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Balancing homogeneity and heterogeneity in design exploration by synthesizing novel design alternatives based on genetic algorithm and strategic styling decision

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ABSTRACT

Designers constantly and consistently draft and develop both general concepts and directions to identify the solution that best fits the styling objectives of the lead designer. Designers often confront design fixations that cognitively clash to explore different design combinations. As design teams explore the range of possible design spaces of a certain design strategy, there is an opportunity for computational approaches to improve the styling process. By implementing product appearance similarity and styling strategy in computational design synthesis, it is possible to discover combinations that would otherwise remain unexplored by human designers. Numerous studies on design synthesis have been conducted. However, there has been no focus on the morphological synthesis of designs with strategic styling decisions. Considering this, the proposed study develops a method to synthesize car styling based on product appearance similarity for effective design exploration in the concept generation phase. The similarities of products across different generations, product portfolios, and competitors' products are calculated to evaluate the strategic styling decision. The results of the strategic styling decision are used to formulate a fitness function. Car styling is then synthesized with a genetic algorithm based on this fitness function to generate car styling in accordance with the target strategic styling decision. In this respect, designers can computationally synthesize novel design alternatives that consider both homogeneity (family look in design) and heterogeneity (design trend in the market) by pinpointing the desired design exploration area. Ultimately, the style synthesis methodology proposed in this research can help designers to utilize the gradual visualization of styling strategies for more effective and efficient managerial design decisions. To do this, we conduct five major tasks: first, car design data are collected for design synthesis; second, the product appearance similarity is calculated to measure the strategic styling decision; third, synthesis validation is conducted to test whether the proposed methodology can create outside-the-box designs; fourth, a genetic algorithm is used to synthesize car designs in consideration of the strategic styling decision; finally, a series of in-depth interviews with experts and validation experiments are conducted with in-house automobile designers to examine the impact of the proposed methodology. The results showed that designers can quantitatively measure and compare the styling strategies of each car brand, then implement design upgrades, while still maintaining that specific style. Correspondingly, computationally generated design alternatives improve the satisfaction in ease, time, objective reflection and novelty of design outcomes when formulating design strategies in the concept generation phase.

1. Introduction

Product aesthetics play an important role in consumer satisfaction and market success [1]. Although the role of designers is expanding to include multi-layered design problems such as determining the target consumers, product concept, user experience, and product manufacturing processes, the major demand that companies place on designers is the styling of products. Companies benefit from good styling because customers are more likely to purchase aesthetically pleasing products [2]. However, the intuitive, holistic, and nonverbal culture of the styling process makes it difficult to analyze [3]. Bloch [4] defined styling as the process of ornamenting product appearances that evoke potential customers' emotions. In fact, "ornamenting product appearance" is a complicated process that must fulfill various design constraints such as incorporating brand identity, testing manufacturability, and evaluating technological efficiencies. Among various types of

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designers, one in particular focuses on the stylistic aspects of product appearance in the design process: car designers. When designing products, the role of car designers is not limited to making new technology more attractive and introducing new features, but also seeks to generate novel ideas and explore new forms [5]. Importantly, car designers must also consider the automobile manufacturers' design strategy of either following or leading the styling trend [6]. To create an optimal styling that fulfills the styling elements, designers constantly visualize design concepts by repetitively generating every possible design variation. Sketching is a major component of the concept selection and embodiment design phases [7]. One of the major tasks of car designers is to draft and develop a general concept and direction according to instructions from the lead designer. They constantly and consistently sketch design alternatives to find that which best fits their styling objective. Often, designers confront design fixations that cognitively clash to explore different design combinations [8]. As teams of designers try to explore the vast possible design spaces of a certain design strategy, there is an opportunity for a computational approach to improve the styling process. Computational design synthesis may be able to discover combinations that would remain unexplored by human designers. This suggests the contribution of our research objective, which is to create a method to automatically synthesize novel design alternatives while satisfying a given styling strategy in the concept generation phase.

In any styling strategy, it is important for designers to know how similar the designs are. Designers explore visual forms of similar products, dissimilar products, historical products, and non-products for inspiration and reference [9]. As a result, design similarities are adjusted based on the company's design strategy. According to Dell'Era and Verganti [10], there are two distinctive design approaches: the homogeneous strategy and the heterogeneous strategy. Companies using the former approach design their products to have a similar appearance across the product portfolio, whereas the latter approach concentrates on differentiating product appearances. The Strategic Styling Decision proposed by Person et al. [11] explains the styling strategy based on the product appearance similarity (Fig. 1). Person et al. [11] suggested there are three major components when making strategic decisions: the present product portfolio, successive product generations, and competitors' products. The present product portfolio is often described as the family look. It reflects the similarities in appearance among products within that brand. A good example in the car design field would be the product appearance similarity measured among different class segmentations, such as small-sized sedans, mid-sized sedans, and large-sized sedans. The successive product generation is the design history of the product. It indicates the degree of similarity with previous generations of the product. The competitors' products indicate the styling trend in terms of the similarity among competitors. The styling strategy and product appearance similarity are therefore interrelated.

