*Metaverse* 2024, 5(1), 2371
https://doi.org/10.54517/m.v5i1.2371

Article

# Evaluation of parametric sedan wheel hub based on Kansei Engineering and regression analysis

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**CITATION**

Chen Y, Peng Q, Huang R, Shao J. Evaluation of parametric sedan wheel hub based on Kansei Engineering and regression analysis. Metaverse. 2024; 5(1): 2371. https://doi.org/10.54517/m.v5i1.2371

**ARTICLE INFO**

Received: 9 November 2023
Accepted: 26 December 2023
Available online: 9 January 2024



**Abstract: Purpose:** Parametric design has become one of the most important means of sedan design. The purpose of this paper is to construct a linear regression model to explore the matching relationship between Kansei words and the morphological elements of sedan wheels and to incorporate perceptual factors into the rational thinking of parametric wheel hub design. **Design/methodology/approach:** To forecast the matching relationship between wheel shape design features and semantics, this research offers a multiple linear regression model. First, using sample similarity matrix data analysis and offline research, 20 typical samples of car wheels were collected. Third, the wheel shape design elements are obtained by applying the semantic difference (SD) method to four groups of users' evaluation data on the perceived words of the car wheels. Firstly, the wheel shape is divided into six basic features and seventeen subdivided features using morphological analysis. The collected car wheel samples are then researched and coded. Ultimately, a multiple linear regression model is built utilizing shape coding matching to the styles to direct the wheel parametric design process, yielding sedan wheel design schemes with various semantics of style. **Findings:** The results show that the regression models can provide good prediction performance (R2 values are greater than 0.7). This study shows that the use of multiple regression models can accurately and cost-effectively predict the wheel hub morphological elements that meet the user's perceptual needs through morphological elements and Kansei words. **Originality/value:** This paper is the first to use a multiple regression model to predict a parametric wheel shape that fits the user's sensibility, which helps the user to present and feel the design scheme in a digital environment. The different wheel hub schemes generated by parametric design can be virtually displayed in the metaverse, helping users and designers to carry out more convenient scheme selections.

**Keywords:** parametric design; Kansei Engineering; regression analysis; wheel hub morphology design; quantification-I theory

## 1. Introduction

For automotive design, the wheel, as one of the important parts of the car, is an important part of automotive styling design, and its beautiful style has a decisive role in the overall image of the car, which is a part of automotive styling design that cannot be ignored. Compared to traditional vehicle design, the automobile design process framework requires us to go through the stages of creative idea and sketching, refining the sketch and program screening, program decision and modeling rendering, etc. A high degree of incontestability is maintained throughout the process. Parametric design uses rational thinking to construct the logical rules of design and generates the design scheme through algorithmic programming to construct the form. By adjusting the parameters, a large number of design schemes can be generated quickly. Since the entire procedure is quite controllable, it is frequently employed in modern sedan design.

In the framework of Industry 4.0, parametric design is widely used, marking the changes in production systems triggered by the fusion of physical systems and digital technologies. Digitization opens up a virtual world through which we can precisely control the physical world. In the field of car design, the first sedan to use parametric design was Renault's "R-Space" concept car, which used parametric design to create an unsteady but rhythmic geometric pattern on the roof. The wheels, interior and exterior trim, and lights of Renault's 2013 Twin-Z concept car are all parameterized and have a geometric rhythm. BMW launched the BMW VISION NEXT 100 concept sedan in 2016, with wheel arches that feature a parameterized design similar to fish scales. Elastic metal plate components cover the entire wheel, and fish-scale elastic components follow the expansion and contraction of the wheel as the car turns [1].

The perceptual requirements of design might sometimes be overlooked in the current rational parametric thinking, despite the fact that parametric design is frequently used in automotive design. Regarding whether a product's design can feed users' intense emotional needs, uncertainty exists. To completely investigate the perceived quality of the product, Kansei Engineering and regression analysis were used to ascertain the fit between morphological design and user perception from the user's standpoint.

Multiple linear regression is a widely used statistical analysis technique in the field of perceptual engineering. It involves examining the relationships between multiple variables and is a powerful and practical application of statistical methods. Its purpose is to extract key information from complex and variable data and create a mathematical relationship model between the independent and dependent variables. This model can also be used to predict and control the value of the dependent variable, providing data support for further design practice. Liu builds a multiple linear regression model by combining the linear DNA and invisible DNA of product design and judges the evolution of the original shape according to the multiple linear regression model to continue the brand gene and innovate the product program [2]. Zhu builds a mapping relationship between the perceptual intention of water-jet cutting machine tools and the elements of styling design, which provides a good basis for the future development of water-jet cutting machines. relationship between perceptual intention and styling elements of water-jet cutting machines, providing objective and reasonable guidance for future water-jet cutting machine product styling [3]. These studies show that linear regression can establish a mapping relationship between users' perceptual needs and product form features. Linear regression is used to establish a model to predict the matching relationship between wheel form design and semantics of style, to select the product shape that best meets users' perceptual needs, and to help users and designers make a more convenient choice of solutions.

In conclusion, while car stylistic design heavily relies on wheel design, parametric design thinking frequently overlooks other factors and the user's emotional demands. To anticipate the wheel morphological elements that meet consumers' emotional demands, this paper builds a multiple regression model to investigate the matching relationship between the morphological design of sedan wheels and the semantics of style in the styling design of wheels. First, 20 representative car wheel samples are obtained through offline research and sample similarity matrix data analysis. Second, the wheel shape is divided into 6 basic features and 17 subdivided features by using the morphological analysis method, and the collected car wheel samples are studied and coded to obtain the wheel shape design elements; third, the semantic difference (SD) method is utilized to obtain four groups of users' evaluation data on the perceived words of car wheels. Finally, using the shape codes corresponding to the styles, a multiple linear regression model is constructed to guide the design practice of wheel parametric design, and the automobile wheel design schemes with different semantics of style are obtained. The proposed research method can make the different wheel schemes generated by the parametric design displayed virtually in the meta-universe, helping users and designers make more convenient scheme selections.

