Eurasia Journal of Mathematics, Science & Technology Education, 2016, **12**(5), 1399-1423
doi: 10.12973/eurasia.2016.1521a

Building a Relationship between Elements of Product Form Features and Vocabulary Assessment Models

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•*Received 9 September 2015*•*Revised 16 November 2015* •*Accepted 6 January 2016*

Based on the characteristic feature parameterization and the superiority evaluation method (SEM) in extension engineering, a product-shape design method was proposed in this study. The first step of this method is to decompose the basic feature components of a product. After that, the morphological chart method is used to segregate the ideas so as to generate new product forms. Finally, the extension engineering method can be used to build the relationship between the feature parameters and the image vocabularies. With this method, designers are able to communicate with their clients via Internet and develop more suitable products for consumers by evaluating their impressions with the assistive system. It has been verified that this approach can reduce the development time as well as enhance the effectiveness and competitiveness of a new product.

Keywords: shape generation, feature base, extension engineering method, morphological chart, superiority evaluation method

INTRODUCTION

In recent years, the concept of Web 3D has been realized and it enables a comprehensive display of a product in the form of three-dimensional presentation. This display approach has an incomparable advantage over two-dimensional imaging approaches, and it allows customers to observe and interact with product feature operations via this medium. Therefore the customers can have a more comprehensive understanding of the product and this approach better enables them to promote product sales.

It requires inspiration, imagination, and planning when designing a product. A design relies on ideas, which may suddenly emerge from a designer's mind or from the inventiveness of an individual. These ideas and inspirations are often uncontrollable as they reside in the designer's mind and this problem gives rise to

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the so-called "black box design theory". In earlier product creation and decision-making processes, any designer's judgment relied solely on his/her personal subjective consciousness or empirical rules. When a product is designed without knowing the users' requirements and preferences, the consumers have to passively adapt themselves to the characteristics of the product. Based on this consideration, Krippendorff (1989) proposed a new design model based on the concept of "design is making sense of things". The point is that it is required to ensure that designers and users are on the same stage by continuous communications during the design stage, and they need to cooperate with each other so as to come up with the new-level cooperated design strategies as shown by Figure 1. With this approach, a designer can get hold of the consumers' cognition of product forms, textures, styles, colors, imagery, and other psychological attributes. The gap in the images perceived by designers and consumers can be bridged so as to design a product that truly meets consumer requirements. This is a research topic that is worthy of further investigation.

With the advances in technologies, computerization is now a typical approach to help improve the efficiency when processing complex data. Any data used in any computerized processing is required to be converted before it can be readily used for any calculation and analysis. If a reasonable data-based organizing approach can be found for the cognitive process of designing a product, it will be possible to use a logical method to anticipate a person's cognitive behavior. With this approach, computers can be used to assist in tasks such as evaluating product images, predicting consumer behaviors, determining market strategies, etc. (Ishihara et al., 1995)

Several theories have been proposed for solving the problem of importing a consumer's feelings and imagery into the design elements. Examples are the artificial neural networks, fuzzy theory, and the quantification theory type 1 (Hsiao 1994; Hsiao and Chen 1997; Hsiao and Chang 1997; Hsu et al. 1999). Inoue et al. (2013) proposed a system for obtaining the multi-objective satisfactory solutions which reflect different designers' intentions. Cao et al. (2012) proposed the optimization of a product family design by taking the factors such as market segmentation, customer purchase behaviors, and customer preferences into investigation. They verified that the proposed joint optimization model can be applied to complex practical scenarios. Sener and Karsak (2012) proposed a method of quality function deployment by adopting the fuzzy linear regression for its analysis. Azadeh et al. (2012) utilized the method of fuzzy simulation to assess customers' satisfaction, and the results were compared with conventional simulation methods. However, the amount of literatures which use a matter-element extension theory to resolve the problem and select the best solution is very few. Therefore, the application in this regard is worthy of exploration. The

State of the literature

- There are many studies related to the transformation of a design into mathematical models. These studies range from the fuzzy theory to the extension theory for determining the optimal design.
- Main focus of these studies was to develop the approach for optimizing a product design and determining the degree of customer satisfaction by evaluating the vocabularies used for describing product shapes by questionnaire surveys.
- More studies need to be done in order to improve the superiority evaluation method proposed in this study so that adjective vocabularies can be defined precisely so as to determine customer preferences accurately.

Contribution of this paper to the literature

- This paper presents an extension engineering superiority based method for generating optimal product shapes based on the results obtained from a questionnaire survey. A superiority evaluation method was proposed for the parameterization of product imagery characteristics.
- It aims to develop an optimized product form design process in which feature components are decomposed for customer evaluation so as to obtain new shapes with the morphological charts.
- The connection between a product feature and the customer image and satisfaction can be determined accurately so as to reduce the development time and raise the competitiveness of the resulting new products.

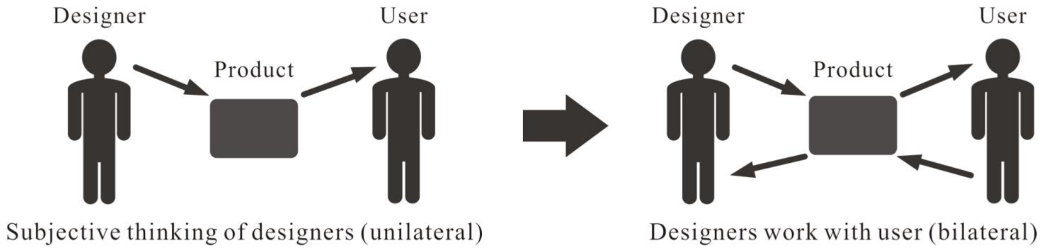


Figure 1. Transformation of design ideas

extension theory is a scientific method for resolving contradictions by analyzing an object's possibility of variations. At the moment, many studies already applied the extension theory to the fields of strategic decision, control, detection, diagnosis, judgment, and identification. The extension theory is a method which studies and resolves contradictions from both qualitative and quantitative aspects by formal tools. The foundation of the extension theory is twofold and they are the matter-element theory and the extension set theory. The matter-element theory describes the possibility of variations in the targets and objects being studied by the matter-elements, affair-elements, and relation-elements. This theory is also referred to as the extensibility of matter-elements. The core concept of the matter-element theory is exactly to study the extensibility of matter-elements, the transformation of matter-elements, and the characteristics of matter-element variations (Cai et al., 1997). The extension theory phrases the transformation of contradictions by supplying quantitative means. It also introduces the extended correlation functions for the description of variations in the characteristics of objective things. It can solve the problem of subjective and objective contradictions by means of the transformation of matter-elements. In this study, the characteristics of the extension theory were utilized to determine the causal relationship of the styles which are preferred by consumers for a computer tower.

In recent years, some scholars proposed different approaches to transform a design into mathematical models so as to assess the degree of vocabularies. Özyurt (2015) proposed that the emphasis of the engineering related education should be on an engineer' tendency of high-level critical thinking and the capability of resolving issues. The study of Adiguzel (2011) resolved the deficiencies in earlier studies which lacked the exact assessment of vocabularies. His study also supported the importance of vocabularies. The study of Sahin, Aydogan-Yenmez, & Erbas (2015) indicated that for the task of mathematical modeling, it is required to have a general thinking behind a concept so as to observe and understand the way students think of things. This approach can be viewed as a type of valuable instruction, which makes the students clearly understand the design results. Zeljić (2015) proposed an approach for developing the concept of variables and the mathematical relationship between literal expressions.

This study built a shape design system assisted by the parameterization of characteristic features for product images. This approach utilizes data processing techniques and analyzes the results available on the Internet by using the extension theory. It built a communication platform between designers and clients and constructed shapes which were optimized by the parameterization of consumer demand-oriented characteristic features. It also proposed some design models to assist designers in mastering clients' ideas so as to facilitate the most effective communication and save unnecessary design costs and time. This approach gives the product design performance full play so that a designer can design products that meet the expectations in the consumers' mind.

This paper consists of three main portions as follows. (1) Extension engineering method and superiority evaluation method (SEM) for system definitions and descriptions (Section 2); (2) Process generation and process-centered organization of information (Section 3); and (3) Applications of the overall system (Section 4).

In particular, Section 2 defined and discussed the extension engineering method and SEM. Section 3 applied the data processing techniques and analysis results by using the extension theory so as to construct a shape design model which is assisted by the parameterization of consumer demand-oriented characteristic features. Finally, Section 4 demonstrated the application of the overall system to the design of computer towers.

