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# Evolutionary grammars based design framework for product innovation

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## Abstract

Innovation and creativity are the key successful factors and a global priority in engineering industries. This paper describes the development of an evolutionary grammars based design framework for product innovation. A new genetic representation of shape grammars is developed in an evolutionary computing environment. The results generated by the genetic algorithm define a new combination of shape features for alternative designs. In this way, traditional shape grammar is extended to an interactive context in which generative and evolutionary computing methods are combined. Both product component design as well as product configuration are supported in this framework. Two important design issues are addressed in this research, 1) Product form exploration, and 2) Product design strategies. To tackle the issues, this research demonstrates the efficient use of evolutionary grammars to support the exploration of innovative product form designs.

*Keywords:* Evolutionary Grammars; Shape Grammars; Evolutionary Computing; Product Innovation; Product Design Strategies

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## 1. Introduction

Innovation and creativity are the key successful factors and a global priority in engineering industries. Creating innovative designs involves research on new algorithms in addressing the design issues. Two important design issues are addressed in this research, 1) Product form exploration, and 2) Product design strategies. To tackle the issues, this research demonstrates the efficient use of evolutionary grammars to support the exploration of innovative product form designs.

Research in shape grammars is concerned with the efficient use of generic shape grammars to support the exploration of innovative forms of a product. For example, Cagan and his team developed the coffeemaker grammar, motorcycle grammar and hood panel grammar [1,2,3] in which the coffeemaker grammar uses function labels to maintain the proper function-to-form sequence, to generate novel designs. The motorcycle grammar is used to capture brand identity. The hood panel grammar can generate the novel designs with shape emergence properties. Other examples include the semantic and shape grammar based approach to product design developed by Hsiao and Chen (1997) [4]. Significant contribution has been made by researchers on supporting product form design.

However, the four topics to challenge researchers working in the area of creative design support identified by

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Smyth, et.al. (2000) remain very challenging today [5]. The four challenging topics identified by Smyth, et.al. (2000) are 1) Potential use of 3D shape grammar, 2) Additional grammar like colour grammar, 3) Loose fit rules and 4) Organic growth of rules. Most of the current grammar based systems can only provide a fixed set of grammar rules which must be developed in advance based on an analysis of the existing products. In this way, the users cannot participate in the process of developing and evaluating the shape grammar rules. The exploration of new shape grammar rules is difficult for designers who do not necessarily have the sufficient knowledge about the coding of grammar rules or other reasoning systems. As a result, the generative capability of a shape grammar based design system is still limited. The four challenging topics should not be underestimated.

This paper outlines the development of an evolutionary grammar framework. The framework consists of two key technologies, 1) Shape grammars and 2) Evolutionary computing. Shape grammars are used to formulate and generate innovative product forms and their components' configuration. The generative capability of shape grammars is enhanced by evolutionary computing. Lee et al. (2004, 2006, 2007, 2008 and 2011) have applied evolutionary algorithms to evolve the shape grammar rules to generate product designs [6,7,8,9,10]. It is different from the traditional approach in applying the evolutionary algorithms to evolve the targeted objects themselves. Recently, Lee (2011) has applied the evolutionary grammars to refine product design strategies [10].

The rest of this paper is organized as follow. Section 2 presents the development of the framework. Section 3 illustrates the implementation using compact digital cameras as examples. Section 4 reports the strategies to targeting the four challenging topics and the issues of product form exploration and product design strategies. Finally, section 5 draws conclusions.

## 2. Evolutionary Grammars Based Design Framework

The trend of product innovation is now more concerned with the customer satisfaction, affordability, production rate, technical ability, value chain and competition (Browning et al., 2003 and 2006) [11,12]. Especially, the level of importance on customer satisfaction is becoming higher. For successfully launching and sustaining the product in the market, the voice of customer on their requirements must be responded. Customer requirements are subject to a variety of factors like technology, and their age, income, profession, education and preference. To address this challenge, customer satisfaction becomes one of the evaluation criteria in the framework as shown in Figure 1 (a).

