A Kansei Engineering Approach to Eco-product Form Design

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Abstract: This paper presents an approach to designing eco-product form for matching a given eco-product image represented by environmental-friendly attributes (EFAs). A consumer-oriented experimental study is conducted to examine the relationship between the key form elements and the eco-product images of office chairs. One hundred office chairs are selected from various makers and models. Twenty-seven representative office chair samples are extracted using multidimensional scaling analysis and cluster analysis. A Kansei engineering experiment is conducted to evaluate the degree to which twenty-seven representative office chair samples match given eco-product images, represented by five representative EFAs derived by using morphological analysis. The relationship between EFAs and form elements is established by developing five Quantification Theory Type I models. These models can help the product designers understand consumers' perception of product form on a given eco-product image and examine the effect of the corresponding eco-product image for a given combination of form elements.

Key words: Kansei engineering, Eco-product design, Environmental-friendly attribute, Product image, Product form

1. Introduction

Manufacturer responsibility or "product stewardship" is enforcing manufacturers to consider the environmental impacts of a product at every stage of its life from extraction of raw materials to end-of-life disposal. For example, furniture manufacturers are making products from renewable and recycled materials and reducing toxins in furniture frames, upholstery, carpet, flooring and adhesives. To address this issue, eco-design aims to combine business oriented design goals and environmental considerations such as carbon emissions, and to increase the products eco-efficiency.

Sherwin [6] discusses product design and sustainability from the perspective of people-centred discipline with industrial practical case studies, which ensures that products and services match consumer's needs, embody their values and connect to their aspirations and desires. There is a strong feeling that designers could influence consumer behaviour, especially by making new (environmentally responsible) products, services and behaviors more appealing and desire to the consumers. However, when it comes to product design, it is hard to neither comprehend nor assess how good a product is for the consumers and environment.

In this paper, we present a new approach for evaluating the product image of eco-products as perceived by consumers. We focus on eco-product form elements excluding color and texture. Specifically, we will address the research issue of the effect of form elements on eco-product image. What kind of eco-product form elements are suitable for a certain image? Which element has a greater influence on eco-product image to the consumers? To illustrate how the relationship between eco-product form and eco-product image can be examined quantitatively, we conduct an experimental study of office chairs. We then apply the Kansei Engineering approach and use Quantitative Theory Type I [5] to analyze the numerical data sets for answering the research questions, and measure the relative importance of eco-product form with respect to eco-product image.

2. Literature review

2.1. Eco-product and its assessment

Eco- products may consist of several aspects such as environmental consciousness, safety, recyclability, reuse, energy consumption, material use, packaging and transportation. The evaluation of such aspects can be done quantitatively, because most of the physical properties can be analyzed numerically. Datschefski [2] has proposed an approach to assessing the beauty of products by scoring products for each requirement whether the product is a bit better than before. Five requirements are defined as follows:

- Cyclic - the product is made from compostable organic materials or from minerals that are continuously recycled in a closed loop.
- Solar - the product in manufacture and use consumes only renewable energy that is cyclic and safe.
- Safe - all releases to air, water, land, or space are food for other systems.
- Efficient - the product in manufacture and use requires 90% less energy, materials and water than products providing equivalent utility did in 1990.
- Social - product manufacture and use supports basic human rights and natural justice.

The aesthetic effectiveness of an eco-product is particularly difficult to judge numerically. Masuda [4] has conducted several experiments about eco-materials qualitatively from design perspective, which has explored the value, consumer's needs, desires, mind, material's texture and the aesthetic surface condition for eco-products.

Depending on the product-use-environment, an eco-product needs to match the design context of the surrounding environment. If there is a mismatch between a form used in a product and the product-use- environment, it will result a design and environmental disharmony [8]. More importantly, a product's quality is usually dependent on its external appearances and characteristics. In order to pass the product form selection process at the planning phase, the optimal eco-product form can be examined quantitatively by formulating form elements for a certain eco-product image. Moreover, the evaluation and final selection of a product's exterior (form) is frequently determined by a designer [7].

However, the correlation between eco-product aesthetics and these criteria is still not well established, which can be analyzed through both qualitative and quantitative methods. Consequently, a Kansei Engineering approach is applied for transferring designer's qualitative product form perception into quantitative analysis.

