

Developing a framework for evaluating creativity in parametric design

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ABSTRACT: Pioneering studies have demonstrated that parametric design generates creative variations. However, there has been a lack of formal understandings to evaluate creativity in parametric design. This research develops an evaluation framework for parametric design in the early design phase. The evaluation framework is derived from the critical analysis of design creativity models and design evaluation criteria. The framework includes the evaluation of creativity from design process to design outcome in the context of parametric design. This paper focuses on the conceptual *evaluation framework*, which comprises a *coding scheme* for the protocol analysis of the design process, and *evaluation criteria* for the expert panel assessment of the design outcome. The theoretically-based framework, including the coding scheme and the evaluation criteria, presents a crucial starting point to formally understand creativity in parametric design as well as a novel approach for evaluating this creativity. Future research will include empirical studies on practices that adopt parametric design, in order to refine and verify this framework.

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Keywords: Parametric Design, Evaluation Framework, Design Creativity, Design Cognition

INTRODUCTION

Parametric design has become a global design issue. Schumacher (2009) claimed, using the term of parametricism, that it is a new global style for architecture and urban design. Parametric design explores variations in design. Moreover, many contemporary architects and even the general public are highly interested in the particular forms or unusual styles of built environment designs generated by parametric design. Why do contemporary designers and the public focus so enthusiastically on parametric design? What makes parametric design so attractive? The answer is probably creativity, as it is one of the most important aspects of design. However, does parametric design support creativity? Of course, it is not a simple question to answer.

Parametric design may force us to evaluate many variations as well as to use a complex process including mathematical algorithms. We may have to evoke and choose a creative form among unfamiliar forms. Most of the variations generated by parametric design may be significantly different to our experience. However, decision-making should always depend on our knowledge or experience. The more we generate new variations in parametric design, the more we should throw many of them away except for selected alternatives. It clearly increases the complexity of the local design decision (Aish and Woodbury 2005), which depends on the designer. In other words, it may make our design process more complicated. It is more difficult to evaluate the unfamiliar alternatives. This is a big challenge for a designer. How do we effectively evaluate creativity and choose the creative alternatives in parametric design? This is an important research question to be addressed.

Prior to proceeding with this study, it is necessary to understand the two underlying notions of design and creativity. The word "design" is used as a verb and a noun in the English language. Design can be mainly thought of as a verb denoting activity (Glanville 1999), in which creativity could emerge. Goldschmidt (1992) suggested that creativity is needed for a study of design behaviour to bridge the gap between design process and design outcome. In addition, technical aspects should be approached simultaneously with the aesthetic aspects. However, there is a lack of research on considering both of them carefully at the same time. Similarly, many studies on creativity have started at the reciprocal concept of novelty and value. Moreover, creativity can be categorized into conflicting notions: historical creativity and personal creativity (Margaret 2004); human creativity and computational creativity (Maher 2010). Creativity would come from a historical, social, and cultural achievement, as well as private and even computational output or process. This study deals with the relatively new design method of parametric design, which should be related to these complementary notions of design and creativity.

Pioneering studies on parametric design considering creativity (Blosiu 1999, Iordanova 2007, Iordanova et al. 2009) have addressed the achievement of creativity subjectively. These studies show that a new research framework needs to be established for a study on parametric design. This paper deals with understanding and exploring this new design territory. There is a lack of formal frameworks for evaluating creativity in parametric design. Furthermore,

there is a controversy in measuring creativity in architectural design. While creativity in the design domain might be a complex human phenomenon that is widely believed to be unmeasurable (Candy and Bilda 2007), some researchers (Gero 1996, Iordanova et al. 2009, Maher 2010) consider that it can be evaluated. In parametric design, a pioneering attempt (Iordanova et al. 2009) measured creativity through a simple questionnaire and subjective observation. However, there is a pressing need for a formal framework including domain-specific criteria to assess creative design in parametric design. The purpose of this paper is to devise a way of measuring creativity in parametric design, and to present a formal framework for evaluating creativity in a parametric design environment.