THEORETICAL BACKGROUND

With the development of Kansei engineering, designers can understand the relativity between features of product forms and consumer perception via the quantitative analysis, and can effectively master a consumer's preference and perception. However in the studies related to Kansei engineering, the construction of the analysis model for product shapes is mostly oriented by the form features of product components. In the cognitive psychology, the theories related to the shape recognition indicated that the perception behavior of human beings could not be completely explained by purely relying on the recognition of object features. The constituent relationship, i.e., the relationship between elements, also plays an important role. In this study, the extension theory was utilized to determine the relationship between elements, and the association between elements and their adjective vocabularies. The descriptions of the related theories and the directions for using them are as follows.

Extension engineering theory

In the fields of engineering technology and economic management, people often encounter various kinds of contradictions. For example, some existing sensors cannot detect certain characteristic values that are to be determined. Otherwise, in certain given environments, sensors that can determine characteristics may not be used. For searching activities (such as looking for criminals, surveying mineral deposits, fault diagnoses, etc.), it may not be able to locate the subject with just the small amount of existing information. In the control field, conflicts among rapidity, stability, and accuracy often occurred. The conventional control system is restricted by the legitimate logical methods which are based on accurate models. Otherwise, the compromised approaches usually cannot solve the problem well. In the past decade, many scholars have used the basic extenics theory and methods (Cai 1999; Yang and Cai 2007) to study these contradictions, and have conducted many beneficial explorations. The extension of information is the embodiment of the matter-element extension. By using the extension of information, a lot of useful new information can be extracted out of the existing information. The extension of information was studied by Li et al. (2009), and the extensive information and its applications were studied by Liu and Ye (1996). Lin (1998) studied the application of extension method to the field of searching. Li and Li (2001) used the extension method to diagnose faulty systems. Huang (2003) used the extenics method to build resource characteristics for various products, and provided the input authorized by this system's resource characteristic values for each store via the e-commerce approach.

Li et al. (2008) proposed the application of the assessment by the extension engineering method to the water environment. The results were compared with that of the fuzzy assessment method which was the most widely used and had an excellent appraisal effect. Qian et al. (2009) applied the extension theory to the bionic engineering and determined the coupling elements in primary and secondary orders. They also analyzed the contribution of each coupling element by the extension analytical hierarchy process (EAHP) so as to provide a quantitative method for coupling elements in primary and secondary orders. Tan et al. (2009) used an extension evaluation model to conduct rock safety assessments, and the comprehensive management of rock slope for construction projects. Zheng et al. (2009) applied the extenics theory and life cycle assessment (LCA) to the assessment of buildings' energy conservation. Analytic hierarchical process (AHP) method and 9-scale pair-wise comparison were adopted to determine the weights of the factors in different hierarchies. An assessment model for buildings' energy conservation which combines LCA with the extenics theory was established.

Based on the advantages of extenics, Yun and Lu (2010) applied the extension evaluation method to the evaluation of brake materials. Preliminary results indicated that it was a feasible evaluation method when being applied to the development of brake friction materials and their application analyses with the evaluation and selection of the five standards. Li et al. (2010) proposed that the web intelligence (WI) can provide enough knowledge, and the extenics approach can assist in knowledge processing during the process of innovation. Therefore, a management model which combines WI with extenics and knowledge was put forward to assist in the innovation process. The innovation issues for small and medium-sized enterprises can be resolved through the simple WI-Extenics-based innovation research. Zhang and Zou (2010) used SEM of the extension theory and AHP to determine the evaluation indicators for weighing in order to choose the logistics service enterprises. At the moment, some scholars also started to study extension method-based information with regards to mining technology. All of these studies used the extension method on the information so as to explore unknown information and to develop new information. Though very preliminary, these efforts showed that the extension method is a promising approach in related applications.

Establishment of relationship between shape generation and images

Among earlier studies on product designs, most studies looked for a model for generating shapes. They attempted to verify the relevance with images and combined a product shape with an image vocabulary. In other words, they looked for a product shape generation and an image model that could meet the image shape requirements by customers and thus this approach is customer-oriented.

Among the previous rules of shape generation, there are few studies with considerations related to images. This was due to the fact that most of these studies required a designer to produce new shapes by a set of rules and models, such as morphological charts (Jones 1992; Cross 1994), shape grammar (Stiny 1980; Stiny and Mitchell 1980; Krishnamurti 1981; Flemming 1987; Chase 1989), structure variation method (Tjalve 1979) and shape equalization method (Hubka et al. 1988; Watkins et al. 1993). However, in recent years, many scholars have combined shapes with image vocabularies for a relevance study. Hsiao and Chen (1997) decomposed a product into many components by means of morphological charts, and then used the quantification theory type 1 and the fuzzy theory to construct the relationship database between type elements and image vocabularies. Catalano et al. (2007) proposed the use of a semantic approach to construct 3D automatic models and to use a knowledge base to retrieve aesthetic elements so as to obtain the explicit and implicit elements of a structure and to define the aesthetics of car shapes. In so doing, the system can also deliver a semantic evaluation of car shapes. Rossitza et al. (2010) proposed the use of semantic information retrieval for assisting in conceptual designs, and the use of semantics to help designers look for and explain the source of inspiration. Innovative core tools can provide information with a certain degree of diversity, vagueness, and uncertainty so as to generate new designs.

Matter-element extension theory

Concept of matter-element

People, events, and objects are collectively referred to as things. Things have various types of characteristics, and a certain feature of one thing has a corresponding quantity value. The name, the characteristic, and the quantity value corresponding to a thing are the three basic elements for describing a thing. Assuming that the name of a given thing is *N* and *v* is the corresponding value of the characteristic *c*, then all of them are used as the basic elements for the description of a thing and these elements are called the matter-elements. The thing, the characteristic, and the quantity value are three elements of the matter-element which can be defined as:

$$R=(N,c,v) \quad (1)$$

or

$$R=(N,c,c(N)) \quad (2)$$

For example, for a combination set of processing parameters, the following matter-element can be written as follows.

$$R=(N,c,v)=\begin{bmatrix} N, & c_1, & v_1 \\ & c_2, & v_2 \\ & c_3, & v_3 \\ & c_4, & v_4 \end{bmatrix}=\begin{bmatrix} \text{Parameter combination 1}, & \mathit{ComputerTowerHeight} & 80cm \\ & \mathit{Memory}, & \text{8G} \\ & \text{USB Slots}, & 4 \\ & \text{Hard Drive Capacity} & 5TB \end{bmatrix}$$

For a further understanding of the three basic elements for the matter-element, one can start from the matter-element space. The so-called matter-element space is for the assignment of the three elements of the matter-element into the x, y, and z axes respectively in a three-dimensional space. The whole matter-element space can then be extended with these three independent variables as shown in Figure 2.

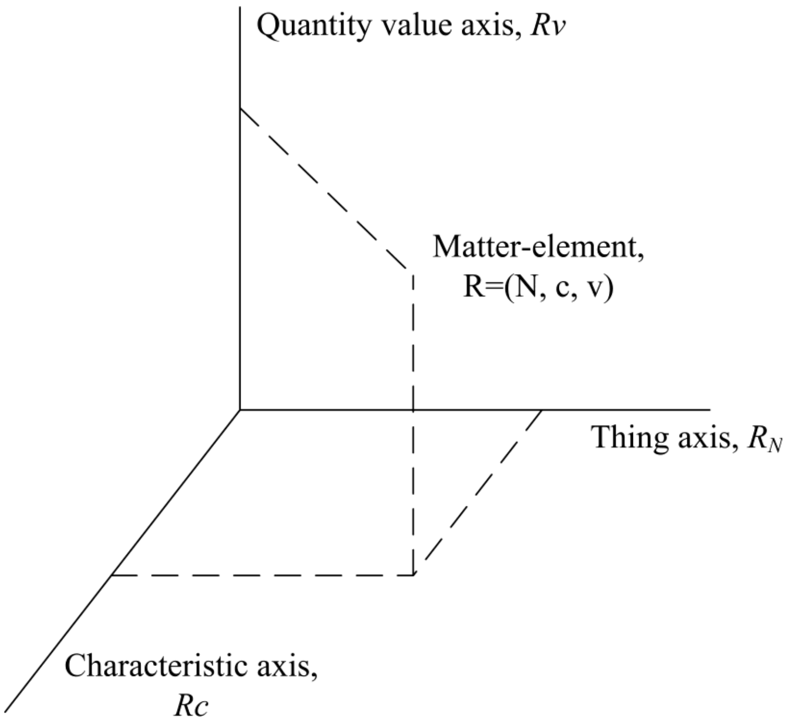


Figure 2. Matter-element space

Simple correlation function

Assuming $X = (a, b), M \in X$, then the correlation function is:

$$K(x) = \begin{cases} \dfrac{x-a}{M-a}, & x \le M \\ \dfrac{b-x}{b-M} & x > M \end{cases} \tag{3}$$