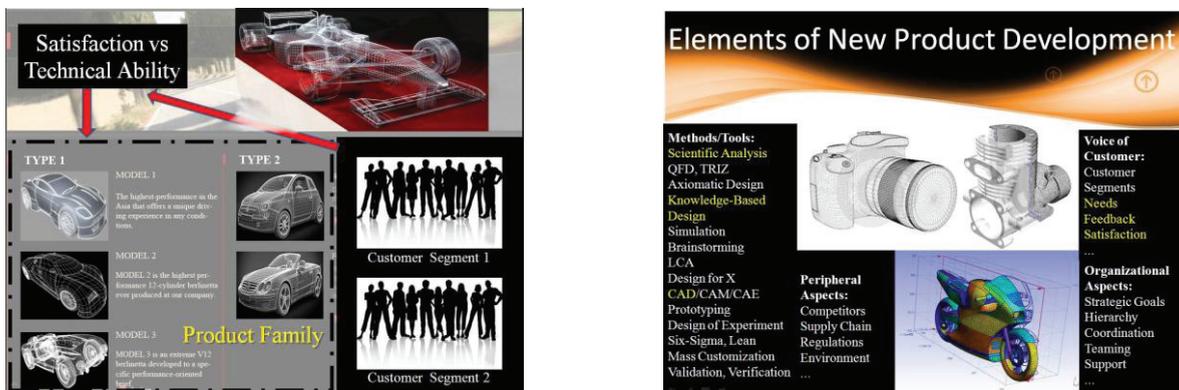


Fig. 1. (a) Main challenge of product innovation; (b) Elements of new product development

New product development involves complex activities which include the change in the design of established products, or the use of new materials or components in the manufacture of established products (White, et al., 1988) [13]. Besides, the activities involve a great deal of human-physical resources, methods, and tools for greater customer satisfaction (Fujita and Matsuo, 2006) [14]. To address this challenge, the methods like Scientific Analysis, Knowledge-Based Design and CAD, and the Voice of Customer like Customer Needs, Feedback and Satisfaction are considered in the framework as shown in Figure 1 (b). Figure 2 outlines such an approach to design support with evolutionary grammars.

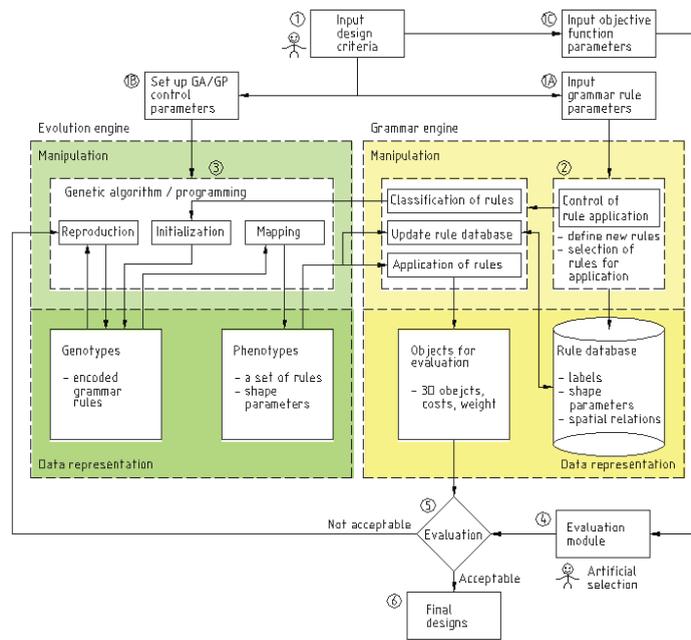


Fig. 2. Interactive design process utilising evolutionary shape grammars

According to Stiny’s seminal work, a shape grammar consists of a vocabulary of shape elements, a set of production rules and an initial shape [15]. On the other hand, generative and evolutionary design techniques are developed based on the inspiration from natural evolution. Centred at the techniques are the generative methods and the testing of the designs generated by these methods [16]. In our research, both classical genetic algorithm (GA) and genetic programming (GP) have been tested as the core of the evolutionary architecture for evolving new shape grammar rules. This paper reports the classical GA while the GP should refer to Lee et al., (2008) [9].

### 3. Implementation

The phenotype representation describes all permissible solutions that can be generated by the system (Figure 3a). It enumerates the design-space for evolutionary search by a GA. The main aspects to be studied are which elements of a grammar rule can be evolved, and how to represent these elements for the manipulation by a GA.

For the first issue, a product has a set of components. These components are configured under spatial constraints to form an assembly. Therefore the phenotype consists of two elements: the rules for constructing these components and the corresponding configuration. For the second issues, these two elements are represented by the corresponding rule number and stored in an array for the GA manipulation (Table 1). The genotype is represented by a single chromosome. A chromosome is a list of alleles which is the binary encoding of the phenotype.

Table 1. The elements of the phenotype: Rule number of each component

Item	Type	Lens	Flash	View finder	LCD	Form style
Rule No.	Choose to 2	Choose 3 to 6	Choose 7 to 9	Choose 10 to 12	Choose 13 to 14	Choose 37 to 45

For each generation, the genotype is converted into the phenotype which represents the solutions. The solutions are a number of individuals, each of which consists of a set of rule numbers and the instructions to change the rules. After execution of the rules in accordance to the generated rule sequence, the components are generated (Figure 3b). The GA will stop if a satisfactory solution emerges. The evaluation of the results leading to deriving a numbers of product design strategies is reported in another paper by Lee (2011) [10].