## 2. Related work

### 2.1. Parametric design

The industrial and technological revolution and the use of innovative software have made it possible to create a virtual world from which we can control the physical world. In particular, this development provides relevant benefits in the field of manufacturing using parametric modeling systems. A parametric design methodology is proposed to improve smart manufacturing in the industry. Parametric design requires the content and form of parameters to be defined in advance, and the designer conceives the parametric rules through logical thinking and applies computer programs for computing, adjusting the form and modeling [4]. Parametric design can be used for the derivation of diverse design solutions in the pre-production design phase [5], and its emergence allows designers to systematically incorporate design-related environmental, material, and production factors into parametric procedures to create more viable products through parameters and logical rules [6]. Rivka proposed that parametric design should be a way of design thinking, reviewing the content and concepts of early cognitive models to parametric design thinking models, and delving into the continuity and changes arising from the development of parametric design thinking [7]. Suyoto proposed a discrete approach to parametric design to help solve the problems of site, structure, and façade planning encountered in design, and his findings are a biased approach to the planning design, which will be more advantageous than traditional design in terms of design synchronization and coordination, etc., but this approach usually requires a lot of optimization iterative work to reach a satisfactory level [8]. Peter Ferschin illustrated how the parametric design process can be extended in the parametric design of lamps, where there is feedback from the production process and the need to consider realistic constraints such as cost and time to obtain a feasible design solution through optimization iterations. Ultimately, it was concluded that the parametric process simulation cannot be limited to the production method, but also needs to consider multiple dimensions of the design. Lim proposed a parametric modeling approach for prosthetic limbs, where the range of motion of the prosthetic finger designed using parametric modeling can closely match the native finger motion path and is manufactured using 3D printing [9].

To summarize, parametric design allows for the systematic integration of materials, production, and other factors into parametric design, as well as the consideration of multiple latitudes during the design process. It also enables the scheme derivation of diversified designs during the pre-production design stage and the designer's creation of parametric rules and models through logical thinking. The study employs parametric coding of sedan wheels to facilitate the swift creation of several wheel stylistic design alternatives. When paired with the online presentation of meta-universe technology, this approach can assist users and designers in selecting choices that are more convenient for them.

## 2.2. Kansei Engineering (KE) and Semantic Differential (SD)

Kansei Engineering (KE) is a new product development technology based on the Consumer-Oriented theory, aimed at the implementation of the customer's feelings and demands into product function and design [10]. Kansei means the customer's psychological feelings and embracing physiological issues. KE is defined as "translating the customer's Kansei into the product design domain" [11,12]. In this study, we use Kansei Engineering to evaluate the perceived quality of product design, emphasizing the interaction between product form elements and semantics. To represent customers' feelings or emotional reactions, known as "Kansei" in Japanese, Kansei Engineering (KE) has developed a systematic approach that is customer-oriented. where the morphological characteristics of things serve as the foundation for the semantics of style [13]. To determine a product's style, a person must first be able to comprehend visual elements, and then their brain must translate that content into abstract aesthetic concepts. Ostrosi et al. [14] proposed a computational method for multi-scale sedan style semantic identification using the style unit concept. Firstly, variable precision rough sets are applied to sedan evaluation; secondly, feature lines of different sedans are extracted from the model. Finally, the nature of double-headed units is used to identify style units, and interactive cluster analysis is used to identify style holograms. Hyun created a hybrid style semantic quantification method to find a way to quantify the semantic differential in styles and identify unique design elements of sedans, using Fourier decomposition, eye-movement experiments, and shape grammar to synthetically assess the similarity of sedan design elements [15]. In the evaluation procedure, subjects were asked to perform a sample screening task and a semantic differential (SD) experiment [16], which measures the subject's perception from a visual and perceptual perspective. The users' subjective perceptions of the product were quantified, and the survey data were analyzed using a perceptual design approach, thus making the experimental results more scientific [17,18]. Commonly, we use the semantic differential (SD) as a main technique to grasp the consumer's Kansei.

The semantic differential (SD) was proposed by Osgood in 1957 as a psychometric method [16,19,20]. It converts perceptual evaluation's abstract qualitative analysis into quantifiable evaluation markers that can be studied using data. The summary of the analysis of the research object's results can be utilized to get intuitive data information in order to optimize the design object. SD will have certain expectations for the experimental outcomes [21]. Bi et al. analyzed the existing elderly companion robot products in the market by SD and constructed a perceptual intention evaluation system for elderly companion robots by combining the Likert scale [22]. Niu et al. conducted SD experiments on the elements in the CMF design of meal box products and obtained quantitative data on material use, color expression, and processing process after statistical analysis, which can be used to guide the CMF design of meal boxes [23]. Hu et al. innovatively used the SD for product design in harmonious contexts, quantifying psychological needs and replacing the insufficiently clear selection of harmonious contextual elements for guiding the design of products in harmonious contexts [24]. To increase the scientific rigor of the experimental findings, this study quantifies the users' subjective opinions of the product and uses a perceptual design method to analyze survey data. It also investigates the relationship between the design form of sedan wheels and the Kansei words through SD [17,18].

To summarize, the integration of KE with SD trials has the potential to convert customers' psychological states and physiological issues into product design domains, as well as their emotions, needs, and wants into measurable design components. In order to achieve the union of user perceptions and product styling, perceptual engineering employs Fourier analysis, eye movement tests, form syntax, and consumer perceptual needs and emotional feedback into product design. In order to quantify the individuals' subjective opinions regarding a sample of wheels into descriptive perceptual words, this study used semantic difference tests.

## 2.3. Quantification-I theory

Quantitative theory is a branch of multivariate analysis, which is the study of transforming quantitative variables into qualitative ones. According to the differences of research problems, it can be divided into four types: Quantitative Theory I, II, III, and IV. Among them, quantitative-I theory is used to study the relationship between one set of quantitative data and another set of qualitative data, using multiple regression analysis to establish a mathematical model and make predictions on the dependent variable [25]. Chen et al. [26] proposed the main steps of constructing the mapping between perceptual imagery and product design elements based on Quantitative Theory I: firstly, get the perceptual imagery evaluation value of a representative sample of products through design research (dependent variable); secondly, extract the product design elements (independent variables); and thirdly, take the product design items as the items, Secondly, the product design elements (independent variables) are extracted; thirdly, a mathematical model is built by taking the product design items as items, the product design elements as categories, and the perceptual imagery evaluation values as dependent variables; then the mathematical model is solved by Matlab or SPSS software; finally, the data results are analyzed, in which the category scores indicate the influence of the product design elements on the perceptual vocabulary, the complex correlation coefficients are used to measure the model's precision, and the partial correlation coefficients represent the contribution value of the design items on perceptual vocabulary. Wang et al. investigated the effects of different combinations of electric scooter components on user emotions based on quantitative-I theory analysis methods and constructed a prediction model for the mapping between the appearance of electric scooters and users' perceptual needs [27]. Chen et al. applied quantitative class I to analyze the influence weights of perceptual factors, constructed a quantitative class I statistical table, and selected the perceptual factors in the table that have a greater influence on the shape of tea pets as a consideration for style adjustment before design [26]. Yu et al. [28] took the new Chinese seat design as an example, extracted the key design elements affecting the styling from the structure, components, materials and decorations, and constructed a correlation model between the user's perceptual imagery and the design elements of seat styling based on the quantization-I theory.