Therefore, $K(x)$ meets the following criteria:

(1) $K(x)$ is the maximum when $x = M$ and $K(M) = 1$

(2) $x \in X$ and $x \neq a, b \Leftrightarrow K(x) > 0$;

(3) $x \notin X$ and $x \neq a, b \Leftrightarrow K(x) < 0$;

(4) $x \neq a$, or $x = b \Leftrightarrow K(x) = 0$;

$K(x)$ is taken as the correlation function between the interval X and the point M as shown in Figure 3 that follows. Especially when $M = \dfrac{a+b}{2}$, i.e., when it is on the mid-point of the interval, the correlation function is

$$K(x) = \begin{cases} \dfrac{2(x-a)}{b-a}, & x \le \dfrac{a+b}{2} \\ \dfrac{2(b-x)}{b-a} & x > \dfrac{a+b}{2} \end{cases} \tag{4}$$

Matter-element identification and the evaluation of SEM

By using the matter-element extension method, many more matter-elements can be developed from a given matter-element according to different methods. Thus this approach can provide many alternative approaches for problem-solving. However, these matter-elements, approaches, and methods can only be utilized after being screened out. The purpose of screening is to eliminate the false ones and retain the true ones, and it can also remove the inferior ones so as to save the optimal ones. During the screening process, it is required to pay attention to the limitation of the conditions and the compatibility of a system.

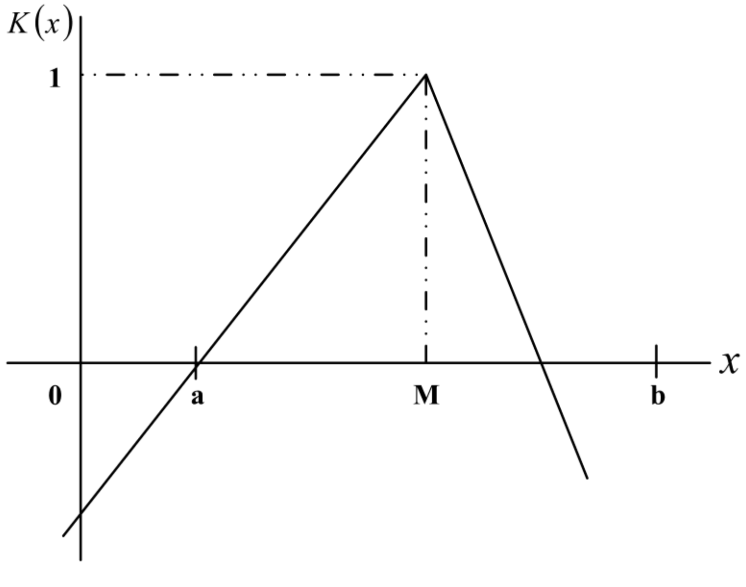


Figure 3. Illustration of the simple correlation function

SEM is just one of the methods, and its main purpose is to evaluate the superiority or inferiority of an object, which may contain things, strategies, methods, and so on. This approach includes several basic concepts as follows.

(1) Qualified degree

Assuming that the condition (or the measurement indicator) to measure advantages and disadvantages is M, the range of the qualified quantity values is X_0, the unqualified value which can be transformed into a qualified quantity is X, and the range of allowable values is U. When X_0 is the classical range and X is the extension set of extendable ranges, they can describe the qualified degree of any u in U to meet the requirements. If the value of the correlation function is set as $K_{\tilde{X}_0}$, it is referred to as the qualified degree of u for measuring condition M. In order to facilitate the comparison of the superior or inferior degrees of a solution, the qualified degree shall be standardized first.

(2) Standardized qualified degrees

Assuming that the qualified degree of the solution I to a certain problem for measuring condition M is $K(I)$, then

$$k_I = \begin{cases} \dfrac{K(I)}{\max\limits_{x \in X_0} K(x)}, & K(I) > 0 \\ \dfrac{K(I)}{\max\limits_{x \notin X_0} K(x)}, & K(I) < 0 \end{cases} \tag{5}$$

This is called the standardized and qualified degree of solution I for M.

(3) Superiority

If the set of measuring conditions of a question is $M = \{M_1, M_2, \cdots, M_n\}$, the standardized qualified degree of solution I for M_i is $k_i (i = 1, 2, \cdots, n)$, and the weight of M_i is a_i. (a_i stands for the real number which indicates the relative importance of the measuring condition) $(i = 1, 2, \cdots, n)$, then

$$C(I) = \sum_{i=1}^{n} k_i a_i \tag{6}$$

This is called the superiority of solution I to the problem.

Specific procedure of SEM

The flowchart of the procedure of SEM is shown in Figure 4 as follows.

(1) Determine the measuring condition

The degree of superiority or inferiority is determined by specific standards and

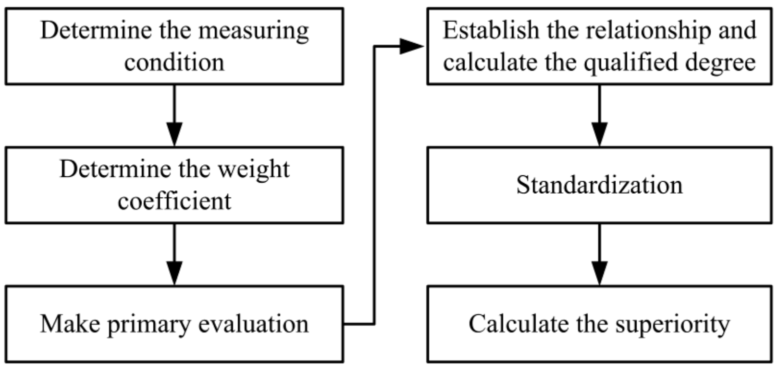


Figure 4. Specific steps of the Superiority Evaluation Method

the measuring conditions shall be provided in advance so as to evaluate whether an object is superior or inferior. An object may have both advantages and disadvantages under different conditions. Therefore, the evaluation of superiority or inferiority of an object must reflect the degree of such advantages and disadvantages and the possible changes. Due to this consideration, it is required to develop the evaluation criteria which meet the technical, economic, and social requirements according to the requirements of actual problems and for the determination of the measuring condition set $M = \{M_1, M_2, \cdots, M_n\}$, among which $M_i = (c_i, V_i)$ is the characteristic element while V_i is the domain of quantified quantity values $(i = 1, 2, \cdots, n)$.

(2) Determine the weight coefficients

The various measuring conditions $M_1, M_2, \cdots, M_n$ are different in terms of importance in the evaluation of the superiority or inferiority of an object N_j $(j = 1, 2, \cdots, m)$, and weight coefficients are used to show the importance of different measuring conditions. Indispensable conditions shall be represented by the indicator $\wedge$, while other measuring conditions shall be assigned as values within the interval [0, 1] respectively according to the importance. The weight coefficients are recorded as

$$a = \{a_1, a_2, \cdots, a_n\} \quad (7)$$

Where, if $a_i = \wedge$, then $\sum_{\substack{k=1 \\ k \neq i_0}}^{n} a_i = 1$.

The weight coefficients play an important role in the discretion of the superiority, and different conclusions will be drawn with different weight coefficients. In order to avoid the loss of truthfulness and reliability of evaluation resulting from a strong subjectivity, other objective methods can be used to determine the relative order of importance for the measuring conditions so as to decide the weight coefficients.

(3) Make primary evaluation

After the weight coefficients of various measuring conditions are determined, the next step is to screen the indispensable conditions. Delete the objects which fail to meet such conditions and then analyze the objects that met the indispensable conditions $\wedge$. In this study it was assumed that $N_1, N_2, \cdots, N_m$ all meet the indispensable conditions. For example, the product style for a design should not lack indispensable conditions such as dimensions, size, and space or the corresponding specified design conditions.

