., Gero, J. S. and Warren, J.: 1998, Understanding Conceptual Electronic Design Using Protocol Analysis, *Research in Engineering Design – Theory, Applications, and Concurrent Engineering*, 10(3), 129–140.
- Qian, C. Z., Chen, V. Y. and Woodbury, R. F.: 2007, Participant Observation can Discover Design Patterns in Parametric Modeling, *ACADIA 2007: Expanding Bodies*, Halifax, Canada, 230–241.
- Salim, F. and Burry, J.: 2010, Software Openness: Evaluating Parameters of Parametric Modeling Tools to Support Creativity and Multidisciplinary Design Integration, in D. Taniar, O. Gervasi, B. Murgante, E. Pardede and B. Apduhan (eds.), *Computational Science and Its Applications – ICCSA 2010*, Springer Berlin / Heidelberg, 483–497.
- Suwa, M., Purcell, T., and Gero, J. 1998. Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions, *Design Studies*, 19(4), 455–483.
- Verstijnen, I. M., van Leeuwen, C., Goldschmidt, G., Hamel, R. and Hennessey, J. M.: 1998, Sketching and creative discovery, *Design Studies*, 19(4), 519–546.
- Weth, R. v. d.: 1999, Design instinct? the development of individual strategies, *Design Studies*, 20(5), 453–463.