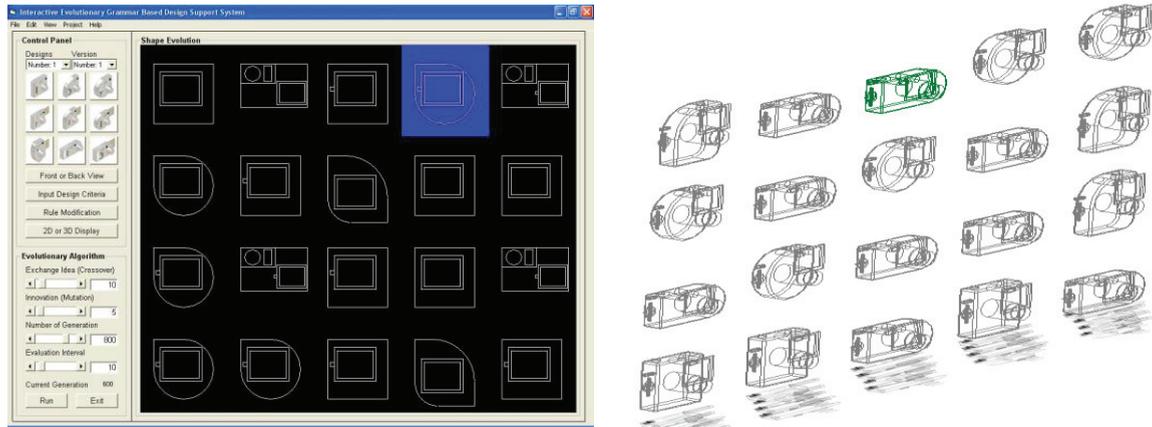


Fig. 3. (a) Evolutionary Grammars Based Design System; (b) The population of the results generated by the system

## 4. Strategies on Creative Design Support

The strategies to target the four challenging topics (Smyth, et al., 2000) [5] and the issues of product form exploration and product design strategies are elaborated in the area of creative design support.

### 4.1. Potential use of 3D shape grammar and additional grammar

The major technical difficulties in developing 3D shape grammars include the representation of complex 3D objects in the form of shape grammar rules. The complexity of the problem is significantly greater on how the rules are manipulated in an evolutionary computing environment. Conflicts of removing stylistic consistent designs are appeared when evolving a shape grammar to generate innovative designs. The new genetic representation (GP-GA-SG representation) developed by Lee et al., (2008) solved these technical difficulties [9].

Additional grammars like colour grammars have been developed by Knight (1989) which has given an insight to researchers on potential design applications in architectural domain [17]. Knight (1999) has described six types of shape grammars: Basic, Nondeterministic Basic, Sequential, Additive, Deterministic, and Unrestricted grammars [18]. Further research direction could be focused on them in solving the engineering design problems.

### 4.2. Loose fit rules and organic growth of rules

In general, the ‘Loose fit’ rules are allowed to be modified by the designers interactively. The generated designs act as a creative stimulus for the designers as they inspire to generation of new ideas. However, most of the current grammars based design systems can only provide a fixed set of rules. In this way, the users cannot participate in the process of developing and evaluating the rules. The framework developed in this research addresses this issue by providing the designers the ability to modify the elements and sequences of the rules indirectly [9]. As a result, the generative capability of a shape grammar based design system is enhanced.

By applying the mutants of the rules such as a small geometric shift at each application, diversity of designs can be generated. The genetic operations on rules presented in this paper allow designers to experiment the evolutionary designs. The designers can understand their impact on the generation of new ideas.

### 4.3. Product form exploration and Product design strategies.

Emergence is an important property of shape grammars. The issues of handling of emergence in the context of shape grammars can be found in research literatures (Knight, 2003 and Stiny, 2006) [19, 20]. Another significant property of shape grammars is the control of design process in form generation. The interactive environment created in this framework allows the designers to explore new rules easily. Designers do not necessarily have the sufficient

knowledge about the coding of grammar rules or other reasoning systems when using the evolutionary system.

The ability for a product developer to successfully launch useful products to a market is tied to the company's product development strategies, thus making profitability. Investigation on the relationships among the shape formulation process and product design strategies becomes a new research direction. Recently, Lee (2011) has research on evolutionary grammars with Kano's model to refine product design strategies [10].

## 5. Conclusion

This paper has illustrated an evolutionary grammars based design framework for product innovation. The two critical issues, 1) Product form exploration, and 2) Product design strategies in the area of creative design support, are addressed in this framework. In addition, the strategies to target the four challenging topics (Smyth et al., 2000) are elaborated [5]. The integration of shape grammars with evolutionary computing techniques facilitates the formulation of design knowledge from the existing designs with parametric shape grammars. The potential of this framework can be further explored in complex form generation and configuration optimisation.

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