This paper is divided into three parts. The first part sets up the background of design creativity and parametric design. Secondly, a conceptual evaluation framework will be presented for guiding the adaption of the underlying approaches that will help understand and evaluate design creativity in parametric design. The first component of the formal framework is a coding scheme for parametric design environments to determine the creative design process and creative activity. The other component of the formal framework provides evaluation criteria for expert panel assessment of design outcomes generated by parametric design. The criteria are developed by analysing previous studies in the field. And finally, the third part will describe a follow-up study and an alternative evaluation model for the future.

1. BACKGROUND

1.1. Design Creativity

This paper focuses on design creativity in parametric design. Of course, given the nature of design and creativity in the mind, the development of a scientific and systematic evaluation framework might be controversial. Design and creativity might be a non-logical event and still be a mystery. Nevertheless, many studies have shown that they could be conducted in scientific way. In this section, we explore previous research models for understanding design and creativity. Guilford's Structure of Intellect (SI) theory, which facilitates creativity with his creative problem-solving model (Guilford 1967), figured out five types of mental operation: cognition, memory, convergent thinking, divergent thinking, and evaluation. Creativity has been described by psychological and cognitive researches in such terms as "creative thinking", "problem solving", "imagination", or "innovation". It is similar to the notions used in the design domain. Krysanov et al. (2001) categorized the notions of creativity into novelty and appropriateness and this combination has met with widespread acceptance. This paper will use the terms of novelty and value for understanding design creativity as the reciprocal contexts.

In the early 20th century, many researchers studied creativity across several disciplines. They had focused on creative characteristics and the creativity factors. Sternberg and Lubart (1999) categorized the scientific approaches on creativity into five approaches: pragmatic, psychodynamic, psychometric, social-personal, cognitive, and confluence. The pragmatic approach to creativity has focused on only commercial and social benefit. The psychodynamic approach is concerned with only the importance of psychology. Since Guilford's 1950 study of the Divergent Thinking (DT) test, the psychometric approach has been widely used in measuring creativity such as the Structure of the Intellect (SOI) and Torrance's Tests of Creative Thinking (TTCT). However, the psychometric approach cannot measure precise design drawings. It just uses simple paper-and-pencil tests and deals more with divergent thinking inside the individual mind. While the social-personal approach has tended to have little consideration for the mental process underlying creativity, the cognitive approach (Gero 1996, Sancar 1996, Kim and Maher 2008) has tended to downplay social contexts or personality. Nevertheless, the cognitive approach for design research has been crucial for understanding creative design process. The confluence approach has growing acceptance in creativity research (Katz 2002). However, it needs to avoid viewing one part as the whole phenomenon (Sternberg and Lubart 1999). This paper will focus on the cognitive and the confluence approaches.

The *cognitive process* in design and creativity research is an important issue whether it generates a creative product or not. Dacey and Lennon (1998) described early creativity models of the mental process as associationism, Gestalt, and cognitive-developmental approaches. They mentioned that the cognitive process has established new theories of two categories: (1) combination and expansion of the early theories, and (2) new theories dealing with metaphor, analogies, and mental models. The combination and expansion theories establish various aspects of the conceptual combination of ideas which may be associated. The theories argue that creative cognition is more than problem solving, and stress that selective and evaluative processes are important parts of the creative process. The new theories deal with metaphor which can shift the interpretation from one understanding of a concept to a new perspective, that is to say 'ontological shift'. Analogy refers to the concept of metaphor in creative cognition and it is one of the emerging issues in the design domain. These cognitive process models play an important role in facilitating creativity across various domains including the design domain. Hayes (1989) discussed the cognitive processes involved in creative acts: Preparation, Goal Setting, Representation, Searching for Solution, and Revision. These special acts might produce creative outcomes as well as facilitate creativity in design process.

