Impact of Visual Topological Features on Priority Attention for Product Shapes

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Abstract

This study hypothesized that humans give priority perception to product shapes that possess topological structures. Three experiments confirmed the proposition accordingly. The first experiment selected existing products that grab people's attention within the prescribed time, with the experimental objects selected according to degree of topological properties and structure complexity. The results showed that visual topological properties in the products had strong visual appeal. The second experiment determined the visual prominence of freely designed and redesigned chairs according to the rating of non-expert users. The results demonstrated that products whose shape adopted topological structures were given priority attention. The third experiment intended to prove the practical value of visual topological features from a direction opposite to that of the second experiment; that is, from topological structures to deconstruction of topological structures. All three experiments showed as well that there are many cognitive limitations in the recognition of topological structures in product shapes. These unexpected problems, such as the contradiction between topological structure and habitual cognition, are discussed. The results of the study and the effects of topological properties on development are also discussed.

Keywords: product shape, visual perception, priority attention, topological structure, topological perception, design

In general, consumers have no access to the designers of the products they buy. Their interpretation of design is based predominantly on their interaction with the product (Norman, D A, 2013). Under normal circumstances, the relationship between a person and a product begins with the visual appearance of the product. Customers tend to identify the features of a product through its visual form, including aesthetic impression, semantic interpretation, and symbolic association (Nathan Crilly et al., 2004). People also match their expectations and level of novelty with a product's usability (Jan P.L. Schoormans, 2012). By manipulating the appearance of products, a designer can elicit certain emotions from or introduce beliefs to users (Lars-Erik Janlert, 1997). In this sense, a product's visual form plays an important role.

Literature Review

The composition of the product form consists of colors, materials, shapes and proportions

(Violin P. Rindova, 2007). Shape is probably the first factor and the most significant property of a product that one can perceive from objects (Stephen E. Palmer 1999). After all, industrial designers generally start with sketches of shape, and not the identification of color, in developing new products.

As products in the same product category should be explicitly distinct from competing products, a product's shape is often the first consideration in distinguishing it from other products in the market (Underhill, P, 2000). The original intention that selecting object comes from the personal preference for shape, just like an influence on people's attitude toward the objects with sharp angled or curved, and more preference of curved visual objects (Moshe Bar 2006). Meanwhile, people use new form to draw on existing products and develop a new schema (Violina P. Rindova 2007). In the development of a new product, the emotional value of the product is likewise an important factor. A biomimetic shape in product design has been found to meet the emotional needs of people (Tyan-Yu Wu et al., 2015).

Although product shape perceived by the senses has been studied for decades, the focus has been on the aesthetic, semantic, and symbolic aspects of shape. This work focuses on priority attention on product shape, on the premise that customers make unconscious comparisons between competing products based on their visual forms either at the store, physically, or according to their memory of a product image. Another case is the comparison of the reality of the product and the imagined model of the same product. This comparison involves empirical perception. If the actual product is similar or more attractive than the imagined model, the consumer will recognize the designer's vision quickly. Thus, how can a product gain instant attention?

Research has shed light on the priority of shape recognition. Experimental phenomena are not necessarily consistent with perceptual experience but with topology (Chen, L, 1982). Topological perception based on physical connectivity occurs prior to the perception of other geometrical properties. Topological properties have three manifolds in 2D: connectivity, number of holes, and inside–outside relationship (Chen, L, 2005).
This study aims to investigate the correlation between product morphology and visual topological features, and improve the visual attention on the product form from the aspect of visual topological features. This research adopts the product morphology theory, which provides a new theoretical basis for product form design.

Many experiments have proved the priority of topological perception. These results support the early cognition of 2D graphics, but not in 3D objects. Two-dimensional graphics can contain information on shape implicitly and locally, and in product design, the main shape features of the product can be shown with six visual images. Meanwhile, experiments have been conducted on the perception of shape constancy of 3D objects. Rock and DiVita provided evidence that the shape constancy of irregular objects is poor (cited in Stephen E. palmer

1999). Nevertheless, people can easily recognize familiar objects in multiple perspectives. Based on the above analysis, this study hypothesizes that topological perception exists in product shape and plays an important role in the human cognition of familiar products. In other words, people pay visual attention to product shapes with obvious topological characteristics.