In summary, quantitative-I theory can realize the prediction model construction for the mapping of product appearance and users' perceptual needs. In this study, we use quantitative-I theory to construct a multiple linear regression model to study the mapping relationship between wheel semantics of style and morphological features, and construct a quantitative one-class scale to guide the wheel morphology design.

## 3. Materials and methods

After obtaining a representative sample of sedan wheel hubs and a Kansei word, quantitative I theory needs to be applied to match the two for the study. The main method is to construct a mathematical model between the independent and dependent variables through multiple linear regression [26,27,29]. This study conducted data analysis in four main stages.

- Step 1: Obtain the samples of wheel hubs and the Kansei words needed for the experiment. Then, use morphological analysis to determine the morphological class codes and quantify them for the wheel hubs.
- Step 2: Conduct SD experiments and employ questionnaire research to ascertain consumers' semantic assessments of various wheel hub sample types.
- Step 3: Utilize the experimental data for multiple linear regression analysis after recovering and organizing them. To create morphological coding tables for various styles, compile the matching linear regression model between the morphological components of the sedan wheel hub design and the Kansei words.

### 3.1. Materials preparation

#### 3.1.1. The selected samples of the wheel hub

In order to determine the user's perceptual understanding of the shape of car wheels, we collected a large number of sedan wheel product images through well-known automotive websites, official websites of various automotive brands, websites of sedan wheel design companies, automotive publications, and books, and automotive 4S stores. In order to make the sample images have clear features, the collected image data were processed. First, we manually excluded repetitive images and images with unknown formal characteristics, next, we used the image processing software Photoshop to remove the background of the image and modulate the background color to white, and second, to avoid the influence of the color factor on the user's perceptual intention, we processed the image in grayscale. Finally, the wheel perspective was adjusted to a uniform front view, and a total of 60 wheel samples were obtained.

To create a representative sample of wheels, the data from the sample similarity matrix and the offline study were integrated for thorough examination. In an offline experiment, twenty-eight design students and automotive designers were asked to classify printed paper wheel samples of the same size based on their personal feelings. The samples were then divided into twenty categories, with the participants who expressed the same emotions being placed in the same category.

The experimental data was organized and evaluated to create a 60 × 60 similarity matrix of the wheel samples as shown in **Table 1**. The similarity between the samples can be visualized through the matrix. The more times each two samples appear in the same category, the more similar the two products are. According to the analysis of the data results of the sample similarity matrix, according to the similarity of the automobile wheel samples will be classified, and the sample morphology coding process, through the sample similarity combined with the automobile wheel morphology elements of the class coding of the data, the integrated sample coding data and sample similarity comprehensive selection of samples between the similarity between the wheel samples of the wheel samples of the lower degree of similarity and different coding. Finally, 20 representative samples of automobile wheels were obtained, and the screened samples were reordered, as shown in **Table 2**.

**Table 1.** Similarity matrix of wheel samples.

| **Sample No.** | **Sample 01** | **Sample 02** | **Sample 03** | **…** | **Sample 58** | **Sample 59** | **Sample 60** |
|---|---|---|---|---|---|---|---|
| Sample 01 | 24 | 19 | 1 | … | 0 | 4 | 0 |
| Sample 02 | 19 | 24 | 2 | … | 2 | 0 | 4 |
| Sample 03 | 1 | 2 | 24 | … | 1 | 0 | |
| Sample 04 | 3 | 4 | 0 | … | 1 | 3 | 2 |
| … | … | … | … | … | … | … | … |
| Sample 57 | 1 | 0 | 2 | … | 2 | 4 | 1 |
| Sample 58 | 0 | 2 | 1 | … | 24 | 2 | 20 |
| Sample 59 | 4 | 0 | 0 | … | 2 | 24 | 3 |
| Sample 60 | 0 | 4 | 1 | … | 20 | 3 | 24 |

**Table 2.** Representative samples of the wheel hub.

| | | | |
|---|---|---|---|
| Sample 01  | Sample 02  | Sample 03  | Sample 04  |
| Sample 05  | Sample 06  | Sample 07  | Sample 08  |
| Sample 09  | Sample 10  | Sample 11  | Sample 12  |

**Table 2.** (*Continued*).

| | | | |
|---|---|---|---|
| Sample 13  | Sample 14  | Sample 15  | Sample 16  |
| Sample 17  | Sample 18  | Sample 19  | Sample 20  |

### 3.1.2. Morphological analysis of sedan wheel hub

Sedan wheel hubs are often manufactured in the style of a ring-shaped array extending from the center point to the surrounding area. The wheels are crucial components for sustaining the weight of the body and transmitting power to the tires [30]. This study introduces the morphological analysis method to characterize the sedan wheel hub model, which can be understood as deconstructing the design object on the basis of morphology, firstly, establishing the research object and dividing it into several independent basic elements; secondly, processing and analyzing the basic elements to refine them; again, arranging and combining the different schemes through reorganization, to obtain a variety of design options; and finally, filtering and optimizing the schemes. The American physicist Fritz Zwicky first proposed morphological analysis. He used it to study the issue of missile design by breaking the missile down into several mutually independent components. Next, he looked for technologies that could accomplish the missile function in several separate components. Finally, these technologies were recombined based on the study, and the results were filtered and optimized to finally obtain [31].

In this study, the main features of automotive wheel morphology are extracted and analyzed using morphological analysis. After an extensive review of 20 samples of sedan wheels, a generic wheel morphology is defined that consists of three basic elements, i.e., spoke units, inter-spokes, and overall spoke structure. Through the study, the morphological element items of car wheels were categorized and coded into six major features: ① number of spokes (A); ② way of connection between spokes and rim (B); ③ way of connection between spokes (C); ④ style of spoke units (D); ⑤ way of rotation of spoke units (E); ⑥ type of bifurcation of spoke units (F). As shown in **Figure 1**, the morphological differences of the overall structure of the spokes include the number of spokes and the way of connecting the spokes to the rim, the differences between the spokes include the way of connecting between the spokes, and the differences of the spoke units include the style of the spoke units, the way of rotating the spoke units, and the type of bifurcation of the spoke units. Under the 6 basic characteristic elements, we have further refined the morphological characteristics of the wheel and split them into 17 morphological design element categories and coded them, as shown in **Table 3**.