The *confluence approach* has regarded creativity as the confluence of domain-relevant knowledge and abilities, creativity-relevant skills, intrinsic motivation, and the social environment (Amabile 1983, Hennessey and Amabile 1999). Amabile (1983) proposed the Consensual Assessment Technique (CAT) used in the assessment of both artistic and verbal creativity. The CAT as an expert panel assessment has been used consistently in research fields such as education, arts, business, advertisement, etc. Some studies (Amabile 1983, Christiaans 2002, Thang et al. 2008) showed that it is meaningful to measure creativity of the design outcome. Two assessment instruments have been applied to measure creativity in the design domain. One is the CAT and the other is the Creative Product Semantic Scale (CPSS) (Besemer and O'Quin 1987). The various versions of CAT have come from Amabile's work,

which has several dimensions of criteria such as the creativity, technical, and aesthetic dimensions. Amabile (1983) proposed that the analysis of inter-judge reliability in the judgments rating on each dimension is related to construct validity. Factor analysis on the various dimensions of judgement, including several subjective dimensions, should be done to determine the degree of independence between one and the other dimensions. The CPSS allowed judges to rate creative outcomes along three dimensions: novelty, resolution, and elaboration and synthesis. The CPSS has 70 bipolar subscales. The CAT and the CPSS have similar dimensions of assessment criteria, and complementary features for measuring creativity. The evaluation criteria in this paper will come from both of them.

The cognitive approach and the confluence approach might have some limitations in exploring design creativity. As we use both of the approaches for developing an evaluation framework, we can overcome the previous research boundaries. The cognitive approach is used to explore creative activities in the design process. The confluence approach would be customized to measure creativity of design outcomes. Mapping between the cognitive activities and the outcome assessment provides a higher level step in exploring design creativity in parametric design. This mixed approach offers the foundation for developing a conceptual framework for evaluating creativity in parametric design.

1.2. Parametric Design

This paper is focussed on evaluating design creativity in parametric design. Hagen and Roller (1991) categorized related researches into the constructive, the numerical, and the knowledge-based approaches. The constructive approach, used the term as history-based constraint design, incorporates in sequence. The numerical approach, called variational geometry and variational design, is independent of the sequence. Monedero (2000) stated that the numerical approach enables us to recompute a design corresponding to the actual situation. The knowledge-based approach emphasised here uses rule-based variants and reasoning. Using these rules in the computational design method has been a crucial issue in design computing, which deals with artificial intelligence and digital creativity.

Parametric design uses a relatively new approach for generating design alternatives compared to the traditional design method. We need to understand the notion of parametric design in advance. This paper, with a focus on creativity, pays attention to parameter and constraints. The two notions could be explained as variable and fixed attributes (Roberto 2006). Parametric design can be described basically by the use of the parameter (Monedero 2000). Robert (2004) concluded that the parametric can be considered in three parts: parametric components, parametric assemblies, and parametric controls. These parametric parts can be eventually represented by the parameter and the constraints.

Parameter, the first factor for facilitating creativity in parametric design, is about *divergence*. Cardenas (2008) explained that the notion of parameter is usually related to factors defining a range of variation. While it originates in mathematics, parameter has referred to design variations in the design domain. Parametric design obviously offers creative *variations* and generates multiple ideas (Kolarevic 2003, Iordanova 2007), indicating divergent thinking which evokes creativity. Parametric design is the process of designing in an environment in which design variations are effortless (Roberto 2006). With the parameter, designers could express and explore varying ideas without being supported by their own drawing skills (Lawson 2002). Making variations is the key to pursuing creativity as well as extending the boundaries of knowledge (Gero 1996, Liu and Lim 2006). However, the danger of parametric design lies in the fact that the variations may be too abstract and may only make sense virtually (Hanna and Turner 2006). It is a crucial issue for the designer to derive a reasonably creative outcome from parametric design.