The shape of a product should thus contain topological structure characteristics, so that the consumers can see them immediately. After all, product appearance determines consumers' first impression (Marie¨lle E. H. Creusen et al., 2005). Once their attention is on a product, they can then proceed to understanding other aspects of the product. For designers, visual topological features have a practical guiding significance for the innovative design of product form.

To test the hypothesis, this study designed three experiments. The first one is on the search for visual topological properties in existing products. The second seeks to prove the existence of visual topological features in the form of products through a design project. Lastly, The third experiment intended to prove the practical value of visual topological features from a direction opposite to that of the second experiment; that is, from topological structures to deconstruction of topological structures. Subsequently, this work discusses the positive role and limitations of visual topological features in product form. This research discusses the guiding role of visual topological characteristics in product shape design.

Research methods

To confirm the existence of topological structures in product shapes and to seize the attention of consumers, three experimental processes were performed composed of different phases of analysis and validation methods.

Purpose of the experiment

Experiment 1 aimed to identify the level of the test using bicycles as test objects. In accordance with the typical characteristics of the topology of the hole, the two wheels of the bicycle tend to be seen primarily as rings. Their shape carries the typical topological property of "hole". Many concept bicycles have been created, some with a novel transmission structure; a new style of wheels could appear as standard rings. In contrast, the traditional wheel with spokes can be seen as circles. From the perspective of visual topology, circles and rings are topologically different. People are expected to pay more visual attention to the bicycle with the ring wheel. In Experiment 2, typical topological visual features are integrated into the shape design of a chair. The design practice is used to prove the existence and function of topological visual features in product form. Meanwhile, Experiment 3 is based on the disassembly of the inherent topology of a product to prove that morphological innovation at the topology level has a high visual priority.

Experiment procedure

Experiment 1. To test the visual prior attention given to bicycles, three bikes were compared. Images of three bikes were laid out side by side in one A3 paper to enable easy comparison (Figure 1). The pictures of the three bicycles were designed using drawing software. The basic structure and style of the three bikes were consistent to reduce the effect of other factors on visual attention. Considering the influence of watching habits, two test objects in each image were arranged in a different order. To avoid the influence of color, all pictures were presented in gray scale on white background. Sixty-three people from various backgrounds participated in the experiment. They were chosen among college students and their relatives, their ages ranged from 9 to 65 years, with an average age of 24 years. Before viewing the pictures, each participant was told to score each object in accordance with the order of visual attention, with the maximum score of 5 points corresponding to "highest visual attention." In other words, the object they first noticed should be given the highest score. Based on the results of a preliminary experiment, the experiment duration was limited to 10–15 seconds.