**Table 3.** Elements of wheel hub shape design.

| Morphological design elements | Project of design elements | Category of design elements | Code | Samples |
|---|---|---|---|---|
| Overall structure of wheel spokes | A<br>Number of spokes | Five spokes | A1 |  |
| | | Five-spoke variants | A2 |  |
| | | More than five spokes | A3 |  |
| | B<br>Spoke and rim connection method | Overlap type | B1 |  |
| | | Internal connection type | B2 |  |
| Between the spokes | C<br>Inter-spoke connection method | Pointed Angle type | C1 |  |
| | | Arc angle type | C2 |  |
| | | Folded line type | C3 |  |
| Spoke unit | D<br>Spoke unit style | Straight type | D1 |  |
| | | Curved type | D2 |  |
| | E<br>Spoke unit rotation mode | Clockwise | E1 |  |
| | | Counterclockwise | E2 |  |
| | | No rotation | E3 |  |
| | F<br>Spoke unit bifurcation type | V-shape | F1 |  |
| | | Y-shape | F2 |  |
| | | Parallel bifurcation type | F3 |  |
| | | Non-bifurcated type | F4 |  |

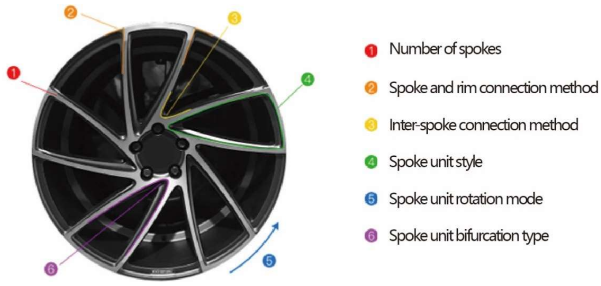


**Figure 1.** Pictorial illustration of morphological analysis results for wheel hub shape.

### 3.1.3. Spanning of the semantic space

In order to obtain data on the relationship between the samples and Kansei words, SD experiments are needed to transform perceptions into concrete data. Prior to the experiment, we conducted a questionnaire survey of car designers and consumers to determine the valid semantic space. We collected 180 perceptual semantic words from a variety of channels, including car magazines, car brand websites, car review websites, e-commerce platforms for selling car wheels, and paper journals. After the first round of vocabulary screening by filtering irrelevant words and merging similar words, opposite word pairing was conducted, and the paired perceptual words were subjected to offline questionnaire experiments, in which subjects were asked to select the vocabulary groups that matched the feelings brought to them by the automobile wheels from the initial screened stylistic semantic vocabulary after carefully observing the wheel samples, and the experimental data were collated, and four groups of Kansei words were finally screened out as shown in **Table 4**, which produced a strong psychological perception effect on the subjects. produced a strong psychological perception effect.

**Table 4.** Representative Kansei words.

| **Final representative Kansei word group** | | | |
|---|---|---|---|
| Modern–Traditional | Hard–Soft | Static–Sporty | Luxury–Simple |

## 3.2. Experiment

### 3.2.1. Participants

The subjects were mainly 20 graduate and undergraduate students with industrial design backgrounds and 8 car designers, who were selected for their knowledge and understanding of product design because of the high requirements for morphological perception. The ratio of male to female was maintained at about 1:1, with no color blindness or visual defects.

### 3.2.2. Data analysis software

Using SPSS multiple linear analysis tool and Matlab software to calculate category scores. SPSS is software for **editing and analyzing all sorts of data**. These data may come from basically any source: scientific research, a customer database, Google Analytics, or even the server log files of a website.

### 3.2.3. Experimental protocol

All 20 pictures with wheel hubs, as shown in **Table 2**, were used as the samples for the SD experiment. The questionnaire for the SD evaluation includes the 4 groups of Kansei word attributes defined in 3.1.3. They were listed on the paper, with each word on the right and its antonym on the left. As shown in **Table 5**, the evaluation was based on a 5-point Likert scale, where "–2" indicated strong agreement with the words on the left, "2" indicated strong agreement with the words on the right, and "0" was neutral [32]. The Kansei words used were written in Chinese and are approximately translated into English in this paper. The SD experiment questionnaire was sent to the subjects, who were invited to carefully observe the samples in the questionnaire and then score them according to their inner feelings on the SD scale. 100 valid questionnaires were collected online and offline. The collected data were analyzed by the mean algorithm through SPSS software to obtain a table of mean values for the sedan wheel samples and Kansei words.

**Table 5.** Form of SD evaluation.

| Sample | Kansei words | Scale | | | | |
|---|---|---|---|---|---|---|
| | | **Strong agreement with the words on the left** | **More agreement with the words on the left** | **Neutral** | **More agreement with the words on the right** | **Strong agreement with the words on the right** |
|  | Modern–traditional | –2 | –1 | 0 | 1 | 2 |
| | Hard–soft | –2 | –1 | 0 | 1 | 2 |
| | Static–sporty | –2 | –1 | 0 | 1 | 2 |
| | Luxury–simple | –2 | –1 | 0 | 1 | 2 |

### 3.2.4. Results

As shown in **Table 6**, the mean values of the sedan wheel hub samples and Kansei words were calculated using the mean method and SPSS software. A larger absolute value of the values indicates that the samples meet the morphological requirements of the corresponding Kansei words. Positive values in the table indicate that the samples are biased toward the words on the right side of the Kansei word group, while negative values indicate that the samples are biased toward the words on the left side of the Kansei word.

**Table 6.** The mean of wheel hub sample and Kansei word.

| **Kansei word** | **Modern–Traditional** | **Hard–Soft** | **Static–Sporty** | **Luxury–Simple** |
|---|---|---|---|---|
| Sample 01 | –0.38 | –0.44 | –1.14 | 0.71 |
| Sample 02 | 0.17 | –0.89 | –0.62 | –1.08 |
| Sample 03 | 0.09 | 0.25 | –1.08 | 0.17 |
| Sample 04 | –0.32 | 0.29 | 0.78 | –0.36 |
| Sample 05 | –0.77 | –0.19 | 0.36 | –1.63 |
| … | … | … | … | … |
| … | … | … | … | … |
| Sample 16 | 0.05 | 0.08 | –0.71 | –0.44 |
| Sample 17 | 0.03 | 1.08 | 1.14 | –1.46 |
| Sample 18 | –1.52 | 0.19 | 0.74 | –1.08 |
| Sample 19 | –1.41 | –0.51 | 0.55 | –1.46 |
| Sample 20 | –1.09 | 0.36 | 0.51 | –1.22 |

## 3.3. Regression analysis model construction

### 3.3.1. Multiple regression equation

Multiple linear regression is the study of how different variables interact with one another. It is a widely used statistical technique whose goal is to identify the key characteristics of complex and variable data and build a mathematical relationship model between the independent and dependent variables [33]. This mathematical relationship model can then be used to predict and control the values of the dependent variables, thereby supplying data [24]. In the actual research process, usually the independent and dependent variables are not unique, the dependent variable (Kansei words) in the study is set as Y, when it is influenced by n factors, n needs to be greater than 1, then $X_1$, $X_2$,...$X_{n-1}$, $X_n$ has a total of n independent variables, then the multiple linear regression mathematical formula of the dependent variable Y and X both is:

$$\mathrm{Y} = \alpha_0 + \alpha_1 \mathrm{X}_1 + \alpha_2 \mathrm{X}_2 + \alpha_3 \mathrm{X}_3 + \cdots + \alpha_{n-1} \mathrm{X}_{\mathrm{n}-1} + \alpha_n \mathrm{X}_{\mathrm{n}} \quad (1)$$

The $\alpha_0$ in the formula is a constant term, and $\alpha_1$, $\alpha_2$, $\alpha_3$...$\alpha_{n-1}$, $\alpha_n$ correspond to the regression coefficient values under different morphological element categories of the wheel.