Constraints, as the other factor in parametric design when considering creativity, are about *convergence* using Knowledge. Appearing in Sutherland's work in 1963 (Sutherland 1963), the constraints define the relations among the elements which must be maintained when generating variations. The constraints define relations among geometric elements (Lee and Kim 1996) and configure the parameter attributes. The constraints can be related to knowledge. Knowledge is one of the important factors eliciting both personal and design creativity (Li et al. 2007). Encoded architectural knowledge, linked to rules such as structure, climate and composition, provides a new way of design thinking and exploration as well as architectural expertise (Iordanova 2007). The early associative rule considers that the parametric constraints could be determined by design factors such as user needs, functional requirements, and structural demands (Park et al. 2004). Design parameters, using the constraints, could achieve an appropriate outcome. The constraints in the traditional design method might prohibit creativity, while parametric design uses the constraints positively. Many architects such as NOX, UN studio and FOA have explored an innovative way using the dynamic factors of motion, information, generation and fabrication (Liu and Lim 2006). Some researchers (Blosiu 1999, Park et al. 2004, Iordanova 2007, Iordanova et al. 2009) have argued that parametric design plays an important role in creativity and design exploration in the conceptual design phase, where *valuable variations* can be generated with constraints such as topological relationships, design rules, and controls of parameter.

Parametric design should be related to the divergent and convergent thinking as the most important factor in creativity model. Divergent thinking generates variations for a variety of answers with the parameters, while convergent thinking identifies a useful or appropriate solution for the right answer to a question with the constraints in parametric design. Both of these factors could be directly related to the definition of creativity as novelty and value. The coding scheme and evaluation criteria presented here are based on the characteristics of 'parameter' and 'constraints', which could evoke convergent and divergent thinking in parametric design.

2. FRAMEWORK DEVELOPMENT

Architecture is a fusion between the mathematical and the imaginative (Lawson 1980). However, parametric design has been mainly focused on the engineering aspect, because it is a mathematical concept and relatively widely-used in the engineering domain. An imaginative design approach should be considered even more in the design domain with a focus on generating various creations. Especially, when studying creativity, there is a research issue in producing a creative artefact and the evaluation of an artefact (Maher 2010). Our evaluation framework adopts the same methodologies to include the evaluation of creativity from the design process to the design outcome. Also, the framework needs to understand both the designing aspect and the engineering aspect of parametric design. The framework will figure out thinking pattern and decision making (Goldschmidt 1992). In order to analyse the design process, many studies have used protocol analysis, observation, and ethnography for determining the thinking pattern. This paper uses protocol analysis (Akin 1986, Suwa et al. 1998, Kim and Maher 2008) for exploring cognitive design activity; and expert panel assessment for measuring design outcomes. The evaluation framework for parametric design as presented below includes a *coding scheme* for cognitive analysis of design process and *evaluation criteria* for expert assessment of design outcome.

The *coding scheme* for exploring creativity in design process is based on previous coding schemes related to cognitive activities in the design domain. Prior to considering the cognitive activities, the coding scheme should be based on creative acts, because of the focus on design creativity. Creative acts (Hayes 1989) give us the fundamental level of the coding scheme. The cognitive activities in the design domain refer to design information in design process. The works of Suwa and Tversky (1997) are considered suitable for understanding these. Some related works (Suwa et al. 1998, Kim and Maher 2008) could suggest meaningful categories and subclasses for developing our coding scheme.

The *evaluation criteria* for expert judges measuring design outcomes starts with creativity criteria including the reciprocal contexts of novelty and value. The detailed assessment criteria are derived from the CAT (Hennessey and Amabile, 1999) and the CPSS (Besemer and O'Quin, 1987). Both of them should be suitable for design assessment. Given the focus on parametric design, the coding scheme and the evaluation criteria should include some specific criteria derived from the particular activities and characteristics of parametric design. The specific criteria were revised and adapted from the descriptions of tutorials on parametric design tools: GenerativeComponents, Grasshopper, ParaCloud, and Houdini. This allowed us to get prior understanding for parametric design.