By implementing product appearance similarity and styling strategy in design synthesis, it is possible to objectively synthesize a novel design that is heavily reliant on the designers' subjective experience and knowledge. Hyun et al. [6] proposed a methodology to quantify product appearance based on the degree of similarity. Unlike traditional product appearance measurement methods, Hyun et al. [6] introduced a new methodology that can taxonomically synthesize product appearance based on the similarity among designs, thus enabling effective design management. Like human designers sketching and rendering design alternatives heuristically, computational design synthesis iterates designs to create novel solutions that are also known as "outside-the-box designs." Iterative designs have often been criticized for their lack of capability in creating superior designs with expanded boundaries, instead being limited to creating local maxima [12]. However, novel designs are often described in terms of newness [13], and therefore it is fair to say that designs that are yet to be introduced are more novel than existing designs. Chen and Parent [14] proposed a method to create novel shapes by averaging two existing shapes. They averaged the silhouettes of a car and a teardrop with different weighting values to synthesize novel aerodynamic car shapes. For example, a designer can explore the gradual visualization of the degree of morphing between teardrop and automobile silhouettes to explore novel shapes. In this respect, it is possible to synthesize novel designs by morphing existing designs. There have been a number of studies on style synthesis by integrating shape morphing with genetic algorithms, but no attention has yet been paid to the morphological synthesis of designs with strategic styling decisions [15–20]. The integration of styling strategy and design synthesis can assist the current car design development process by pinpointing the desired area for efficient and effective design exploration. This is supported by Helm et al. [21], who developed the Idea Mapping Board. They found that the visualization of a vast number of design ideas on a map, during the concept generation phase, helps when comparing and viewing possible design spaces. In this respect, designers can discover unvisited but novel designs that satisfy their design strategy from among myriads of possible design alternatives. Thus, this research focuses on morphologically synthesizing car designs based on the positioning of product appearance similarity among the three strategic styling decision components—degree of similarity among the product portfolio, product generations, and product competitors (Fig. 2). By doing so, we can computationally create novel designs that consider both homogeneity (family look in design) and heterogeneity (design trend in market). To do this, we consider five major tasks: first, car design data are collected for design synthesis; second, the product appearance similarity is calculated to measure the strategic styling decision; third, synthesis validation is conducted to test whether the proposed methodology can create outside-the-box designs; fourth, a genetic algorithm is used to synthesize car designs in consideration of the strategic styling decision. Finally, a series of in-depth interviews with experts and validation experimentations are conducted with in-house automobile designers to examine the impact of the proposed methodology.

2. Related work

2.1. Design exploration in concept generation phase

There are four phases in the design process: analysis, concept generation, preliminary design, and detailed design [22]. The literature on the design process emphasizes the importance of concept generation. Yang [23] stated that "the generation of idea is the key activity in the design process." Generating a vast number of ideas at the start of the design process will lead to better design outcomes [24]. To generate design ideas, the act of sketching is widely used. Studies have highlighted the importance of sketching for concept generation. First, sketching is the most effective way to visualize one's design thinking [22], providing a fast but rich representation of the design idea and allowing designers to explore designs efficiently. Second, sketching can lead to the creation of more creative design ideas through the generation of many designs [25]. In the early design stage, it is critical to simulate the potential of design ideas. Quality and efficiency of sketching is important in creating the detailed design but, in the early design phase, the quantity of sketches is more important. Yang [26] stated that "by broadening the initial pool of ideas, quantity yields quality."

Schrage [27] stated that the success of a design is closely related to the representation of ideas through drawing and prototyping. However, the quality of idea representation varies depending on one's expertise. Concept generation is known as the "black-box" of the design process, and depends on the designer's subjective experience and knowledge [22,28]. The proficiency of sketching changes the quality of the design outcome [29]. Thus, the act of sketching is critical to the concept generation phase. Sketching is an essential activity, especially in the automotive industry. Bae and Kijima [7] therefore attempted to make the sketching process more efficient for automobile styling. Fig. 3 is