2.2. Kansei engineering

The product image of consumers' perception is called "kansei" in Japanese. Consumers' view of product image is usually different from the way that designers look at product elements or characteristics. To best meet consumers' need of a product form from a design perspective, the physical elements of the product require being linked to consumers' perception of the eco-product. Image words are often used to describe the consumer's psychological feeling and perception about the image of a new product. In this regard, Kansei Engineering has been developed as "translating technology of a consumer's feeling (Kansei in Japanese) and image of a product into design elements". In other words, the process of Kansei Engineering is used to extract experimental samples as numerical data sets required for analysis, using surveys or experiments.

3. Methodology

3.1. Experimental subjects

This study involved 73 subjects, divided into four groups. We asked the first group of 20 subjects to extract the representative samples from 100 office chairs by using the Kawakida Jirou (KJ) method [1] for sample grouping. The second group consisted of three experienced furniture designers who were asked to perform the morphological analysis in order to extract the form elements of office chairs. The third group, formed by 10 professional furniture designers with an average of 15 years design experience, was involved for extracting visually perceived EFAs for office chairs. The fourth group had 20 males and 20 females both with product design background for evaluating the eco-product image of the experimental samples.

3.2. Experimental samples

The office chair is a general consumer product and exhibits wide variety in product form with various visual structures. In this study, the product of office chairs is selected as eco-product (environmental-friendly product) sample, from which part of them may apply environmental-friendly technology and be entitled environmental-friendly labels such as, LEED (USA), UN-Global Compact, ISO9001/14001, GREENGARD^{TM}, and GECA (Environmental Choice, Australia). However, consumers can hardly distinguish general products from eco-products due to complex criteria, such as recycled material, assembly and disassembly, reuse, and waste management. Thus, this study assumes all product samples are eco-products with varying levels of technical and environmental consciousness.

To identify the commonly used form elements of office chairs in the market, we first selected 100 office chairs of various makers and models. The pictures of product samples are all treated in grey scale for avoiding interruption from color and texture. Twenty subjects were invited to classify these 100 office chairs based on their similarity degree, using the KJ method. This method was introduced by Kawakida Jirou in 1953 for classifying ideas, concepts, or objects into several groups by their similarity degree. It has been successfully applied to a variety of classification problems. We then performed the multidimensional scaling (MDS) analysis and the cluster analysis [3] based on the classification result obtained from the 20 subjects. This result was then used to extract the 27 representative office chair samples from hierarchical cluster analysis (as shown in Fig. 1). The experimental procedure for extracting the office chair samples is summarized by the following nine steps:

Step 1: Select 100 office chairs of various makers and models.
Step 2: Make 100 small paper cards according to the original size of each office chair photo.
Step 3: Separate 100 small paper cards into 8-12 groups by their similarity degree, using the KJ method.
Step 4: Build a similarity matrix from the classification result obtained at Step 3 by applying Visual Basic software.
Step 5: Transform the similarity matrix into a dissimilarity matrix for the analysis at Step 6.
Step 6: Apply the MDS analysis to the dissimilarity matrix data.
Step 7: Choose six dimensions as a result of the MDS analysis with stress=0.097 (smaller than 0.1) and RSQ=0.875. In determining the dimensionality to use for a set of data, a commonly used measure of fit in MDS is "stress", which is the square root of a normalized residual sum of squares. A smaller stress value indicates a better fit. Another common measure of fit is the squared correlation (RSQ) value. The higher the RSQ value, the better the fit. The stress value for the two to six dimensions examined are 0.318, 0.208, 0.155, 0.119, and 0.097 respectively, and the RSQ values are 0.514, 0.674, 0.773, 0.840, and 0.875 respectively.
Step 8: Perform the cluster analysis based on the MDS result, and then generate a cluster tree diagram.
Step 9: Extract 27 representative office chair samples based on the cluster tree diagram. The number is manageable by the survey and experimental process.