Based on theoretical development, a conceptual evaluation framework has two main stages of design process and design outcome as shown in Figure 1. The coding scheme should be used in exploring the creative design process, while evaluation criteria are used in judging the design outcomes. The evaluation framework, the coding scheme and the evaluation criteria are refined in the next sections.

The evaluation framework provides the crucial mapping process between the protocol analysis with the coding scheme and the expert panel judgements on design outcomes. In order to determine the correlation between their results, the evaluation framework needs to have a higher level of methodology such as the second coding and retrospective interview. This is a big challenge. Though we do consider mapping when we develop the coding scheme and evaluation criteria, there should be a few strong correlations between them. In the case of design activities in the design process, a set of activities might engender a different design pattern or thinking pattern, which will be more easily related to the results of measuring creativity of design outcomes. Also, the criteria for expert panel judgements could be refined through a retrospective interview, which can determine the effect of other criteria on the judgement. The next section will describe the coding scheme and the evaluation criteria in detail, to establish the crucial foundation for adopting the evaluation framework in the design domain.

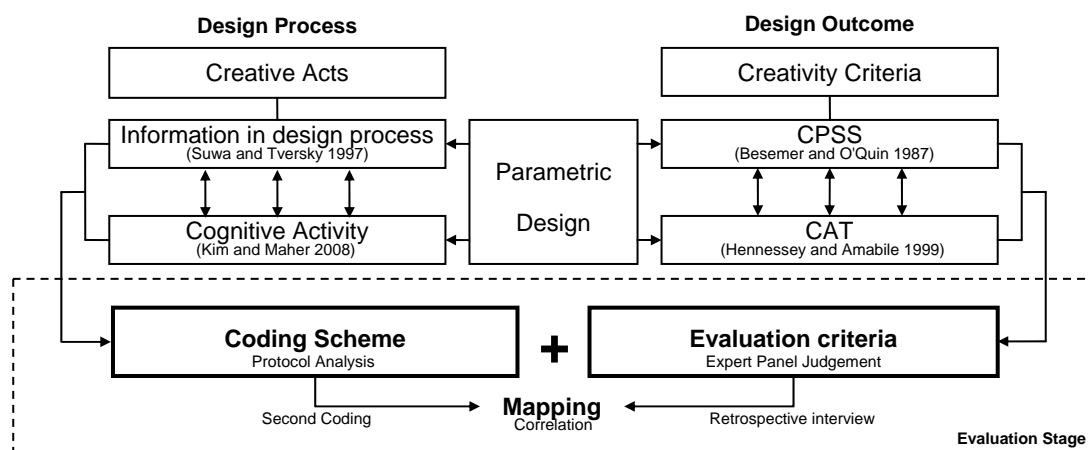


Figure 1: A conceptual framework for evaluating creativity in parametric design

2.1. Coding scheme for understanding creativity in design process

The coding scheme has seven categories of creativity actions on three levels. These levels come from cognitive process in creativity (Hayes 1989). This author regarded the creative process as the five creative acts of preparation, goal setting, representation, searching for solution, and revision. With the exception of preparation, we have customized the creative acts into three levels: *Representation*, *Perception*, and *Searching for solution* (Table 1). In order to develop categories and subclasses for detailed actions, we selectively borrowed design actions (Suwa and Tversky 1997) and cognitive actions (Kim and Maher 2008). Since parametric design has the crucial factors of parameter and constraints, we divide each of these levels into the two categories of Geometry and Algorithm. Next, we revised the design actions into parametric actions; for example, RA-Reference and PG-Transformation. Also, specific actions of parametric design such as RA-Parameter and RA-Constraints were added into the coding scheme. These levels and categories could be related to each other in the design process. Actions coded into an upper level could depend on other actions into lower levels. This facilitates the coding of the relationships among those actions.