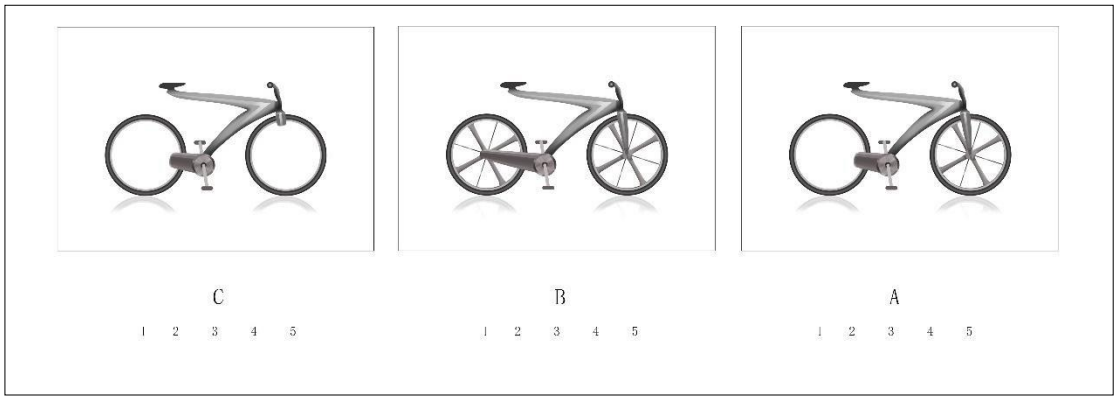

Figure 1: Example of the evaluation tool used in Experiment 1

Experiment 2. First, eight design students were asked to design one chair freely (Figure 2). Second, each participant was asked to improve a previous design according to specified requirements and elements (Figure 3). To ensure the objectivity of the experimental results, the design scheme was based on the pencil line and white background and should show a 45-degree angle of the chair. Lastly, the two groups of design were combined in a picture, and 20 design non-expert users, their ages ranged from 18 to 45 years, with an average age of 32 years, were asked to score each sketch based on a five-point scale (Figure 4). The experiment emphasized that the subjects focused on the degree of visual attention to the shape of the chair; the function of the chair, manufacturing processes, and other factors were not considered.