(4) Build the correlation functions and calculate the qualified degrees

Assuming that the measuring condition set is $M_i = (c_i, V_i)$, the next step is to build the correlation functions for $(i = 1, 2, \cdots, n)$ concerning $V_1, V_2, \cdots, V_n$. Record the values of the correlation functions of object N_j for various measuring conditions M_i as $K_i(N_j)$. Therefore, the qualified degrees of various objects $N_1, N_2, \cdots, N_m$ for M_i can be represented by the following equation.

$$K_i = (K_i(N_1)), (K_i(N_2)), \cdots, (K_i(N_m)) \quad (i = 1, 2, \cdots, n) \quad (8)$$

(5) Standardization

$$k_{ij}=\begin{cases}\dfrac{K_i(N_j)}{\max\limits_{x\in X_0}K_i(x)}, & K_i(N_j)>0\\ \dfrac{K_i(N_j)}{\max\limits_{x\notin X_0}K_i(x)}, & K_i(N_j)<0\end{cases} \quad (i=1,2,\cdots,n);(j=1,2,\cdots,m) \tag{9}$$

Then the standardized qualified degrees of various objects $N_1, N_2, \cdots, N_m$ for M_i are

$$k_i=(k_{i1},k_{i2},\cdots,k_{im})\ (i=1,2,\cdots,n)$$

(6) Calculate the superiority

Standardized qualified degrees of the object N_j for various measuring conditions $M_1, M_2, \cdots, M_n$ are

$$K(N_j)=\begin{bmatrix}k_{1j}\\ k_{2j}\\ \vdots\\ \vdots\\ k_{nj}\end{bmatrix}, (j=1,2,\cdots,m) \tag{10}$$

Then the superiority of object N_j is

$$C(N_j)=aK(N_j)=(a_1,a_2,\cdots,a_n)\begin{bmatrix}k_{1j}\\ k_{2j}\\ \vdots\\ k_{nj}\end{bmatrix}=\sum_{i=1}^{n}a_ik_{ij} \tag{11}$$

where a is the weight coefficient.

The final step is to compare the superiority of object N_j, *if* $C(N_0)=\max\limits_{j\in\{1,\cdots,m\}}\{C(N_j)\}$, then object N_n is superior. The larger the value, the more superior an object is.

Advantages of SEM

It is required to meet some conditions in the solution to practical problems. Otherwise, certain conditions cannot be used no matter how good they are. For example, during the process of building a design, the selection of materials and the configuration of equipment are indispensable conditions for the safety coefficient. Any materials, equipment, or schemes that fail to meet the safety requirements cannot be used.

The evaluation of an object needs to consider not only the advantageous aspects, but also the disadvantageous aspects. When an enterprise is considering the production of a product from which they may potentially benefit but the product's exhaust gases cause very serious harm to the environment, the enterprise needs to incorporate alternative products into consideration. There may be another product, which is less profitable and harmless to the environment and the enterprise shall consider both the advantageous and disadvantageous aspects in order to determine which product is better. They need to conduct comprehensive evaluations and then select the appropriate screening plan. In the evaluation, the effects and the potential advantages and disadvantages shall be taken into account as well.

The SEM was specifically proposed based on the consideration of these practical situations. It has the following two functions:

(1) Describes the indispensable conditions with $\wedge$.

(2) Since the value of the correlation function can be either positive or negative, the superiority can reflect the degree of advantages and disadvantages of an object.

As a result of knowledge gleaned from the above discussions, the use of the extension analysis and the extension transformation can provide people with many solutions and strategies for resolving contradictions. However, these solutions or strategies can be utilized only after being screened out. Therefore, the SEM, which is a basic method for the evaluation of an object which may be a thing, a strategy, a solution, or a scheme, is established by using an extension set and the correlation functions. Its advantage lies in the inclusion of "indispensable conditions" in the measuring conditions, and this approach makes the evaluation more practical. The qualified degrees and the superiority of various objects can be determined by using a correlation function, and the correlation function can be either positive or negative. Superiority can reflect the degree of advantage or disadvantage for a solution or a strategy. Since the extension set can describe the variability, this study has established the relationship between the characteristic feature parameters and shape vocabularies by using such characteristics.

RESEARCH PROCESS AND METHODS

This study is divided into four stages, and the tasks to be conducted at each stage are briefly described as follows. All of the steps are illustrated in Figure 5 as well.

Stage 1

1. Select the computer towers for the case study.
2. Collect product data available on the existing market.
3. Use the MDS and cluster analysis to select the representative product for the case study.

Stage 2

1. Collect the vocabularies which correlate to the products.
2. Select fifteen words that had the most votes as per the questionnaire survey.
3. Conduct a questionnaire survey on the fifteen primary vocabularies and the representative products selected in Stage 1 for investigation.
4. Conduct factor analysis on the average value of the questionnaire results, and select the representative vocabularies.

Stage 3

1. Simplify the representative products, and analyze the morphological characteristics and shape rules.
2. Summarize the representative products according to the basic concepts of the feature base, and determine the characteristic combination of the component prototypes for the computer tower products.
3. Define a reasonable range of variations for the component parameters according to the shape rules and the basic component elements.
4. Study shape generation rules and the feasibility of the gradual generation of a shape in order to obtain the shape rules in gradual variations.
5. Build CAD (computer-aided design) prototypes and establish a set of characteristic groups for generating component shapes according to the common characteristic combination of the products. A reasonable range of variations in component parameters can be defined.
6. Arrange component types obtained by the shape generation process into morphological charts, and re-combine them so as to generate more new shapes.

Stage 4

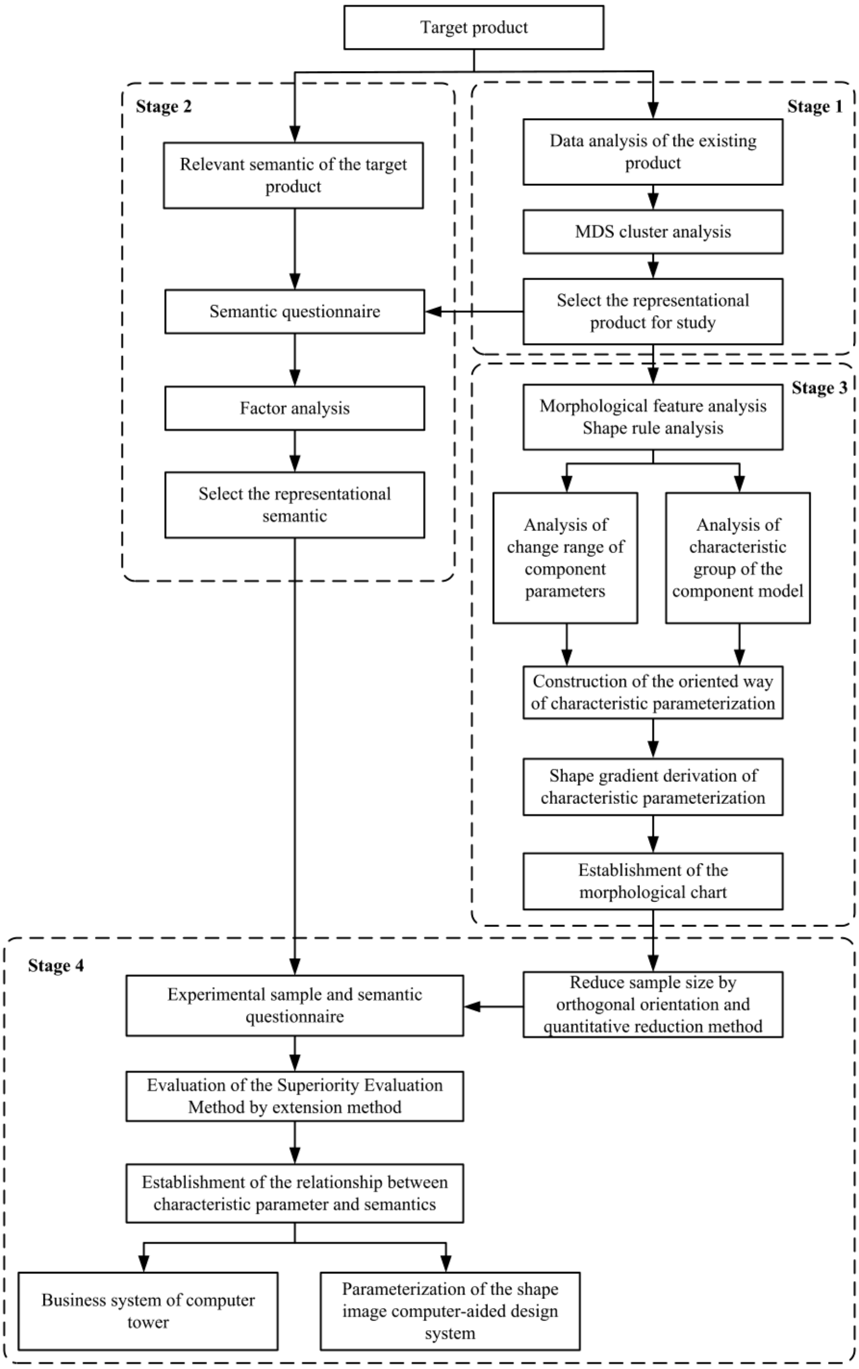


Figure 5. Flowchart of the research process

1. Based on the resulting value obtained from Equation (12), reduce the number of samples to 33 by the orthogonal orientation and the quantitative method so as to reduce the burden on the respondents (after the arrangement and re-combination of the morphological charts, there will be tens of thousands of experimental samples).