The *Representation* level represents modelling activities in parametric design. It refers to the physical actions (Suwa et al. 1998) and the 3D modelling actions (Kim and Maher 2008) of other coding schemes. Geometry actions represent the modelling activities on digital geometries, while Algorithm actions represent generative algorithms, which describe the 'parameter' and 'constraints' as well as the 'reference'. The reference is regarded as an internal guideline (Iordanova, 2007) to transform data (e.g. structure, climate, sun, wind, etc.). The action of 'RG-Primitive' is separated to distinguish primitive geometrical shapes that will be changed and generated by parametric design.

The *Perception* level represents the activities of visual imagery in the creative process, which describes seeing relationships among elements (Flowers and Garbin 1989) or components. This level also has the two categories of Geometry and Algorithm actions. The perception level as cognitive level is related to the notion of incubation in Wallas's creative stage model (Wallas 1926), which might facilitate the creativity.

The *Searching for solution* level represents the activities of 'problem-posing' or 'problem-formulation'. This level consists of three categories of actions: Finding Ideas, Evaluation, and Adopting Idea. The activities of this level should be considered as a chain of creativity activities. For example, if an 'Evaluation' action occurs, this could be linked to some activities of 'Finding Idea' or 'Adopting Idea'. Specifically, the activities of 'Adopting Idea' should follow the activities of 'Finding Idea' or 'Evaluation'. These linked activities could be more closely correlated with some of the criteria for expert panel assessment in the next section.

Table 1: Coding scheme for understanding creativity in parametric design

Level	Category	Subclasses	Description
Representation	Geometry	RG-Primitive	make primitive geometries
		RG-Change	change existing geometries
		RG-Transformation	perform deformations (or morphing of forms)
		RG-Variation	make variations (or generate forms)
	Algorithm	RA-Parameter	make initial parameters
		RA-Change Parameter	change existing parameters
		RA-Constraints	make initial constraints (or rules)
		RA-Change Constraints	change existing constraints (or rules)
Perception	Geometry	PG-Geometry	attend to existing primitive or changed geometries
		PG-Transformation	attend to transformed geometries
		PG-Variation	attend to variations (or generated forms)
	Algorithm	PA-Parameter	attend to existing parameters
		PA-Algorithm	attend to existing algorithms
		PA-Reference	attend to existing reference data
	Finding Idea	SF-Initial Goal	introduce new ideas (or goals) based on initial goal
		SF-Previous Goal	introduce new ideas extended from a previous ideas (or goal)
		SF-Knowledge	introduce new ideas derived from knowledge (or experience)
Searching for solution	Evaluation (Geometry)	SE-Geometry	evaluate primitive or changed geometries
		SE-Transformation	evaluate transformation
		SE-Variation	evaluate variations (or generated forms)
	(Algorithm)	SE-Parameter	evaluate existing parameters
		SE-Algorithm	evaluate existing algorithms
		SE-Reference	evaluate existing reference data
	Adopting Idea (Geometry)	SA-Geometry	adopt new ideas to primitive or changed geometries
		SA-Transformation	adopt new ideas to transformation
		SA-Variation	adopt new ideas to variations (or generated forms)
	(Algorithm)	SA-Parameter	adopt new ideas to parameters
		SA-Algorithm	adopt new ideas to algorithms
		SA-Reference	adopt new ideas to retrieve or get internal/external reference