### 3.3.2. Mathematical model of linear regression

In this study, the quantification-I theory is used as a guide, and the class of wheel hub morphological elements is set as the independent variable X and the Kansei word is set as the dependent variable Y. The multiple linear regression mathematical relationship equation is constructed by combining the research data as follows:

$$\begin{aligned}\mathrm{Y} = \alpha_0 &+ \alpha_{A1}\mathrm{X}_{\mathrm{A1}} + \alpha_{A2}\mathrm{X}_{\mathrm{A2}} + \alpha_{A3}\mathrm{X}_{\mathrm{A3}} + \alpha_{B1}\mathrm{X}_{\mathrm{B1}} + \alpha_{B2}\mathrm{X}_{\mathrm{B2}} + \alpha_{C1}\mathrm{X}_{\mathrm{C1}} + \alpha_{C2}\mathrm{X}_{\mathrm{C2}} + \alpha_{C3}\mathrm{X}_{\mathrm{C3}} + \alpha_{D1}\mathrm{X}_{\mathrm{D1}} + \alpha_{D2}\mathrm{X}_{\mathrm{D2}} \\ &+ \alpha_{E1}\mathrm{X}_{\mathrm{E1}} + \alpha_{E2}\mathrm{X}_{\mathrm{E2}} + \alpha_{E3}\mathrm{X}_{\mathrm{E3}} + \alpha_{F1}\mathrm{X}_{\mathrm{F1}} + \alpha_{F2}\mathrm{X}_{\mathrm{F2}} + \alpha_{F3}\mathrm{X}_{\mathrm{F3}} + \alpha_{F4}\mathrm{X}_{\mathrm{F4}}\end{aligned} \quad (2)$$

$X_A$, $X_B$, $X_C$, $X_D$, $X_E$, and $X_F$ in the formula represent the six morphological elements of the number of spokes, spoke and rim connection, inter-spoke connection, spoke unit style, spoke unit rotation, and spoke unit bifurcation type, respectively. Y in the formula denotes four different groups of Kansei words. The number of spokes in $X_{A1}$ corresponds to the A1 coded morphological element category, and A1 denotes the regression coefficient of the A1 category. Similarly, the way the spokes are connected to the rim in $X_{B1}$ corresponds to the B1 coded morphological element category, and B1 denotes the regression coefficient of the B1 category.

### 3.3.3. Performance evaluation criteria

Partial correlation coefficient $r$ and goodness of fit $R^2$ were used to evaluate prediction performance. The partial correlation coefficient aims to exclude the influence of other factors and simply reflects the closeness between a certain independent variable and the dependent variable. The $\alpha$ is calculated as follows,

$$r_{12,3} r_{12,3} = \frac{r_{12} - r_{13} r_{23}}{\sqrt{1 - r_{13}^2}\sqrt{1 - r_{23}^2}} \quad (3)$$

Multiple linear regression judgment analysis frequently uses the $R^2$ coefficient of determination and the estimated standard error value. $R^2$ commonly referred to as "goodness of fit", is a tool for determining how well a mathematical model's independent variables account for changes in the dependent variable and for gauging the size of the model's fit. The $R^2$ is calculated as follows, where $\hat{y}$ is the regression prediction and $\bar{y}$ is the mean of the experimentally.

$$\sum(y-\hat{y})^2=\sum y^2-(b_0\sum y+b_1\sum x_1 y+b_2\sum x_2 y+\cdots+b_k\sum x_k y) \tag{4}$$

$$\sum(y-\bar{y})^2=\sum y^2-\frac{1}{n}(\sum y)^2 \tag{5}$$

$$R^2=\frac{\sum(\hat{y}-\bar{y})^2}{\sum(y-\bar{y})^2}=1-\frac{\sum(y-\hat{y})^2}{\sum(y-\bar{y})^2} \tag{6}$$

Generally, a smaller *r* value (close to 0) and a larger $R^2$ value (close to 1) include that the generalization performance of the proposed model is better.

## 4. Results

### 4.1. Results of quantification-I scale

In this study, morphological analysis was used to yield six morphological element items and 17 wheel hub morphological element classes, which were then coded, as shown in **Table 7** collected sedan wheel hubs were coded to provide a representative sample. Following the coding table of the morphological components of wheel hubs, the multiple linear regression analysis is required to convert the qualitative data into quantitative data and finish the quantification. To create a quantitative one-class scale for the morphological components of wheel hubs, the assignment approach is to assign a value of 1 when the sample contains the morphological element class and 0 if it does not. This is illustrated in **Table 7**.

**Table 7.** Quantitative scale for wheel hub shape elements.

| Code | A1 | A2 | A3 | B1 | B2 | C1 | C2 | C3 | D1 | D2 | E1 | E2 | E3 | F1 | F2 | F3 | F4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 02 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| 03 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 04 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 05 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| 06 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| 07 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 08 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| 09 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| 10 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| 11 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 12 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 13 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 14 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 15 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 16 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 17 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 18 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 19 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 20 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |

### 4.2. Results of the regression analysis model

Based on the results of multiple linear regression, the data of matching associations between four groups of Kansei words and numerous morphological characteristics were obtained. The independent variables are morphological element items and classes, while the dependent variables are distinct sets of Kansei words. Each table corresponds to a different set of Kansei words, or the independent variable in the multiple linear regression. The correlation between the various design elements and Kansei words can be evaluated using the regression coefficient value, which indicates the SPSS study's scores for each category of morphological elements. According to the range of item coefficients, the range of morphological element items that have the greatest influence on the evaluation of this style is the one that is larger in the analytical context matching to the semantics of style. The constant value in the mathematical model of multiple linear regression is also referred to as the partial correlation coefficient *r*.