2. Conduct the questionnaire survey on the reduced number of samples and the representative vocabularies obtained in Stage 1.

3. Build the relationship between characteristic parameters and image vocabularies which are achieved by means of the matter-element identification extension method and SEM. A designer can enter the vocabulary values, and then

evaluate and combine them so as to generate product models that meet the characteristic parameters of an image vocabulary.

4. Program the results from the analyses mentioned in the above four stages. This portion will be further explained in Section 4.

Selection of product shapes

This study selected computer towers as the objects for investigation. The main function of a computer tower is to contain the computer parts (CPU, display card, main board, etc.). A computer tower can be considerably popular and diversified in terms of shapes since different shapes generate different psychological feelings. Therefore, in addition to the thermal performance, its shape is often a major consideration for the majority of consumers and clients when they select a computer tower. The computer tower was selected as the target product for the case study since it belongs to a type of product that is within the maturity stage of a typical product life cycle. The practical functions of a computer tower have already been well defined. The variations within a product family mostly belong to the variations in the product style. The main design goal is to design a product style which best complies with the customers' preference.

For the purposes of this study, 80 computer tower samples were collected. Those towers which were too exaggerated or were for special purposes were deleted (e.g., industrial computers used in the manufacturing industry and internet servers), leaving 50 samples. Then after appropriate image processing, the background of these samples was removed so as to conduct a grouping experiment. At this stage, a total of 30 designers or students of design backgrounds joined the experiment. They included fifteen female and fifteen male students aged from 22 to 25 years old. The researchers first verbally described the experiment contents and the answering method to the respondents, and the respondents then classified the samples with similar styles or similar images into one group according to their inner feeling. About five to eight groups of different styles and images were created.

The researchers then summarized the samples by the grouping frequency, transformed them into a similarity matrix (by comparing the frequency of a sample occurring in the same group, or the similarity degree). It was further transformed into an oppositional matrix by EXCEL, and then an MDS analysis was conducted from two-dimensional to six-dimensional domains. The analysis results and the stress coefficients are shown in Table 1.

Based on the Kruskal stress coefficients, when a stress coefficient is 0.100, the result is fair. When it is less than 0.050, the result is good or excellent. However, Kruskal and Wish indicated that when determining the number of dimensions, the explainability, usability, and stability shall be taken into consideration as well. Therefore, a stress value of 0.03646 is good since it is less than 0.050, and so the five-dimensional data is adopted for cluster analysis and the Euclidean distance square of Ward was used for clustering.

By observing the grouping results and comparing the samples, it was determined to classify the samples into five groups according to the direct-line grouping boundaries and the distance from each product sample to the core of the cluster

Table 1. Values of the stress coefficient from two-dimension to six-dimension

	Stress	**RSQ**
Six-dimension data	0.02938	.99254
Five-dimension data	0.03646	.98943
Four-dimension data	0.05258	.98020
Three-dimension data	0.07148	.96857
Two-dimension data	0.15007	.89279

according to the K-means method. The study also assigned the samples with the shortest distance to a cluster, and then they were recalculated to obtain a cluster of new things and the core of the group which lost most of the points can be determined. By the K-means method, the distance from each sample to the core of each group was obtained. The sample with the shortest distance to the core shall be regarded as the representative sample of each cluster. For example, the most representative samples in the second cluster are shown in Figure 6.

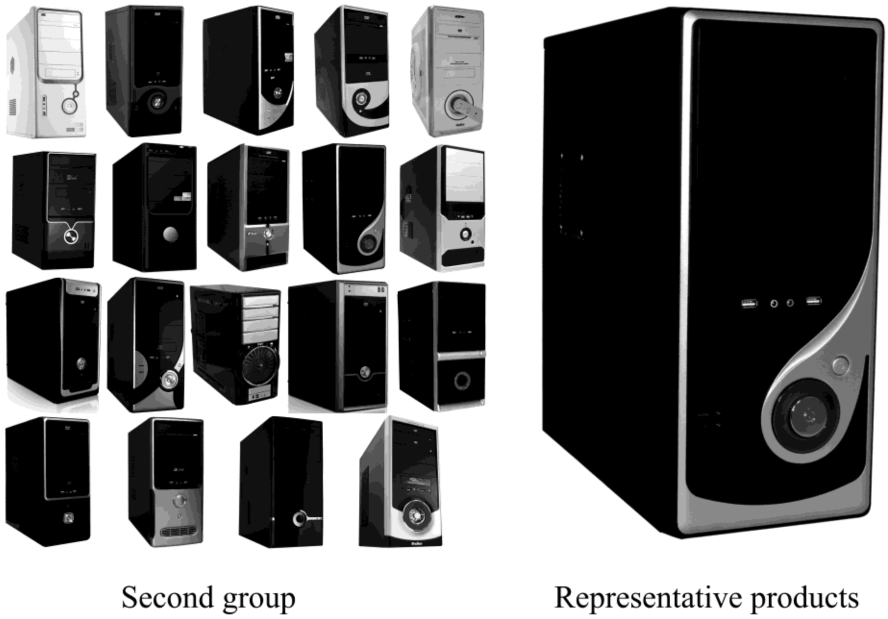


Figure 6. Most representative samples in the second cluster

Screening out adjective vocabularies

The purpose of screening out adjective vocabularies is to obtain the feelings and image information related to a computer tower. The popular vocabularies and the psychological feelings of customers were selected in this study. The adjective vocabularies which were relevant to the computer tower images were then collected. The 60 groups of adjective vocabularies that were collected were sent to 45 respondents for their evaluation. These respondents included fifteen people who had over four years of design experience and 30 people without any design background. They were asked to select 10-15 vocabularies for each shape of these computer towers and the data was collected for further statistics. Eventually, fifteen groups of adjectives with the maximum cumulative value were selected as the basis for further analysis. Then the researcher conducted a secondary screening out on the vocabularies by using the fifteen groups of adjectives and the five representative product samples selected in Section 3.1. The fifteen groups of adjectives were divided according to a seven-stage scale with semantic differential (SD) to be matched with pictures of five styles of the representative products so as to constitute the product vocabulary questionnaire. Then a factor analysis was conducted on the average values obtained from the questionnaire survey, and a representative adjective vocabulary for each computer tower was selected.

The factor analysis of the questionnaire survey targeted a total of 30 young people aged 22-26 years and they include fifteen males and fifteen females. The mean value of the total results was calculated, and entered into the statistical software for the factor analysis. The value of Kaiser-Meyer-Olkin (KMO) is 0.86. If KMO is closer to 1, it indicates that the correlation between two questions of the scale is good. The more the common factors, the better the system is suitable for the factor analysis. Factors with a characteristic value greater than 1 were selected according to the screening test, so as to identify the potential characteristics of these image adjectives and to select the more representative factors from these adjectives. Four factors were obtained after conducting the abovementioned method. The correlation between the adjectives and factors is shown in Table 2.

Table 2. Results of the factor analysis

Factor	Image vocabulary	Factor 1	Factor 2	Factor 3	Factor 4	Characteristic value	Contribution degree	Accumulative contribution degree
Surrounding environment	Practical-decorative	-0.984				5.839	38.729%	38.729%
	Unique-featureless	-0.907						
	Noble-mediocre	-0.904						
	Modern-classical	0.85						
	Lively- formalistic	0.675						
	Light-heavy	0.643						
Design	Streamlined-geometric		1.012			4.604	30.439%	69.168%
	Simple-complex		1.01					
	Dynamic-static		0.79					
	Rounded-acuminate		0.65					
Feeling	Popular-personalized			0.99		3.376	22.109%	91.277%
	Luxurious-simple			-0.807				
	Feminine-masculine			-0.701				
Age	Avant-garde-classic				-1.009	1.179	7.863%	99.14%
	Mature-young				-0.614			

In Table 2, various adjectives are sorted in an order according to their loads in the factors. A positive value represents a positive correlation, and a negative value stands for a negative correlation. Whether the correlation is positive or negative, the larger the factor load, the greater the correlation is. According to Table 2, the contribution rates of the four factors are 38.729%, 30.439%, 22.109%, and 7.863% respectively. By taking the balance and average values into account, the adjectives with a higher load among these factors were determined. Four pairs of adjectives were obtained eventually and they are namely: practical-decorative, streamlined–geometric, popular–personalized and avant-garde -classic.