3.3. Morphological analysis of product form elements

In this study, the product form of office chairs is represented by both the outline shapes and the product elements. The morphological analysis is used to extract the form elements of the 27 office chair samples. A focus group of three office chair design experts are asked to list the influential form elements of the office chairs individually according to their knowledge and experience. The results are grouped into two parts: form feature and form treatment. The form feature part includes the size and shape of outline components making up the office chair, such as Back Area, Shape of Back, Back Thickness, Seat Thickness, Type of Armrest, and Type of Base. The form treatment part indicates the relationship between outline components, e.g. the connection of Back and Seat.

Figure1. Twenty-seven extracted product samples

As a result of the morphological analysis, Table 1 shows the seven form elements extracted from the 27 representative office chair samples, together with their associated types. Each form element has different types of its own, ranging from two to five, as indicated by the type number 1, 2, 3, 4, and 5 in Table 1.

Table 1 Product elements extracted by morphological analysis on office chair samples

Elements	Type 1	Type 2	Type 3	Type 4	Type 5
1. Back and Seat (X_1)	Separated (X_{11})	Integrated (X_{12})			
2. Back Area (X_2)	Large (X_{21})	Medium (X_{22})	Small (X_{23})		
3. Shape of Back (X_3)	Square (X_{31})	Square with Rounded Corner (X_{32})	Trapezoidal (Rounded corner) (X_{33})	Round (X_{34})	
4. Back Thickness (X_4)	Thick (X_{41})	Thin (X_{42})			
5. Seat Thickness (X_5)	Thick (X_{51})	Thin (X_{52})			
6. Type of Armrest (X_6)	Loop (with/without support) (X_{61})	T-shaped (X_{62})	2- point support (back + seat) (X_{63})	1-point support (back or seat) (X_{64})	None (X_{65})
7. Type of Base (X_7)	5-wheel (X_{71})	4-wheel (X_{72})			

3.4 Consumer's perception of the eco-product image

For extracting EFAs and from which can be perceived visually, expert interviews were conducted by providing a semi-structured questionnaire and on-line Skype phone. Seven male and three female professional furniture designers with an average of 15 years' design experience are interviewed. Each of them has more than 10 years' professional furniture design experience. To extract EFAs for describing the consumer's perception of the eco-product image about office chairs, the following steps were carried out:

Step 1: Collect a set of EFAs from the literature and designer interviews.

Step 2: Evaluate the collected EFAs using the semi-structured questionnaire.

Step 3: Apply the percentage (50%) rule to the result of semi-structured questionnaire survey obtained at Step 2. Table 2 shows that all of the proposed EFAs have passed 50% percentage rule except No. 11 "Natural Form" (4) based on 10 subjects who are professional furniture designers.

Step 4: Determine the representative EFAs image and its concise description of the eco-product based on the visual perception performed at Step 3, as shown in Table 3.

Table 2 EFAs selected by 10 experienced design experts with selection frequency in parentheses.

No.		No.		No.	
1	Durable (10)	8	Disassembly (8)	15	Reduced Energy (10)
2	Upgradability & Modularity (9)	9	Renewability (10)	16	Harmony with Environment (7)
3	Individuality & Diversity (5)	10	Serviceability (7)	17	Product life Extension (10)
4	Space Adaptability (10)	11	Natural Form (4)	18	Consumer-Designer Relationship (5)
5	Simplicity & Minimalism of Mechanism (9)	12	Natural Material (9)	19	Consumer's Environmental Awareness (10)
6	Recyclability (9)	13	Local Design /Production (9)	20	Consumer-Product Relationship (10)
7	Repairable (8)	14	Reduced Material (8)	21	Reuse (10)

Table 3 EFAs perceived visually by grayscale image, with the selection frequency enclosed in parentheses.

No.	EFA
2	Upgradability & Modularity (ease of maintenance (ease of replace, and extending product life) (5)
4	Space Adaptability (suitable for various office spaces e.g. large or small size spaces, visitor room, or other public areas) (8)
5	Simplicity & Minimalism of Mechanism (reducing numbers of components and material) (6)
8	Ease of Disassembly (shorter process and using simple tools) (5)
16	Harmony with Environment (Harmonious relationship between the consumer, product, and environment) (7)

We finally selected five representative EFAs for describing the product EFAs images of office chairs, including Upgradability & Modularity, Space Adaptability, Simplicity & Minimalism of Mechanism, Ease of Disassembly, and Harmony with Environment. These five EFAs can be visually perceived and assessed for evaluating the consumer's perception of the 27 representative office chair samples. A five-point Likert scale ("1" as Strongly Disagree and "5" as Strongly Agree) was applied in an on-line questionnaire to obtain the assessment value for each EFA image of a given office chair. Forty subjects were involved in evaluating the degree to which the 27 representative office chair samples match a given product image.