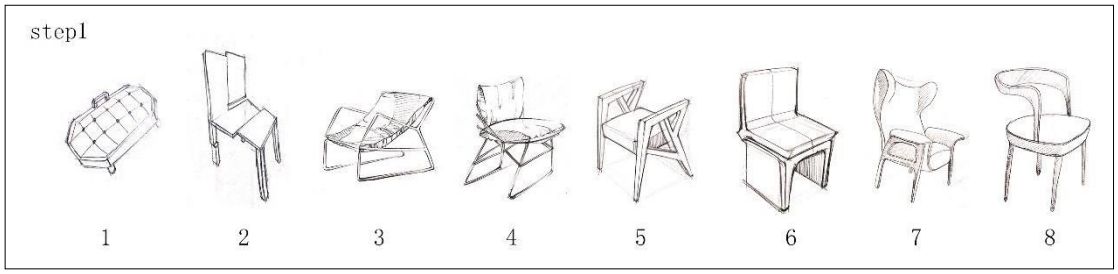

Figure 2: The first step of the design

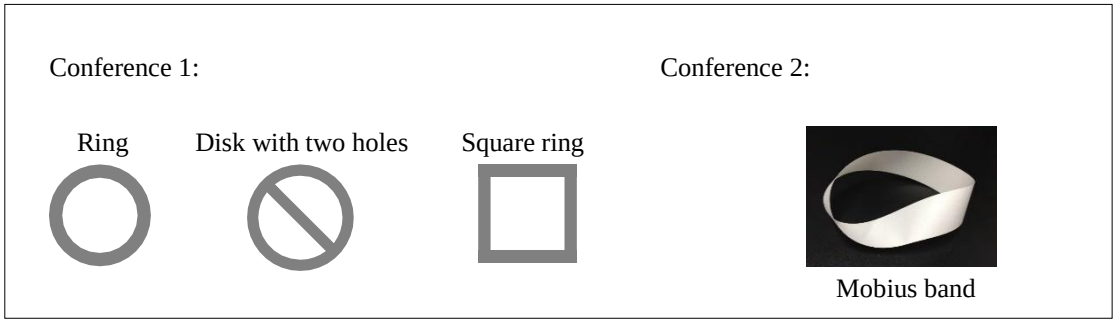

Figure 3: Specified requirements and elements

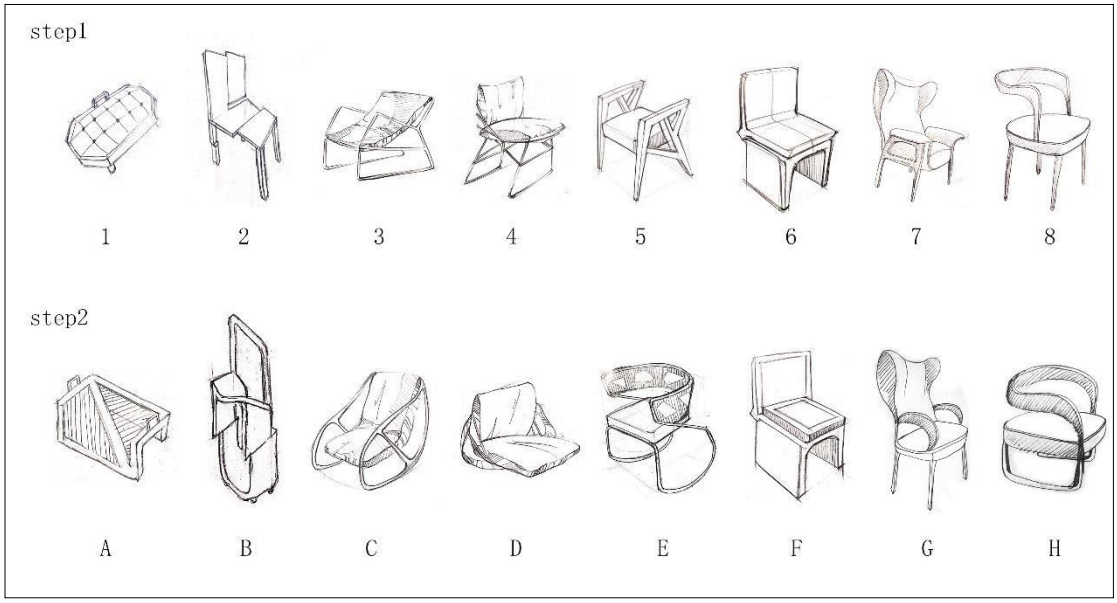

Figure 4: Two groups of design

Experiment 3. The cup was taken as experimental object. The most common cup shape was used as prototype for shape innovation design. From a topological point of view, the cup and the doughnut have the same structure. To reduce the interference of excessive shape as factor, three new forms were made on the cup handle only (Figure 5). The first two options changed the shape of the cup handle, whereas the third scheme changed not only the shape of the handle but also the topology of the cup. These cups were presented in gray scale on white

background to avoid the influence of color on attention. At total of 70 people from different backgrounds, ranging in age from 12 to 70 years (average age of 25 years), participated in the experiment. Before viewing the pictures, each participant was told to score each object in accordance with the novelty of the product form, with the most novel being scored 5 points. Based on a preliminary experiment, the experiment duration was limited to 10 seconds.

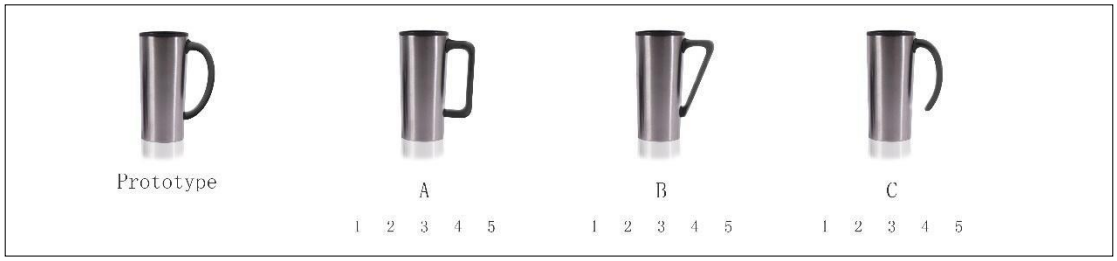

Figure 5: Three new forms were made on the cup handle

Discussion

In Experiment 1, 63 participants scored three bicycles using a five-point scale. The parameters of the experimental objects are provided in Table 1. Bicycle C was rated to have the highest degree of visual attention, followed by bicycle A. A multiple comparison test for parametric data showed significant differences between bicycles A and B ($p<0.01$) in terms of average reaction time when rating; similarly, differences were observed between bicycles B and C ($p<0.01$). The findings further indicated that bicycles A and C received obvious visual attention compared with bicycle B.

Table 1: Parameters of the experimental objects in Experiment 1

	Score	Average	Number of highest scores	Number of lowest scores
A	208	3.301	19	9
B	157	2.492	15	34
C	235	3.730	29	9

In Experiment 2, 20 participants scored 16 chairs using a five-point scale. The parameters of the experimental objects for Experiment 2 are given in Table 2. After calculating the scores in steps 1 and 2, we compared the objects by conducting a paired t-test. The results showed significant differences in average reaction time between the two groups of chairs ($p<0.01$). The improved scheme of adopting visual topological features in the design shape gained obvious visual attention. In particular, C and E were scored the highest. The shape of C and E had more obvious visual topological features: holes and connectivity.