Morphological analysis and characteristic construction

This study focused mainly on the investigation of shapes. The experimental analysis didn't include the aspects of material, color, texture, grain, and mechanism. The analysis of the five representative products selected in Section 3.1 indicated that a computer tower is composed of eight parts: roof cover, panel appearance, DVD-ROM slot, keyboard arrangement, front cooling vent, side cooling vent, side panel handles, and USB sockets. By consulting with experts, designers, and other related personnel, it was found that among the components of a computer tower, consumers pay more attention to the overall shape when they want to buy a computer tower. They give less consideration to the details such as the USB ports, DVD-ROM slots, and other components in a fixed size or form. Therefore, since the parts such as the USB socket, roof cover, and DVD-ROM slots have no significant impact on the overall tower shape, they were not included into the investigation of the study. Therefore, only six parts were taken into account for the purpose of this study and they are the panel appearance, keyboard arrangement, panel cooling vents, decorative elements, side panel cooling vents, and side panel handles.

According to the shape generation rules, components were included into a morphological chart matrix as shown in Table 3. After that, more new shapes were derived by re-arranging and re-combining the matrix. Each component can be described by a parameter group and a prototype characteristic group. These data served as a part of the database in the programming.

Select experimental product samples and build the perceptual matrix of product samples

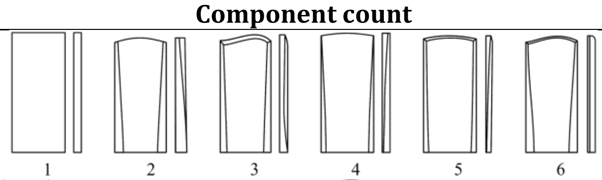
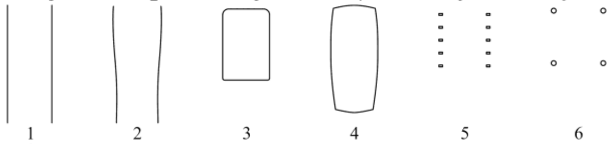
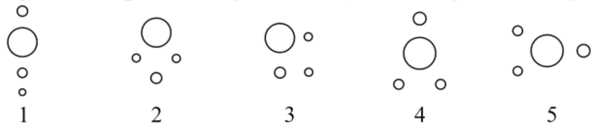
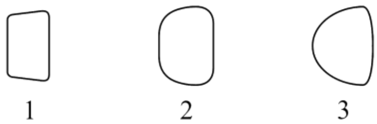
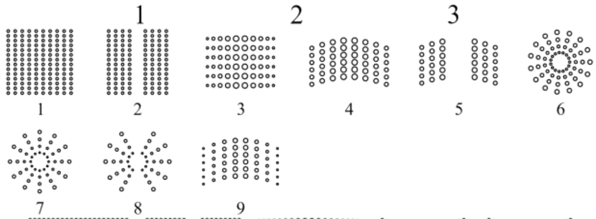
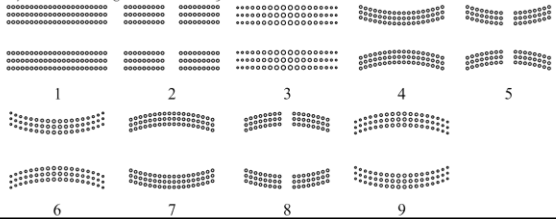
According to the morphological chart in Table 3, there are a total of $6\times6\times5\times3\times9\times9=43740$ shape samples derived from the morphological arrangement and combination. This number would be quite a heavy burden for the respondents. Therefore this study used an orthogonal arrangement method and a quantitative method to reduce the sample count to a certain extent.

The sample count in a questionnaire survey affects the accuracy and cost of an investigation. The quantitative analysis method was adopted in this study. The computational method for determining the infinite population sample size is as follows.

$$n=\frac{Z^2\times V^2}{D^2} \tag{12}$$

where Z is the reliability coefficient, which can be obtained from the probability table. V is the coefficient of variation, $V = S\sqrt{x}$, which is the ratio of the samples' standard deviation to the samples' mean.

Table 3. Morphological chart of a computer tower

Component element	Component count
Display appearance	
Decorative elements	
Lamp and key arrangement	
Handle	
Display cooling hole	
Side plate cooling hole	

By substituting the values for the above parameters into Equation (12), it can be determined that 33 samples were required for this study. The study built a 3D model as the sample source of the vocabulary questionnaire. Four pairs of representative adjectives from the adjective vocabulary database were selected in Section 3.2 and an assessment by a seven-stage SD method was conducted. All of the 30 respondents had the experience of design for over a year. Finally, a perceptual scaling matrix was built after averaging the subjective assessment of the 30 respondents for subsequent data analysis and data processing. The results are shown in Table 4 as follows.

Table 4. Perceptual assessment matrix

	Practical-decorative	Streamlined- geometric	Popular- personalized	Avant-garde-classic
Sample 1	3.35	2.6	2.33	3.45
Sample 2	2.93	5.68	3	5.73
Sample 3	3.88	2.43	2.43	2.6
Sample 4	4.13	3.45	3.83	3.35
Sample 5	2.65	4.33	2.55	4.25
Sample 6	4	4.75	3.2	4.68
Sample 7	5.15	2.7	4.65	2.25
Sample 8	3.5	4.13	4.48	3.68
Sample 9	4.18	3.45	4.6	2.98
Sample 10	3.23	3.25	4.48	3.7
Sample 11	3.85	4.15	4.68	4.38
Sample 12	4.08	3.53	3.9	3.68
Sample 13	4.58	3.65	4.08	3.38
Sample 14	3.3	4.5	2.83	4.95
Sample 15	3.65	3.35	2.75	3.63
Sample 16	3.83	5.2	3.85	5.05
Sample 17	3.03	3.78	3.73	4.73
Sample 18	4.05	2.3	2.8	2.8
Sample 19	5.13	2.85	4.25	2.23
Sample 20	5.08	2.88	4.45	2.65
Sample 21	3.4	6.15	4.28	5.63
Sample 22	3.28	4	2.58	3.88
Sample 23	4.1	5.38	5.43	4.53
Sample 24	3.45	4.8	3.38	4.28
Sample 25	4.73	3.78	4.6	2.98
Sample 26	4.05	3.85	4.65	3.28
Sample 27	3.95	3.43	4.43	3.5
Sample 28	3.23	2.83	2.48	3.6
Sample 29	4	4.03	4.38	3.25
Sample 30	2.38	3.83	2.28	5.5
Sample 31	4	2.63	3.7	2.53
Sample 32	2.55	2.8	2.4	4.9
Sample 33	2.9	3.6	4	2.63

Build the relationship between characteristic parameters and vocabularies

This study utilized the SEM in the extension method due to the fact that the SEM can be used to resolve the contradictions between matter-element and things so as to determine the fuzzy relationship between the shape characteristic parameters and the image vocabularies in this study. Based on this method, a relationship model between the characteristic parameters and the vocabularies can be established.

Evaluation by the SEM

Assuming that a computer tower is composed of four groups of vocabularies, which include practical-decorative, streamlined–geometric, popular–personalized, and avant-garde-classic and that these four groups of vocabularies could describe a computer tower by different scores, we can define a computer tower as follows.

$$R = (N, \quad c, \quad v) = (\text{Optimal computer tower}, \quad \text{Vocabularies}, \quad \text{Scores})$$

(a) Build the correlation functions

An example of the scores of the vocabularies by the customers is shown in Figure 7 with 3, 4, 5 and 3 points respectively.