The "modern and traditional" multiple linear regression equations are as follows:

$$\begin{aligned} Y = &-0.185A1 - 0.034A2 + 0.103A3 - 0.196B1 + 0.08B2 - 0.001C1 - 0.195C2 + 0.08C3 + 0.057D1 - 0.195D2 \\ &- 0.444E1 - 0.187E2 + 0.516E3 - 0.327F1 - 0.262F2 - 0.155F3 + 0.628F4 - 0.116 \end{aligned} \quad (7)$$

**Table 8** shows the results of the multiple linear regression analysis for the "modern-traditional" Kansei words. The most "traditional" morphological elements are A3, B2, C3, D1, E3, and F4, while the most "modern" morphological elements are A1, B1, C2, D2, E1, and F1.

**Table 8.** Results of "modern–traditional" analysis.

| Project of morphological elements | Category of morphological elements | Code | Regression coefficient | Project coefficient range values |
|---|---|---|---|---|
| Number of spokes | Five spokes | A1 | –0.185 | 0.288 |
| | Five-spoke variants | A2 | –0.034 | |
| | More than five spokes | A3 | 0.103 | |
| Spoke and rim connection method | Overlap type | B1 | –0.196 | 0.276 |
| | Internal connection type | B2 | 0.08 | |
| Inter-spoke connection method | Pointed angle type | C1 | –0.001 | 0.275 |
| | Arc angle type | C2 | –0.195 | |
| | Folded line type | C3 | 0.08 | |
| Spoke unit style | Straight type | D1 | 0.057 | 0.116 |
| | Curved type | D2 | –0.059 | |
| Spoke unit rotation mode | Clockwise | E1 | –0.444 | 0.960 |
| | Counterclockwise | E2 | –0.187 | |
| | No rotation | E3 | 0.516 | |
| Spoke unit bifurcation type | V-shape | F1 | –0.327 | 0.955 |
| | Y-shape | F2 | –0.262 | |
| | Parallel bifurcation type | F3 | –0.155 | |
| | Non-bifurcated type | F4 | 0.628 | |
| Partial correlation coefficient *r* | | | –0.116 | |
| Goodness of fit $R^2$ | | | 0.951 | |

The "hard–soft" multiple linear regression equations are as follows:

$$Y = -0.293A1 + 0.097A2 + 0.202A3 + 0.05B1 - 0.044B2 - 0.004C1 + 0.189C2 - 0.178C3 - 0.134D1 + 0.14D2 - 0.003E1 + 0.166E2 - 0.157E3 - 0.078F1 - 0.37F2 + 0.225F3 + 0.23F4 + 0.006 \quad (8)$$

**Table 9** shows the results of the multiple linear regression analysis for the "hard–soft" Kansei words. The categories that best fit the "soft" morphological elements are A3, B1, C2, D2, E2, and F4, while the categories that best fit the "hard" morphological elements are A1, B2, C3, D1, E3, and F2.

**Table 9.** Results of "hard–soft" analysis.

| Project of morphological elements | Category of morphological elements | Code | Regression coefficient | Project coefficient range values |
|---|---|---|---|---|
| Number of spokes | Five Spokes | A1 | –0.293 | 0.495 |
| | Five-spoke variants | A2 | 0.097 | |
| | More than five spokes | A3 | 0.202 | |
| Spoke and rim connection method | Overlap type | B1 | 0.05 | 0.094 |
| | Internal connection type | B2 | –0.044 | |
| Inter-spoke connection method | Pointed angle type | C1 | –0.004 | 0.367 |
| | Arc angle type | C2 | 0.189 | |
| | Folded line type | C3 | –0.178 | |
| Spoke unit style | Straight type | D1 | –0.134 | 0.274 |
| | Curved type | D2 | 0.14 | |
| Spoke unit rotation mode | Clockwise | E1 | –0.003 | 0.323 |
| | Counterclockwise | E2 | 0.166 | |
| | No rotation | E3 | –0.157 | |
| Spoke unit bifurcation type | V-shape | F1 | –0.078 | 0.595 |
| | Y-shape | F2 | –0.37 | |
| | Parallel bifurcation type | F3 | 0.225 | |
| | Non-bifurcated type | F4 | 0.23 | |
| Partial correlation coefficient $r$ | | | 0.006 | |
| Goodness of fit $R^2$ | | | 0.83 | |

The "static–sporty" multiple linear regression equations are as follows:

$$Y = 0.012A1 + 0.021A2 - 0.072A3 + 0.091B1 - 0.129B2 + 0.003C1 + 0.209C2 - 0.251C3 - 0.393D1 + 0.355D2 + 0.139E1 + 0.223E2 - 0.4E3 - 0.094F1 + 0.101F2 - 0.131F3 + 0.085F4 - 0.038 \quad (9)$$

**Table 10** shows the results of the multiple linear regression analysis for the "static–sporty" Kansei words. The morphological elements that best fit the category of "sporty" are A2, B1, C2, D2, E2, and F2, while the morphological elements that best fit the category of "static" are A3, B2, C3, D1, E3, and F3.

The "luxury–simple" multiple linear regression equations are as follows:

$$Y = 0.608A1 - 0.388A2 - 0.402A3 - 0.215B1 + 0.033B2 - 0.191C1 - 0.269C2 + 0.278C3 + 0.284D1 - 0.103D2 - 0.291E1 - 0.437E2 + 0.546E3 + 0.43F1 - 0.74F2 + 0.272F3 - 0.143F4 - 0.182 \quad (10)$$

**Table 10.** Results of "static–sporty" analysis.

| **Project of morphological elements** | **Category of morphological elements** | **Code** | **Regression coefficient** | **Project coefficient range values** |
|---|---|---|---|---|
| Number of spokes | Five spokes | A1 | 0.012 | 0.093 |
| | Five-spoke variants | A2 | 0.021 | |
| | More than five spokes | A3 | –0.072 | |
| Spoke and rim connection method | Overlap type | B1 | 0.091 | 0.220 |
| | Internal connection type | B2 | –0.129 | |
| Inter-spoke connection method | Pointed angle type | C1 | 0.003 | 0.460 |
| | Arc angle type | C2 | 0.209 | |
| | Folded line type | C3 | –0.251 | |
| Spoke unit style | Straight type | D1 | –0.393 | 0.748 |
| | Curved type | D2 | 0.355 | |
| Spoke unit rotation mode | Clockwise | E1 | 0.139 | 0.623 |
| | Counterclockwise | E2 | 0.223 | |
| | No rotation | E3 | –0.4 | |
| Spoke unit bifurcation type | V-shape | F1 | –0.094 | 0.232 |
| | Y-shape | F2 | 0.101 | |
| | Parallel bifurcation type | F3 | –0.131 | |
| | Non-bifurcated type | F4 | 0.085 | |
| Partial correlation coefficient *r* | | | –0.038 | |
| Goodness of fit $R^2$ | | | 0.829 | |

**Table 11** shows the results of the multiple linear regression analysis for the "luxury–simple" Kansei words. The categories that best fit the "simple" morphological elements are A1, B2, C3, D1, E3, and F1, while the categories that best fit the "luxury" morphological elements are A3, B1, C2, D2, E2, and F2.