4. Discussion

In Table 4, the correlation coefficients indicate the relationship between 7 variables (X_1, X_2, X_3, X_4, X_5, X_6 and X_7) of eco-products and each eco-product image (Y_1, Y_2, Y_3, Y_4, or Y_5). For example, the highest variable of the partial correlation coefficient in the "Upgradability & Modularity" image is the "Type of Armrest" variable ($X_6 = 0.748$), meaning that "Type of Armrest" primarily affects the "Upgradability & Modularity" image of the product. In addition, Table 4 shows that "Type of Armrest" also affects the "Space Adaptability" image, and "Harmony with Environment" image, but the "Shape of Back" variable ($X_3 = 0.601$) mainly influences the "Simplicity & Minimalism of Mechanism" image. The "Shape of Back" variable ($X_3 = 0.610$) also mainly influence "Ease of Disassembly" image. The "Back and Seat" (X_1) and "Seat Thickness" (X_5) variables are both less significant on the five images of EFAs.

In the last two rows of Table 4, *R* means the correlation between the observed and predicted values of the dependent variable, and R^2 is the square of this correlation. R^2 ranges from 0 to 1. If there is no linear relation between the dependent variable (Y_1, Y_2, Y_3, Y_4, or Y_5) and independent variables (X_1, X_2, X_3, X_4, X_5, X_6 and X_7), R^2 is 0 or very small. Otherwise, if all the values fall on the regression line, R^2 is 1. In addition, R^2 is also called the

Table 4 The results of Quantitative Theory Type I

		Upgradability & Modularity (Y_1)		Space Adaptability (Y_2)		Simplicity & Minimalism of Mechanism (Y_3)		Ease of Disassembly (Y_4)		Harmony with Environment (Y_5)	
	Type No.	Category grade	Partial c. c.	Category grade	Partial c. c.	Category grade	Partial c. c.	Category grade	Partial c. c.	Category grade	Partial c. c.
X_1	1	−0.043	0.285	−0.030	0.140	−0.013	0.049	−0.030	0.106	0.021	0.123
	2	0.054		0.037		0.016		0.037		−0.027	
X_2	1	−0.221	0.689	−0.284	0.624	−0.173	0.554	−0.242	0.581	−0.105	0.391
	2	0.003		0.061		−0.223		−0.209		0.069	
	3	0.218		0.223		0.396		0.451		0.035	
X_3	1	−0.113	0.697	−0.062	0.621	−0.154	0.601	−0.201	0.610	−0.083	0.501
	2	0.153		0.219		−0.070		0.053		0.145	
	3	0.145		0.066		0.171		0.141		0.089	
	4	−0.234		−0.414		0.383		0.332		−0.210	
X_4	1	−0.138	0.613	−0.087	0.314	−0.084	0.225	−0.066	0.175	−0.070	0.254
	2	0.128		0.080		0.078		0.061		0.065	
X_5	1	0.056	0.291	−0.031	0.113	−0.038	0.102	−0.030	0.080	−0.040	0.152
	2	−0.060		0.034		0.040		0.032		0.043	
X_6	1	−0.094	0.748	−0.015	0.764	0.356	0.600	0.248	0.571	−0.172	0.672
	2	0.126		0.294		0.045		0.078		0.155	
	3	−0.090		−0.144		0.090		−0.024		−0.004	
	4	−0.198		−0.374		−0.367		−0.335		−0.243	
	5	0.252		0.233		0.125		0.265		0.149	
X_7	1	0.024	0.443	0.047	0.532	−0.019	0.165	−0.014	0.118	0.034	0.417
	2	−0.137		−0.273		0.108		0.078		−0.195	
Constant		3.069		3.099		3.157		3.067		3.079	
		R = 0.865		R = 0.842		R = 0.812		R = 0.835		R = 0.780	
		R^2 = 0.748		R^2 = 0.710		R^2 = 0.659		R^2 = 0.697		R^2 = 0.609	

Note: X_1 to X_7 are design elements.

coefficient of determination [9]. The result shows that the "Upgradability & Modularity" image (R^2 being 0.748 and the R being 0.865) has the highest prediction consistency while "Harmony with Environment" (R^2 being 0.609 and R being 0.780) has the lowest prediction consistency.