Table 2: Parameters of the experimental objects in Experiment 2

	Step 1								Step 2							
	1	2	3	4	5	6	7	8	A	B	C	D	E	F	G	H
Score	24	46	60	57	45	24	67	57	38	30	88	68	86	44	48	67
Average	1.2	2.3	3	2.85	2.25	1.2	3.35	2.85	1.9	1.5	4.4	3.4	4.3	2.2	2.4	3.35
Number of 5	0	0	0	0	0	0	2	0	0	0	10	1	8	0	0	0
Number of 1	16	1	0	0	0	16	0	0	5	12	0	1	0	2	1	0

In Experiment 3, 70 participants rated three cups using a five-point scale. The parameters of the experimental objects for this experiment are listed in Table 3. Cup C was deemed to have the highest degree of shape innovation, based on it gaining the highest score. Cup B ranked second. A multiple comparison test for parametric data revealed significant differences in the average reaction time between cups A and C ($p<0.05$) and between cups B and C ($p<0.05$). Cup C had obvious shape innovation compared with cups A and B. From the perspective of product innovation as a measure of the characteristics of visual topology, the shape of the cup itself is a typical visual topological feature, and thus, such a shape has become a common form in human cognition. The novel square and triangular cup handles retain the topology but change the shape, with reference to Euclidean geometry. Nevertheless, when change was made to the form of the glass structure, and although the new shape does not have visual topological features, the redesigned cup still grasps significant visual attention precisely because of the change in topology. This experiment proved that the topological structures have practical significance to product shape innovation.

Table 3: Parameters of the experimental objects in Experiment 3

	Score	Average	Number of highest scores	Number of lowest scores
A	212	3.028	17	22
B	223	3.185	18	15
C	253	3.614	32	10

Discussions

The results of three experiments confirm our hypothesis that visual topological properties exist in the shapes of products. In addition, people give visual attention to a product shape with obvious topological characteristics. After the product gains priority visual attention, the opportunity for

people to understand the attributes of its aspects will greatly increase. Morphological specialization thus attracts the attention of customers, thereby indicating its value in the product development process, compared with costly functional and technical innovation. Especially for newly established small companies, product shape design is a suitable way of development: products with eye-catching shape can grab the attention of consumers, stimulating sales. Indeed, for many famous brands of products in a mature market, which is teeming with similar products, designers focus on product form to capture the attention of consumers (Nathan Crilly et al., 2009). This is an important premise for product brand image promotion and sales. With the perception of visual topological properties as a primitive and general function of the visual system, product shape innovation based on topological structure offers a certain security.

Product shape design is not only for the sake of aesthetics, as the shape of products bears other aspects of information. For example, the use of the product is often encoded in the shape, but these codes can only be identified by product design professionals. Common consumers generally do not notice the coding of these shapes, and thus, they cannot decode accordingly. Visual topological features can be applied to the shape of the coding and seize people's visual attention, thereby improving the user's ability to decode product function. Many products work with software, so there are many people who operate new products and do not know how to operate. And because of the simplicity of the product styling, many of the operating keys have disappeared, completely converted into touch plane. In this way, many users who do not have relevant product knowledge accumulation, what is placed in front of them is the product without any clues and hints. In addition to visual topological features has the characteristics of visual priority attention and it also has the possibility of blending with form design at the same time. We can strengthen the visual priority attention of the key operation part by using visual topological features.

This study focused on the attention of people to the shape of products. The perception stage does not belong to subjective consciousness, as it relates to the absence of produced emotion. Distinguishing from simple physical elements in a stimulus can mediate high-level judgments of preference, such as on the sharp angles or curves of an object (Moshe Bar, Maital Neta, 2006); studies have proven the overall preference for objects with rounded rather than angular form, which should be considered in the design of consumer products (Steve J. Westerman et al., 2012). Moreover, the study does not involve the methods of product shape design. According to the key words that describe a product, designers create the shape parameter axis, in accordance with the design guidelines for shape design (Roberta Gorno and Sara Colombo, 2012).

Experiment 2 had discrepancies and revealed unexpected findings. The study created a lot of topology in the product shape. However, a considerable part of the non-topological shape is also a crucial feature of attention. This insight suggests that within the scope of the product

shape, the topology should not be rigidly applied; instead, the semantic, functional, and symbolic conditions of the product itself should be taken into account. Future research should pursue defining non-topological structures in the product form of the product and determining whether it can be considered as a topological structure.