**Table 12** also shows the performance evaluation parameters of the multiple linear regression model. As can be seen, for the test sets, the $R^2$ values of the regression model are both higher than 0.7 and the *r*-value is low. The results can indicate that our regression model performs well.

**Table 11.** Results of "luxury–simple" analysis.

| **Project of morphological elements** | **Category of morphological elements** | **Code** | **Regression coefficient** | **Project coefficient range values** |
|---|---|---|---|---|
| Number of spokes | Five spokes | A1 | 0.608 | 1.010 |
| | Five-spoke variants | A2 | –0.388 | |
| | More than five spokes | A3 | –0.402 | |
| Spoke and rim connection method | Overlap type | B1 | –0.215 | 0.248 |
| | Internal connection type | B2 | 0.033 | |
| Inter-spoke connection method | Pointed angle type | C1 | –0.191 | 0.547 |
| | Arc angle type | C2 | –0.269 | |
| | Folded line type | C3 | 0.278 | |
| Spoke unit style | Straight type | D1 | 0.284 | 0.387 |
| | Curved type | D2 | –0.103 | |

**Table 11.** (*Continued*).

| Project of morphological elements | Category of morphological elements | Code | Regression coefficient | Project coefficient range values |
|---|---|---|---|---|
| Spoke unit rotation mode | Clockwise | E1 | –0.291 | 0.983 |
| | Counterclockwise | E2 | –0.437 | |
| | No rotation | E3 | 0.546 | |
| Spoke unit bifurcation type | V-shape | F1 | 0.43 | 1.170 |
| | Y-shape | F2 | –0.74 | |
| | Parallel bifurcation type | F3 | 0.272 | |
| | Non-bifurcated type | F4 | –0.143 | |
| Partial correlation coefficient *r* | | | –0.182 | |
| Goodness of fit $R^2$ | | | 0.884 | |

**Table 12.** The performances of the regression model.

| Kansei words group | Modern–Traditional | Hard–Soft | Static–Sporty | Luxury–Simple |
|---|---|---|---|---|
| Goodness of fit $R^2$ | 0.951 | 0.83 | 0.829 | 0.884 |
| Partial correlation coefficient *r* | –0.116 | 0.006 | –0.038 | –0.182 |

## 5. Discussion

In this study, we try to explore the matching relationship between wheel form elements and semantics of style by constructing a multiple regression model. To the best of our research knowledge, this study is the first to use multiple regression models to incorporate perceptual factors into rational thinking about parametric wheel design. The goodness of fit for the four groups of Kansei words ranged from 0.8 to 1, which indicated that the regression model was very reliable. The results show that our multiple regression model performs well. This provides guidance for perceptual research on parametric design, which suggests that it is possible to pair parametric design morphological elements with user emotions. In future work, the predictive model obtained from regression analysis is used to develop a wheel configuration system for parametric design of sedans. The metaverse provides a virtual, digital world in which the user is allowed to interact and adjust in real time, based on which the system is able to meet the different stylistic semantics of switching and dynamic manipulation of wheel configurations for sedans, observing changes in the design, and thus allowing for more flexible creative exploration, with intuitive, efficient, and cost-saving advantages.

Kansei Engineering establishes a suitable framework for working with symbolic attributes and user perceptions, expressed in their own words. Other techniques based on product development on user preferences for functional aspects considered in terms defined by experts. It also establishes a framework for quantifying the relationships between design characteristics and emotional responses [34,35]. Chongqing University of Technology [36] proposed a semantic difference method based on perceptual engineering and combined with eye-tracking technology to analyze the relationship between the stylized imagery and stylized features of the wheel before, but the study mainly focused on the user's visual perception cognition and did not take into account the user's emotional needs. Llinares proposed the use of Kano's models in Kansei engineering to analyze the influence of different subjective attributes on consumer purchase decisions, and regression analysis and Kano's models were used to determine the relative weights of different affective attributes in purchase decisions [37].

The limitations of the current study include the fact that the samples in the experiment were selected to be de-colored, so the influence of factors such as material and color in the product form on the user's semantic evaluation was not considered, and the factors such as material and color can be studied in depth in subsequent studies. Secondly, the choice of factors and the expression of the factors in the regression analysis are only speculative, which affects the diversity of power consumption factors and the unpredictability of some factors, making the regression analysis limited in some cases. In future research, GEP can be developed to combine other design features (such as material, color, and texture) as influencing factors with parametric design.

## 6. Conclusions

The goal of this study was to create a regression analysis model to examine how the morphological elements and the semantics of the style of sedan wheel hub design line up. Regression analysis revealed an accurate model of the matching relationship, which was reassuring given the experimental results. Further research on practical use will be carried out in our future work.

**Author contributions:** Conceptualization, YC; methodology, YC; software, RH; investigation, QP; resources, JS; data curation, RH; writing—original draft preparation, QP; writing—review and editing, YC; visualization, QP; supervision, JS; project administration, YC; funding acquisition, YC. All authors have read and agreed to the published version of the manuscript.

**Funding:** This study was partly supported by the National Natural Science Foundation of China (No. 51905175), the second Batch of 2022 MOE of PRC Industry-University Collaborative Education Program (No. 220701710291027), the Shanghai Soft Science Key Project (No. 23692104700) and Xie Youbai Design Science Research Foudation (No. XYB-DS-202301).