2.2. Evaluation criteria for measuring design outcomes

The evaluation criteria for the expert panel assessment measuring creativity of the design outcomes are comprised of three categories: *Novelty*, *Value*, and *Aesthetics* as shown in Table 2. We adopt selectively some subscales from the CAT (Hennessey and Amabile, 1999) and the CPSS (Besemer and O'Quin, 1987). Some specific subscales with a focus on parametric design are derived from Iordanova's indicators (Iordanova et al., 2009) such as abundance, flexibility, evolutions and originality of ideas. The parametric pattern (Qian et al., 2009) and dynamic factors (Liu and Lim 2006) allowed us to understand the design outcomes in advance, as well as devise the subscales. The total number of subscales of the evaluation criteria must be carefully designed, because the evaluation framework in Figure 1 deals with mapping between the cognitive activities and the judgements on design outcomes. This paper stresses the evaluation criteria, not as the large set for measuring design outcome itself or developing the criteria themselves, but as the relatively small set for facilitating a correlation with the cognitive data. Of course, the large set might be used for the correlation through the mean values of factors using factor analysis. However, it would be time consuming for measuring and analysing it. After developing a prototype of the large set of the evaluation criteria, including the domain specific subscales, the large set was condensed into the final evaluation subscales as shown in Table 2. We selected the subscales through the results of correlation and factor analysis of related works (Besemer and O'Quin 1987, Hennessey and Amabile 1999, Christiaans 2002). Even if we subjectively choose the evaluation subscales, we can construct validity through the analysis of inter-judge reliability and factor analysis (Amabile 1983).

Novelty is comprised of 'Originality (Idea)', 'Complexity', and 'Evolution'. Originality refers to the degree to which the design itself show a novel idea (Amabile 1983). 'Complexity' refers to the degree to which the design shows the level of complexity of the design (Amabile 1983). This might be related to the special notion of parametric design as well. 'Evolution', representing to what extent the design shows evolutionary and progressive features, comes from the Iordanova's indicator, a specific subscale with a focus on parametric design.

Value is comprised of 'Function', 'Usefulness', and 'Understandable form'. 'Function' represents the degree to which the outcome shows the function of a given design task. 'Usefulness' (Besemer and O'Quin 1987) refers to the degree to which the design shows the quality of being of practical use. Understandable form refers to the degree to which the model makes sense and is sufficiently understandable.

Aesthetics is comprised of 'Aesthetic form', 'Elegance', and 'Well-transformation'. Aesthetic form refers to the degree to which the design is aesthetically appealing (Amabile 1983). 'Elegance' represents the degree to which the design has been elegant and attractive (Besemer and O'Quin 1987). 'Well-transformation' represents the degree to which the model has been technically transformed. This is derived from the CPSS's well-craft (Christiaans 2002).

Table 2: Evaluation criteria for expert panel assessment

Novelty	Value	Aesthetics
Originality (Idea)	Function	Aesthetic form
Complexity	Usefulness	Elegance
Evolution*	Understandable form	Well-transformation*

*Specific criteria referring to parametric design evaluation

3. DISCUSSION: AN ALTERNATIVE EVALUATION MODEL

There might be several evaluation stages in the design process. In order to investigate the more complex stages of parametric design process, we may need to establish an alternative model. We would pay attention to 'problem-posing' or 'problem-formulation' in creativity or design research. Problem-posing should refer to the recurrent or cyclical approach of the previous problem-solving models. Creative thinking models in the design domain as well as the modelling process of parametric design tools have already been reviewed here. In summary, we can classify the evaluation stage in parametric design into four stages: *Problem-interpreting stage*, *Function-associating stage*, *Form-generating stage*, and *Final Assessment stage*. The first three stages have Analysis Node (defining constraints) and Evaluation Node (decision-making). The Final Assessment stage is about measuring the design outcomes judged by the expert panel. Therefore, the alternative model is comprised of three Analysis Nodes and four Evaluation Nodes as shown in Figure 2. Current research is limited to two stages of the exploration of the design process and the assessment of the design outcomes design outcomes, but will be extended to four stages in the model.

The three stages in the design process have a non-routine process, and each stage shows a recursive thinking pattern of convergent thinking and divergent thinking. The *Problem-interpreting stage* configures the parametric components and primitive geometry, which are derived from problem definition and strongly relevant to goal setting in design creativity. TOC and TRIZ (Altshuller and Altov 1996) could bring an understanding to this stage. In the *function-associating stage*, geometrical and algorithmic relations will occur in parametric design. The creative pattern and evaluation happening in the stage could be represented effectively as the FBS model (Gero 1996). Also, this stage might be referred to as associationism in creativity models of the mental process. The *form-generating stage* enables the designer to explore various design alternatives. This stage uses the specific algorithm and references which could connect to a knowledge-based model.