The category grades shown in Table 4 indicate the preference degree of the consumer perception on the each category of independent variables. If the grade is negative, the consumer perception leans towards "disagreed". On the contrary, the positive grade indicates that the consumer perception favors "agreed". For example, the category grades of five selected values of "Type of Armrest" (X_6) in the "Upgradability & Modularity" (Y_1) image are -0.094, 0.126, -0.090, -0.198, and 0.252 respectively. The result shows that the consumer perception prefers the "Strongly Agreed" to "Upgradability & Modularity" (Y_1) image when types of the armrest are "T-shaped" (X_{62}) or "None" (X_{65}), and favors the "Strongly Disagreed" for "Upgradability & Modularity" (Y_1) when types of the armrest are "Loop" (X_{61}), "2- point support" (X_{63}), or "1-point support" (X_{64}). In another example, the category grade of two values of "Type of Base" (X_7) in "Simplicity & Minimalism of Mechanism" (Y_3) image are -0.019 and 0.108 respectively, which shows consumer perception favors "4-wheel" (X_{72}) type of base.

As a result of Quantitative Theory Type I analysis, the five models are developed for indicating the relationship between product form elements on a set of eco-product images for the five EFAs. For example, the model for the image of "Upgradability & Modularity (Y_1)" has shown the value of category grade for each element (X_1- X_7) is added up and is shown as follows:

Y_1 (Upgradability & Modularity)

$= -0.043\ X_{11} + 0.054\ X_{12} - 0.221\ X_{21} + 0.003\ X_{22} + 0.218\ X_{23} - 0.113\ X_{31} + 0.153\ X_{32} + 0.145\ X_{33} - 0.234\ X_{34} - 0.138\ X_{41} + 0.128\ X_{42} + 0.056\ X_{51} - 0.0.060\ X_{52} - 0.094\ X_{61} + 0.126\ X_{62} - 0.090\ X_{63} + 0.198\ X_{64} + 0.252\ X_{65} + 0.024\ X_{71} - 0.137\ X_{72} + 3.069.$

We can use these five models to input values of seven product variables, and then output the prediction value of eco-product image, i.e. an environmental-friendly attribute. These models can help the product designers understand consumers' perception of product form for the corresponding eco-product image. These models can also be used to

Table 5 Optimal combination relationship of product form elements

	Upgradability & Modularity	Space Adaptability	Simplicity & Minimalism of Mechanism	Ease of Disassembly	Harmony with Environment
1. Back and Seat	Integrated	Integrated	Integrated	Integrated	Separated
2. Back Area	Small	Small	Small	Small	Medium
3. Shape of Back	Square with rounded corner	Square with rounded corner	Round	Round	Square with rounded corner
4. Back Thickness	Thin	Thin	Thin	Thin	Thin
5. Seat Thickness	Thick	Thin	Thin	Thin	Thin
6. Type of Armrest	None	T-shaped	None	None	T-shaped
7. Type of Base	5-wheel	5-wheel	4-wheel	4-wheel	5-wheel

examine the effect of the corresponding eco-product image for a given combination of form elements. Table 5 shows the design support information for product designers to find out the optimal combination of form elements in terms of a given eco-product image.

5. Conclusion

In this paper, we have used the concept of Kansei Engineering to extract the representative experimental samples of office chairs. We have conducted the Quantitative Theory Type I analysis to examine how eco-product form may affect EFA image of office chairs. The results of this study provide useful insights in designing form of an eco-product with enhancing the EFA image. The five models developed for the EFA images can be used to predict the value of eco-product image for a given set of product form, which can help product designers better understand consumer's perception of eco-product form. Other eco-product form evaluation and prediction experiments may also be carried out through applying various proper methodologies such as fuzzy logic and neural networks.

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