**Conflict of interest:** The author declares no conflict of interest.

## References

1. Ou C, Wang M. Research on the application of parametric design based on sedan styling design. Automobile Design. 2016, 16: 96–97.
2. Liu S. Research and Application on Product Identification of Household Bread-Making Machine [Master's thesis]. Qilu University of Technology; 2021.
3. Zhu Y, Tang W. Modeling design of waterjet machine tool based on Kansei Engineering. In: Lecture Notes in Networks and Systems, Proceedings of AHFE 2021 Virtual Conferences on Design for Inclusion, Affective and Pleasurable Design, Interdisciplinary Practice in Industrial Design, Kansei Engineering, and Human Factors for Apparel and Textile Engineering; 25–29 July 2021; Online conference. Springer; 2021. pp. 1064–1071. doi: 10.1007/978-3-030-80829-7_130
4. Feng Y. From scripting the future to fabricating the future. Times Architecture. 2012, 5: 10–21.
5. Anton I, Tănase D. Informed geometries. Parametric modelling and energy analysis in early stages of design. Energy Procedia. 2016, 85: 9–16. doi: 10.1016/j.egypro.2015.12.269
6. El-Dabaa R, Abdelmohsen S. A methodology for evaluating the hygroscopic behavior of wood in adaptive building skins using motion grammar. IOP Conference Series: Materials Science and Engineering. 2018, 362: 012011. doi: 10.1088/1757-899x/362/1/012011

7. Oxman R. Thinking difference: Theories and models of parametric design thinking. Design Studies. 2017, 52: 4–39. doi: 10.1016/j.destud.2017.06.001
8. Suyoto W, Indraprastha A, Purbo HW. Parametric approach as a tool for decision-making in planning and design process. Case study: Office tower in Kebayoran Lama. Procedia—Social and Behavioral Sciences. 2015, 184: 328–337. doi: 10.1016/j.sbspro.2015.05.098
9. Lim D, Georgiou T, Bhardwaj A, et al. Customization of a 3D printed prosthetic finger using parametric modeling. In: Proceedings of International Design Engineering Technical Conferences and Computers and Information in Engineering Conference; 26–29 August 2018; Quebec City, Quebec, Canada. doi: 10.1115/DETC2018-85645
10. Luo S.J., Fu Y.T., Korvenmaa P. A preliminary study of perceptual matching for the evaluation of beverage bottle design. International Journal of Industrial Ergonomics. 2012, 42(2): 219–232. doi: 10.1016/j.ergon.2012.01.007
11. Nagamachi M. Kansei engineering as a powerful consumer-oriented technology for product development. Applied Ergonomics. 2002, 33(3): 289–294. doi: 10.1016/s0003-6870(02)00019-4
12. Nagamachi M. Kansei Engineering: A new ergonomic consumer-oriented technology for product development. International Journal of Industrial Ergonomics. 1995, 15(1): 3–11. doi: 10.1016/0169-8141(94)00052-5
13. Giannini F, Monti M, Podehl G. Styling properties and features in computer aided industrial design. Computer-Aided Design and Applications. 2004, 1(1–4): 321–330. doi: 10.1080/16864360.2004.10738273
14. Ostrosi E, Bluntzer JB, Zhang Z, et al. Car style-holon recognition in computer-aided design. Journal of Computational Design and Engineering. 2019, 6(4): 719–738. doi: 10.1016/j.jcde.2018.10.005
15. Hyun KH, Lee JH, Kim M, et al. Style synthesis and analysis of car designs for style quantification based on product appearance similarities. Advanced Engineering Informatics. 2015, 29(3): 483–494. doi: 10.1016/j.aei.2015.04.001
16. Osgood CE, Suci GJ, Tannenbaum PH. The Measurement of Meaning. University of Illinois Press; 1957.
17. Chou JR. A Kansei evaluation approach based on the technique of computing with words. Advanced Engineering Informatics. 2016, 30(1): 1–15. doi: 10.1016/j.aei.2015.11.001
18. Razza B, Paschoarelli LC. Affective perception of disposable razors: A Kansei Engineering approach. Procedia Manufacturing. 2015, 3: 6228–6236. doi: 10.1016/j.promfg.2015.07.750
19. Zhao Q, Wang Z, Fan B. An introduction of Kansei Engineering and it's research status in Japan. Art and Design. 2007, 4: 32–34.
20. Samsonovic AV, Ascoli GA. Principal semantic components of language and the measurement of meaning. PLoS One. 2010, 5(6): e10921. doi: 10.1371/journal.pone.0010921
21. Myllyntaus O. Visual arts education reasoning the acquisition and placement of public sculptures—Case of the public sculptures of the Jyväskylä City Art Collection in 1977–2007. Procedia—Social and Behavioral Sciences. 2012, 45: 605–614. doi: 10.1016/j.sbspro.2012.06.
22. Bi Y, Wang N, Zhe Y. Form design of accompany robot for the elderly based on Kansei Engineering. Packaging Engineering. 2018, 39(2): 160–165.
23. Nui Z, He S. Research on design of Lunchbox CMF based on semantic difference method. Design. 2017, 15: 104–105.
24. Hu X, Li D, Hu X. Office warm treasure design based on harmonious situation and semantic difference method. Packaging Engineering. 2019, 40(20): 130–136.
25. Dunia R, Joe Qin S. Joint diagnosis of process and sensor faults using principal component analysis. Control Engineering Practice. 1998, 6(4): 457–469. doi: 10.1016/s0967-0661(98)00027-6
26. Chen HS, Li Y, Song W. The application of traditional artifacts design evaluation based on glamour engineering. Packaging Engineering. 2021, 42(08): 303–313.
27. Wang XT, Wang C, Wang HH. Modeling design of electric scooter for the elderly based on the theory of quantification-1 type. Machinery Design & Manufacture. 2020, 7: 165–169.
28. Yu N, Zhang C, Du Y, Wang H. Furniture modeling image design based on quantitative theory. Packaging Engineering. 2018, 39(22): 183–188.
29. Wang J, Yannou B, Alizon F, et al. A usage coverage-based approach for assessing product family design. Engineering with Computers. 2012, 29(4): 449–465. doi: 10.1007/s00366-012-0262-1
30. Wang J, Lu G, Zhang Y. Quantification-I theory based IGA and its application. Journal of Zhejiang University (Engineering Science). 2013, 47(10): 1697–1704. doi: 10.3785/j.issn.1008-973X.2013.10.001
31. Wei Y. The design of electric drill based on Kansei Engineering. Packaging Engineering. 2016, 37(24): 108–113.
32. Likert R. A technique for the measurement of attitudes. Archives of Psychology. 1932, 22(140): 55–59.
33. Gan Y, Jj Y, Shi Y, Liu X. Method and application of user Kansei perception and product Kansei design. Packaging Engineering. 2021, 42(2): 22–34.
34. Nagamachi M. Kansei Engineering. Kaibundo Publishing Co. Ltd.; 1989.
35. Aktar Demirtas E, Anagun AS, Koksal G. Determination of optimal product styles by ordinal logistic regression versus conjoint analysis for kitchen faucets. International Journal of Industrial Ergonomics. 2009, 39(5): 866–875. doi: 10.1016/j.ergon.2009.06.007
36. Cheng Z, Ren X, Ke S, Qin Y. Parametric design of car wheel hub based on Kansei image. Journal of Machine Design. 2022, 39(4): 135–141.
37. Llinares C, Page AF. Kano's model in Kansei Engineering to evaluate subjective real estate consumer preferences. International Journal of Industrial Ergonomics. 2011, 41(3): 233–246. doi: 10.1016/j.ergon.2011.01.011