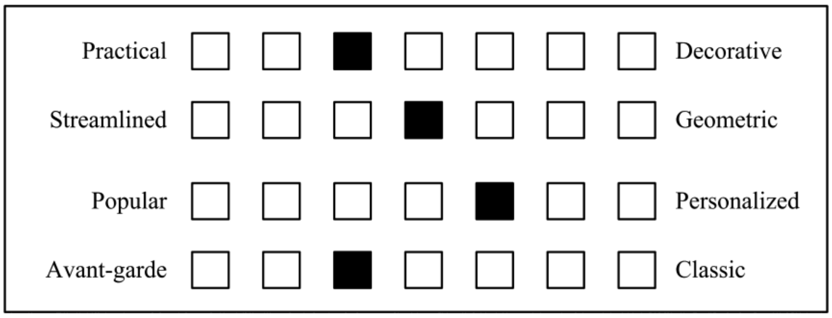


Figure 7. Scores of vocabulary input by customers

± 0.5 is added before and after the scores of input vocabularies to generate a fuzzy matrix. In order to more accurately determine the imagery shapes of a computer tower that is satisfying for the customers, the fuzzy matrix shall meet the criterion of $M = \frac{a+b}{2}, b > a$, where M is the score entered for vocabularies, and where a and b are the values of the vocabulary scores with ± 0.5. The correlation function of each vocabulary is derived from Equation (4) as follows.

$$K(x) = \begin{cases} \frac{2(x-2.5)}{3.5-2.5}, & x \leq 3 \\ \frac{2(3.5-x)}{3.5-2.5} & x > 3 \end{cases}$$ is the correlation function for practical-decorative (13)

$$K(x) = \begin{cases} \frac{2(x-3.5)}{4.5-3.5}, & x \leq 4 \\ \frac{2(4.5-x)}{4.5-3.5} & x > 4 \end{cases}$$ is the correlation function for streamlined-geometric (14)

$$K(x) = \begin{cases} \frac{2(x-4.5)}{5.5-4.5}, & x \leq 5 \\ \frac{2(5.5-x)}{5.5-4.5} & x > 5 \end{cases}$$ is the correlation function for popular- personalized (15)

$$K(x) = \begin{cases} \frac{2(x-2.5)}{3.5-2.5}, & x \leq 3 \\ \frac{2(3.5-x)}{3.5-2.5} & x > 3 \end{cases}$$ is the correlation function for avant-garde -classic (16)

(b) Calculation of qualified degrees

The average value of the sample vocabularies was incorporated into the perceptual assessment matrix in Table 4 so as to obtain the qualified degrees. For example, if the average value of Sample 1 corresponding to the vocabulary practical-decorative is 3.35 and when $x = 3.35$ is incorporated into Equation (13), then the value of the qualified degree can be determined as 0.3. The rest can be done in the same way and thus the qualified degree of Sample 1 is as follows. K (S_1) =(0.3, -1.8, -

4.34, 0.1). Similarly, the qualified degrees of other samples can be obtained and they are shown in Table 5.

(c) Calculation of standardized qualified degrees

Assuming that the qualified degree of solution I to a question for measuring condition M is $K(I)$, it is called the standardized qualified degree of solution I for M. When $M = \frac{a+b}{2}$, $K(x)$ reaches the maximum value. By substituting the correlation function M into *x*, the resulting value is 1. By substituting $K(I)$ and the values obtained from the above steps into Equation (9), the standardized qualified degree of Sample 1 is $K(S_1)$= (0.3/1, -1.8/1, -4.34/1, 0.1/1) = (0.3, -1.8, -4.34, 0.1). The rest of them can be derived in a similar way. The qualified degrees for all of the samples are shown in Table 5.

(d) Determine the weight coefficients

For an object with different conditions, the weight coefficients can be used to indicate their degrees of importance. An indispensable condition needs to be indicated as $\wedge$. Other measuring conditions shall be assigned with values within the range of $[0,1]$ according to their degree of importance. This can be represented by

$$a = (a_1, a_2, \cdots, a_n)$$

The contribution degrees of the vocabularies in Section 3.2 are taken as the weight coefficients. These values are 8.729% for practical-decorative, 30.439% for streamlined–geometric, 22.109% for popular–personalized, and 7.863% for avant-garde -classic.

Table 5. Qualified degrees of various samples

Sample 1	0.3	-1.8	-4.34	0.1
Sample 2	0.86	-2.36	-5	-4.46
Sample 3	-0.76	-2.14	-4.14	0.2
Sample 4	-1.26	-1	-1.34	0.3
Sample 5	0.3	0.34	-3.9	-1.5
Sample 6	-1	-0.5	-2.6	-2.36
Sample 7	-3.3	-1.6	0.3	-0.5
Sample 8	0	0.74	-4	-0.36
Sample 9	-1.36	-1	0.2	0.96
Sample 10	0.54	-0.5	-4	-0.4
Sample 11	-0.7	0.7	0.36	-1.76
Sample 12	-1.16	6	-1.2	-0.36
Sample 13	-2.16	0.3	-0.84	0.24
Sample 14	0.4	0	-3.34	-2.9
Sample 15	-0.3	-0.3	-3.5	-0.26
Sample 16	-0.66	-1.4	-1.3	-3.1
Sample 17	0.94	0.56	-1.54	-2.46
Sample 18	-1.1	-2.4	-3.4	0.6
Sample 19	-3.26	-1.3	-0.5	-0.54
Sample 20	-3.16	-1.24	-1	0.3
Sample 21	0.2	-3.3	-0.44	-4.26
Sample 22	0.44	1	-3.84	-0.76
Sample 23	-1.2	-1.76	0.14	-2.06
Sample 24	1	-0.6	-2.24	-1.56
Sample 25	-2.46	0.56	0.2	0.96
Sample 26	-1.1	0.7	0.3	0.44
Sample 27	-0.9	-0.14	-0.14	0
Sample 28	0.54	-1.34	-4.04	-0.2
Sample 29	-1	0.94	-0.24	0.5
Sample 30	-0.24	0.66	-3.24	-4
Sample 31	-1	-1.74	-1.6	6
Sample 32	1	-1.4	-4.2	-2.8
Sample 33	0.8	0.2	-1	0.26

(e) Calculate the superiority

By substituting the values of the standardized qualified degrees into Equation (11) respectively and then substituting the values of α as 0.38729, 0.30439, 0.22109 and 0.7863, the superiority $C(S_1)$ of Sample 1 was obtained as follows.

$$C(S_1) = (0.38729\ \ 0.30439\ \ 0.22109\ \ 0.7863)\begin{bmatrix} 0.3 \\ -1.8 \\ -4.34 \\ 0.1 \end{bmatrix} = -1.31262$$

It was found from the above calculation that $C(S_1)$ of Sample 1 is -1.31262. The rest of them can be derived in a similar way and the ranking is shown in Table 6. The higher the score, the more suitable the vocabulary is to describe the shape. The ranking of the superiority can be obtained by further calculations and it is shown in Table 6. It was found that Sample 33 is the one that best matches the shape described by the vocabulary scores determined by the customers.

Confirmation of the relationship

It was found from the results calculated by using the SEM that, Sample 33 is the shape model with the optimal vocabulary description. The parameters and component styles can be obtained correspondingly by using the morphological chart method. The model allows single-item and multiple-item vocabulary inputs. For example, if only the shape vocabulary practical-decretive is selected, other three groups of vocabulary will be zero. After that, the correlation functions were built and the operation was complete.

Table 6. Superiority values and the ranking of various samples by the superiority values

Superiority sequence	Samples	Superiority value
No.1	Sample 33	0.35398
No.2	Sample 9	0.241625
No.3	Sample 29	0.238775
No.4	Sample 26	0.199221
No.5	Sample 25	1.65E-02
No.6	Sample 8	-0.6656
No.7	Sample 10	-0.2663
No.8	Sample 27	-0.42213
No.9	Sample 4	-0.57889
No.10	Sample 13	-0.74231
No.11	Sample 22	-0.97155
No.12	Sample 12	-0.97926
No.13	Sample 15	-1.18568
No.14	Sample 31	-1.22351
No.15	Sample 28	-1.24915
No.16	Sample 1	-1.31265
No.17	Sample 11	-1.3618
No.18	Sample 20	-1.38759
No.19	Sample 18	-1.43666
No.20	Sample 3	-1.70385
No.21	Sample 17	-1.73953
No.22	Sample 5	-1.82157
No.23	Sample 24	-1.86531
No.24	Sample 7	-2.09175
No.25	Sample 19	-2.19326
No.26	Sample 23	-2.58868
No.27	Sample 14	-2.86292
No.28	Sample 6	-2.96928
No.29	Sample 16	-3.40577
No.30	Sample 32	-3.5168
No.31	Sample 30	-3.75238
No.32	Sample 21	-4.37267
No.33	Sample 2	-4.55412

According to the SEM model, the relationship model between the component characteristic parameters and the vocabularies can be obtained as shown in Figure 8. This model was programmed to build the relationships between vocabularies, component characteristic parameters, and the database. After that, it was then combined with the CAD software so that designers can clearly understand the vocabulary shape parameters which were demanded by the consumers. With this approach, any product designed by a designer can better meet the image in the consumers' mind. The designer can deliver the best product performances, the product development time can be reduced, and the competitiveness of a product can be enhanced.

SYSTEM CONSTRUCTION AND THE DESIGN OF THE OPERATION INTERFACE

This study built a computer-aided tower design system with the shape image parameterization according to the analysis results obtained in Section 3. A designer can determine customers' most favorite computer tower by using the vocabulary input method. When a designer entered the vocabularies into the system, it will generate vocabulary correlation functions of the computer tower in real-time. As a first step, it is required to capture the vocabulary data of the perceptual assessment matrix from the database. A superiority evaluation by the extension engineering can then be conducted so as to obtain the optimal combination of the component parameters. After that, researchers can enter the database to capture the parameter data of the characteristic groups for the component prototype models so as to generate the parameter shapes with the optimal vocabularies for the designers. The procedure of operating the system interface is as follows.