Meanwhile, in Experiment 1, the pictures were adjusted to a degree of similarity in color and brightness, and the main structure of the three bicycles was made similar, to weaken the influence of these factors on visual attention. However, the actual comparison between products is a highly complex process. Apart from the non-topological characteristics of the structure, the material, color, and other elements play critical roles in human visual attention, thereby affecting consumer choice. In addition, knowledge of the product affects priority attention. The experiment clarified that some people know relatively more about bicycles, so the bicycle without hubs quickly caught their attention, and they gave much higher scores to it compared with the other two. Meanwhile, some of the participants selected the bicycle without hubs from a solely visual level, and the gap between scores given is not significantly large.

In Experiment 2, the results verify the superiority of topology in securing priority attention. The design students used topological characteristics in the creation of product concept sketches with a deliberately stressed topology. The other attributes to product form rarely consider, such as aesthetic, semantics, and symbolism in the form of performance, so the second stage of the chair looks stiff and rigid. This issue merits future research.
In experiment 3, some participants recalled the selection process, and they were similar to B and C in visual recognition, but tended to C at the moment of scoring. They also pay special attention to the triangular corners of the handle of the cup B. For this reason, we tried to remove the participants in this situation, and then we conducted second experiments with the remaining 52 participants, and found that there was no significant difference between B and C ($p>0.05$).

However, there are still significant differences between B and A ($p<0.05$), C and A ($p<0.01$). The curvature of handles of B and C are different. The triangular handle of B has higher curvature than the arc handle of C. Because of the principal normal to point into the figure, it point into the handle corner. A concave cusp is a point of negative curvature with the greatest absolute value of curvature. According to the partition rule, a plane curve is divided into parts at negative minima of curvature (Hoffman, D. D., & Richards, W. A. 1984). This explains that the priority attentions are so close of B and C. This gives us some insights into the activities of visual priority attention. There are other morphological structures that can also cause visual priority attention, and then we will study these kinds of features and compare them with visual topological ones.

The experiments anchored sample product selection and comparison on 2D features in the case of the bike and the cup, whereas the chair design was limited to the draft level. Future experiments will adopt 3D presentation, and consequently, research on visual topological

features of structure in product form can yield comprehensive and in-depth findings. Further, the present research involved products with relatively simple structures, whereas future research may focus on complex structure products. We found that the topological invariants and variants of product form relate to the logical relation among the parts of functions of product in this study.

The variants of topological structure occur in each part of the product and its corresponding functions, not only the form of the product changes with the topological variant, but also generates new product cognition and experience to people. If this can be translated into visual node planes, showing a topological invariant or variant model of product design thinking. This model of thinking can inspire the designer to break the link between the inherent things and create new things to recognize. This topology-based cognition is the innate cognitive power that comes naturally, and people react most strongly when the topology changes. Great deals of experiments are needed to prove the existence of the process that visual cognition transforms into thinking. We will study the connection between the two kinds human activities from the experimental cases and compare the topology creative model with other creative methods, and find the advantages and disadvantages of this method.

Conclusion

This study on the topology of product shape aimed to define two pairs of relationships: the link between topological structure and product form, and that between priority attention and successful product design. In the case of the first relationship, the application of topological structure should be constrained under the law of product shape. Graphical representations of topological structure tend to be simple. Experiment 2 shows that methods or models for topological structures in product design can be formed. As for the second relationship, the advantage of adopting topological structures is priority attention, although this does not mean that a product shape adopting a topological structure is a successful design. However, with reference to the principle of beauty, form structure and topological structure may achieve seamless integration, and the connectivity, continuity, and compact visual expression exude formal beauty. Indeed, product design often uses a language of keywords, but turning keywords into visual image is a complex process (Y. Nagai et al., 2003). The keywords transformed into visual images by visual topological structures may be able to meet design requirements and gain priority visual attention. This involves the combination of vocabulary and organizational rules in the product form design. The form vocabulary still is the lines presenting for the keywords and the lines combine into topological structure. The use of topological structures in representing aesthetic impression, semantic interpretation, and symbolic association should also be examined toward the goal of making topology more natural and harmonious in product forms.

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