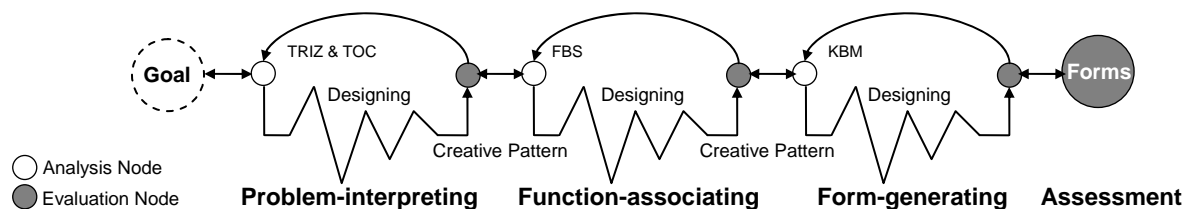


Figure 2: An alternative evaluation model for understanding creativity in parametric design

4. CONCLUSION AND FUTURE DERECTIONS

The evaluation framework proposed in this research presents a crucial starting point for formally understanding creativity in parametric design. It represents a novel approach for evaluating parametric design through the framework devised from familiar cognitive models and design theories. The notion of design and creativity were considered as reciprocal contexts from the design process to the design outcome. The characteristics of parametric design were categorised into parameter and constraints; divergence and convergence. The three main outcomes of this paper are the creative cognition coding scheme for protocol analysis, the evaluation criteria for expert panel assessment, and the conceptual evaluation framework. These will contribute to the understanding and exploration of parametric design for facilitating creativity.

The coding scheme based on creativity acts was developed into three levels of Representation level, Perception level, and Searching for solution level. The coding scheme should be suitable for determining creative activities. The algorithm actions, describing the 'parameter' and 'algorithm' presented here, may establish the foundation of cognitive research on parametric design. The linked creativity activities in the Searching for solution level will enable us to figure out the core feature of creativity in the design process. The evaluation criteria, with the three categories of Novelty, Value, and Aesthetics, will open the way for us to measure the design outcomes. The total number of subscales in the evaluation criteria is carefully designed to correspond to the research goal. This paper stressed the small evaluation set for facilitating a correlation with the cognitive data, but the large evaluation set might be useful for other research like design education. The evaluation framework could be extended to a progressive phase in more detailed future studies. The coding scheme and the evaluation criteria could have some limitations in investigating all of the design creativity in parametric design. However, this paper has extended the boundary through mapping both of them. Mapping between the cognitive activities and the outcome assessment should provide a progressive step in evaluating creativity in parametric design.

The conceptual evaluation framework presented here, including the coding scheme and the evaluation criteria, will be refined and verified through a pilot study. In order to proceed with the empirical study, five professional architects who have experience in parametric design will be recruited for the design process stage with the coding scheme. Also, a panel of seven design experts who have over five years' experience will assess the design outcomes using the evaluation criteria. The judges should be familiar with the domain in which the outcome was created, i.e. "appropriate observers" (Amabile 1983). Application techniques (Amabile 1983) with the appropriate judges may produce a reasonable assessment. Future work will investigate the two stages of the exploration of the design process and the assessment of the design outcomes for understanding creativity in parametric design. To map the activities to the evaluation criteria, correlation analysis will be performed (as illustrated in Figure 1). The mapping process will be conducted with the second coding and retrospective interview.

The alternative evaluation model for future research described here will allow us to investigate creativity in the more complex stages of parametric design process. Evaluation, with 'constraints defining' and 'decision-making' in the model, enables us to facilitate exploring creativity in parametric design. Future research will include empirical studies on practices that adopt parametric design, in order to refine and verify this framework.

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