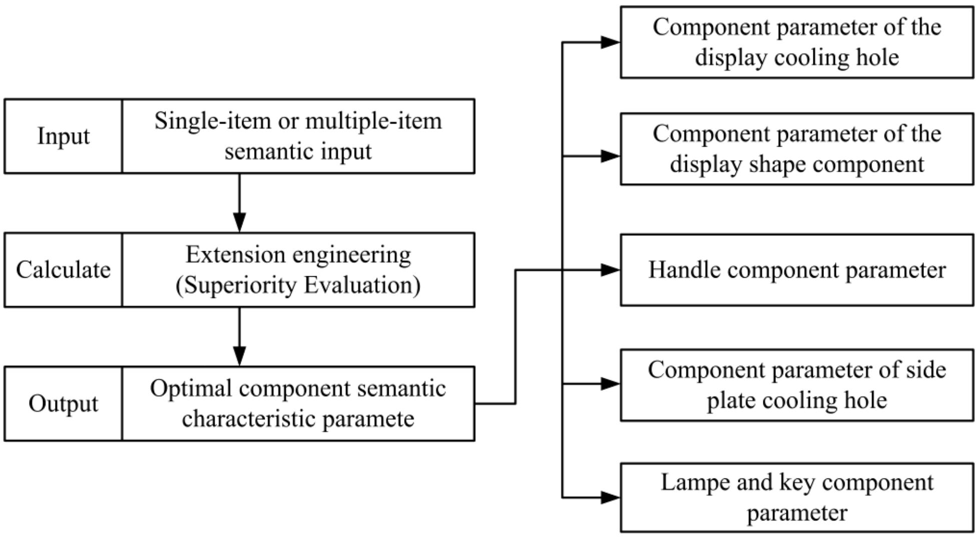


Figure 8. Relationship model between the characteristic parameters and the vocabularies

Step 1: The first step is to enter the scores of the shape vocabularies for the computer towers as shown in Figure 9. Either one, two, or three vocabularies can be entered here. If a user only likes the shape vocabulary of practical-decretive, the scores of the other three pairs of vocabularies were left empty. The operation of this step can be thus completed.

Step 2: Click to confirm the vocabulary input.

Step 3: After the previous steps, Figure 10 shows the ranking of the top four optimal vocabularies for the computer towers. Click a favorite computer tower and

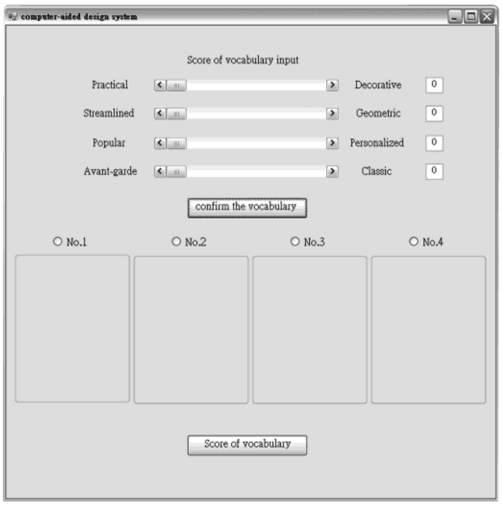


Figure 9. Screenshot of the vocabulary input window

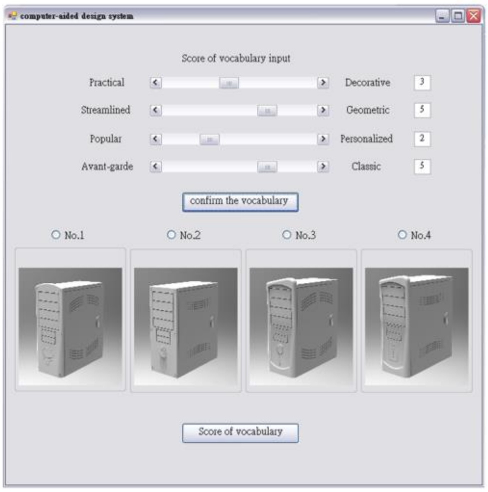


Figure 10. Generating the optimal shape for a computer tower

then click Confirm shape to enter the CAD software and generate the optimal shape for the computer tower.

Step 4: During this step, the scores of the vocabularies selected previously will be translated into the description of the product parameters by the extension method. This step is for the user who is not satisfied with the components within the optimal product and they can modify/select those components by following the steps as shown in Figure 11.

CONCLUSION

A product shape generation method was proposed in this study based on the extension engineering SEM and the characteristic parameterization by classifications. The collected shape characteristics of a computer tower were first classified. The perceptual evaluation matrix was then used to build the shape image data for the computer towers. Finally the SEM of the extension engineering was used to build the relationship between the computer tower shapes and the image vocabularies so as to create a computer-aided design system with the parameterization of shape images. SEM can also be used to quickly determine customers' requirements on the shape parameters of images so as to correctly

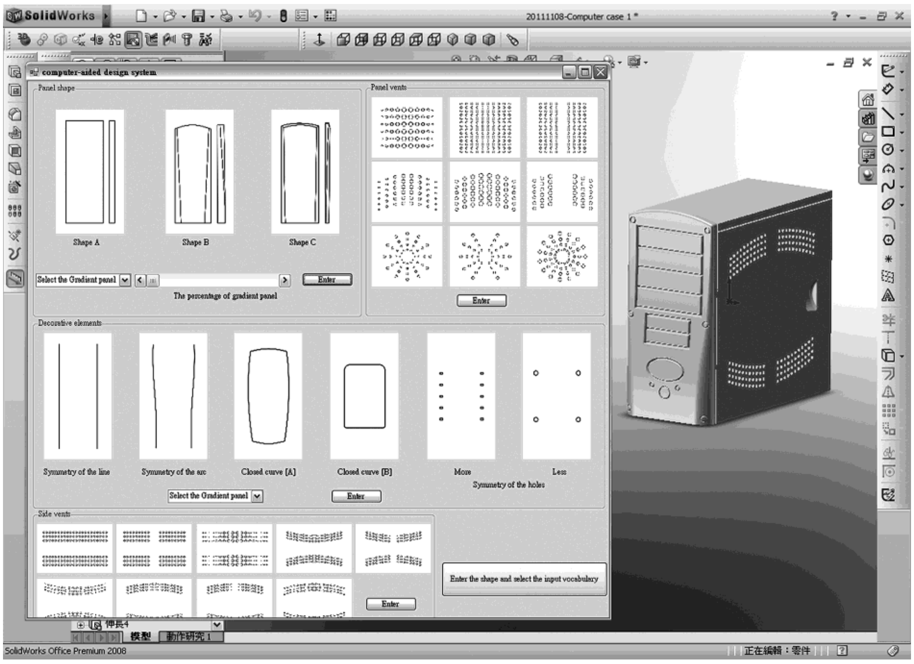


Figure 11. Screenshot of the step to connect the program to the CAD software

describe the desired shapes. A designer can efficiently design computer towers that meet customer requirements by using the proposed computer-aided design system. A designer can also study the additional descriptions offered by customers via this system so as to carry out further detailed shape modifications as requested by customers.

In this study, a shape design system which is assisted by the parameterization of products' imagery characteristics was established. This consumer-oriented approach can help designers and customers communicate with each other efficiently on product shapes. During the product development stage, a designer can master the exact shape that possesses the imagery feeling preferred by customers. The imagery, which was presented on computer screens, can then be realized concretely.

The emotional evaluation matrix was also used in this study and the corresponding parameters can be obtained by the calculation of SEM in the extension engineering method. After that, the relationship between the parameterized characteristics and the shape vocabularies can be established. With this method, the problem of one-way input or multiple-way input for vocabularies can be resolved. For example, even if a customer entered only the score of the adjective vocabulary of practical-decorative, the method proposed in this study can still determine the characteristic parameters preferred by the customer by further calculations. Even if the customer entered two or three adjective vocabularies, the related characteristic parameters can be obtained as well and the results can be utilized to determine the product style design preferred by customers. Other methods such as the neural network training, quantification theory type 1, and gray theory might also be able to establish the relationship between the styling and adjective vocabularies. However, these methods can only obtain the characteristic parameters after all of the customers' various preferences on each of the adjective vocabularies are entered and clearly defined. None of the other methods can perform calculations based on the incomplete data.

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