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# Using Kansei Engineering for the Design Thinking Framework: Bamboo Pen Holder Product Design

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**Abstract:** Recently, as a potential source of stationery products, bamboo has been continuously excavated for its commercial value in sustainable development. The research on the design of the bamboo pen holder, based on the concept of sustainable design, is not only a symbol of Chinese culture but also a reflection of perceptual factors underlying college students' preferences. This study aims at user-centered product design by integrating Design Thinking (DT) and Kansei Engineering (KE). We proposed the KE–DT framework which allows designers to coordinate the user's feelings as design elements. With various college student questionnaires, expert interviews, and cluster analysis, 7 Kansei words were selected to describe the sentimental value first. Using statistical analysis, the users' emotional preference for each Kansei word was determined. Finally, the best shape of the pen holder was obtained by Sequential Quadratic Programming (SQP), and the stereoscopic product was displayed. A new round of questionnaire surveys was conducted with the optimized pen container and the previous group. The results indicated that curvature had a significant effect on the preference for bamboo stationery in terms of user and designer cognitive differences. Furthermore, the bamboo pen holder designed by the KE–DT framework proved widely popular.

**Keywords:** product design; design thinking; kansei engineering; bamboo pen holder; shape optimization

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## 1. Introduction

During recent decades, the variety and productivity of stationery products have changed on a never-before-seen scale. According to TechNavio, consumer stationery retailing will accelerate at a CAGR (Compound Annual Growth Rate, GAGR) of 2.57% in the period from 2021 to 2025. In the post-COVID-19 era, retailers have begun to adopt omnichannel retail strategies, e.g., traditional retail outlets and online retail platforms to distribute consumer stationery products. This shows that there is a potential market demand for the bamboo pen holder. Besides, as a natural resource, not only has bamboo been repeatedly proven as a recyclable and environmentally friendly material [1] but it also has a special cultural significance in China. Hence, bamboo has gradually been used in product design in recent years. Moreover, it has sustainable commercial and market value [2]. However, there is a perceptual divide between the design of the product and the needs of consumers in regard to current consumption [3]. College students, as the main consumer group of stationery, are less likely to purchase bamboo pen holders nowadays. One reason that accounts for this may be that the users used to care more about the function than the appearance while using stationery. However, the market demand for stationery is growing in recent years. After the functions of the product meet the demands of consumers, aesthetic appearance is another selling point. Hence, how to improve the aesthetics of stationery is worth discussing. Incorporating the emotional value of users into the design process not only enables users to become 'co-creators' but also enables designers to better understand user needs.

Therefore, it is necessary to propose a new KE–DT framework that is not only beneficial to the upgrading of the traditional pen holder industry but also has great significance for optimizing the product design process. By optimizing the shape of the bamboo pen holder and understanding the multiple emotional needs of college students, this study can promote communication between designers and users, and enhance the design innovation of bamboo products. Using this method, college students will start to pay attention to the pen holder made of bamboo, thereby enhancing the purchase desire of the university student group for the bamboo pen holder.

On the one hand, KE [4], proposed by Nagamachi, is an effective way for designers to understand user demand. It can be applied to effective design methods in various product fields (see Table 1) such as cars [5,6], sofas [7], ceramics [8], basketball shoes [9], vehicle-mounted UAVs [10], and shared bicycles [11], etc. In previous studies, KE can transform the user's emotional needs into effective elements of product design through the Kano model [12], visual stimulus materials [13], deep learning [14], text mining [15], data mining [16], or product-integrated decision systems [17]. In terms of educational areas, KE is powerful in the area of catching students' feelings, images, and requirements for existing educational products, e.g., electronic devices [18,19], e-learning [20], and furniture [21], etc. On the other hand, DT [22] can help designers effectively solve complex problems and create design solutions. In previous research, DT has contributed in helping designers solve product optimization problems such as small enterprises' business profits [23] and new product development capabilities [24]. The DT was also used in other areas, such as the promotion of stakeholders' engagement [25], the path of student engagement [26], and the narrow gap between novice and expert in the education system [27]. KE and DT focus on user perception in product design from the perspective of users and designers, respectively, and then translates it into design elements. Nevertheless, the perceptual gap between designers and users has not been effectively addressed. The KE–DT framework proposed in this study can help to systematically solve the potential perception gap in the process of product design and establish cognitive empathy between designers and users in product design.

In traditional KE, although the user's perceived value could be discovered, designers pay more attention to their subjective aesthetic tendencies when designing the shape of the bamboo pen holder. Once the design does not conform to the popular aesthetic, the designer needs to improve it again. This shows that the designer's favorite product may not necessarily be the consumer's favorite one. In general, designers need to seek a method to effectively perceive the sensory demands of the youth and increase purchase rates. Due to the abovementioned issues, in this study, we aimed to bridge the gap between the designers and youth through a KE–DT framework. First, we determined the Kansei word sets according to the interview with experts and online comments. To obtain the representative word, these Kansei words were grouped into several groups using the Euclidean distance. After cluster analysis, we selected 7 representative words. Among these words, we are groundbreaking in choosing desire of purchase to be a key Kansei word. After the questionnaire survey, the correlations between the desire to purchase and the other Kansei words are computed to determine the most important Kansei word. Moreover, we also determined the representative products of each Kansei word according to the survey's results. However, after getting the evaluation of the product, the designers would sketch the product scheme which requires strong drawing ability and workload. When the designers redesigned the products according to the evaluation of the users, it was still difficult to avoid the effect of their subjective aesthetic. The emergence of the KE–DT framework based on computer-aided design simplifies the tasks. In this paper, SQP was utilized to optimize the shape of the bamboo pen holder. This study provides a quantitative method and a design concept to match visual perception between users and designers. The optimized product shape can be automatically generated. The bamboo pen holder design not only reflects the sustainable development of the material but using the

proposed method can also greatly reduce manpower and material resources. Hence, the main contribution lies in:

(1) A focus on the positive and cultural interactions between college students and environmentally friendly educational tools, which can help increase consumer preference for sustainable products.
(2) The KE–DT framework proposed in this study is an extension of the existing KE and DT product design methods. With the KE–DT framework, the cognitive gap between users and designers is narrowed. This helps to deal with more complex technical issues in technical product design or sustainable product design.
(3) The presentation of a KE–DT framework that could promote purchasing desire for environmentally friendly products and an optimization of the design process. Promoting the purchase of bamboo-based stationery products is conducive to the development of a sustainable design.
(4) An automated method for generating stationery shapes in the KE–DT framework, and, after obtaining the questionnaire, the shapes of products such as bamboo pen holders can be automatically optimized. This can significantly shorten the design cycle and reduce the waste of resources.

This study is structured as follows: (a) emotional preferences of bamboo pen holder products, (b) experimental elements and design, (c) construction and analysis (e.g., representative experimental KE images selection), (d) optimization and validation, and (e) conclusion.

**Table 1.** Survey of products of KE.

| Author, Year, and Reference | Products | Methods and Summary |
| --- | --- | --- |
| Hsiao et al. (2017) [28] | Hotel Service | - KE and Online Review Mining<br>- Investigated the customer feelings on the hotel service through KE and text mining |
| Yuhazri et al. (2018) [6] | Car | - KE and Bezier cubic equation<br>- Investigated customer Kansei for automotive design and investigate customer satisfaction |
| Kittidecha (2018) [8] | Thai Ceramic | - KE and Data Mining<br>- A model is proposed to analyze the factors that influence customers to choose Thai porcelain through WEKA software |
| Green (2018) [9] | Basketball shoes | - KE and Product Design<br>- Research on visual elements such as color and style that influence customer purchases of basketball shoes |
| Wang et al. (2020) [11] | Shared Bicycle Service System | - KE and Product Service System<br>- Established the perceived image space of the shared bicycle product service system through questionnaires and KE |
| Oey et al. (2022) [7] | Sofa | - KE and New Sofa Model<br>- Investigated emotional factors influencing sustainable product design elements |
| Yang et al. (2022) [10] | Vehicle-mounted UAV | - KE, Support Vector Regression, and Kano Model<br>- A model is proposed to analyze the prioritization of UAV modeling design elements and obtain user emotional imagery |

## 2. Theoretical Background

### *2.1. Kansei Engineering*

KE can transform user feelings into parametric design elements to serve user-centered product design [29]. The purpose of KE is to evaluate users' systematic impressions of Kansei's understanding of a certain class of product attributes [30]. In recent years, KE has gradually been widely used in various product fields to support designers' innovation in product design. KE can obtain reliable quantitative data more effectively by collecting the KE vocabulary of the research object and analyzing the questionnaire. Therefore, KE has a high utilization rate and reliability in product design. In the process of design practice application, KE enables designers to iterate the design elements of products in the design process through investigation and research on consumers. This enables designers and manufacturers to produce products that better match consumers' experiences, thereby enhancing the market competitiveness of products.

### *2.2. Design Thinking*

DT is an approach to solving design problems through a collaborative, systematic approach [31]. Using a DT method can synthesize subjective and objective factors such as prototype, design, and emotion of product design, which is important for revealing the rational construction process of DT. Participating in the product development process and understanding the emotional needs of users in a timely manner is an effective way to stimulate designers' design insights. The DT method enables designers to directly obtain user feedback on the product from the experimental process [32] which helps designers to redesign and rethink design elements during the design process. In the DT method, the combination of a designers' subjective feelings about their own creativity and a users' subjective needs is a way of thinking to promote the effective iteration of products.

## 3. Emotional Preferences of the Bamboo Stationery Product

### *3.1. Bamboo Stationery Product*

As an environmentally friendly material, the bamboo product not merely has a better curvature than the wooden product but bamboo fibers are biodegradable [33] as well. The bamboo item has developed as an outstandingly profitable and predominant substitute for the wood item in recent years. This is the positive path for the saving and restoration of forest resources. Bamboo stationery, such as the bamboo pen holder, was briefly appreciated in 18th century China [34]. The bamboo pen holder was admired by the Chinese literati in the 18th century, so it has educational significance as well as aesthetic value. Bamboo has a wide range of uses in countries rich in bamboo resources. This is also conducive to the development of its green design. A green design product is conducive to the protection of the environment [35], the promotion of green marketing [36], and enhances students' quality of life [37], etc. Ref. [38] have noticed the importance and educational significance of the bamboo pen holder. Our study will further discover the design innovation and emotional value of the bamboo pen holder. Although the design of the bamboo product is a vital component of green design nowadays, the quality of the bamboo pen holder design varies widely. Currently, the shape design of the bamboo pen holder is not enough to provide tailored answers to changing consumer demand. Therefore, the eagerness to analyze the user's emotional tendencies in bamboo pen holder products has created a demand for a definite design method and knowledge about new design frameworks.

To analyze the affective need and tendency regarding bamboo stationery as a pen holder product, this study aims to use the combined insight to discover the potential of bamboo stationery. This is a method for the consumer to focus more on the pleasurable rather than the functional aspects of the product. In previous research there exists a lot of praise for the effective use and practical application of bamboo [39]. However, bamboo products in the market are still at the Original Equipment Manufacturer (OEM) stage [40] instead of the Own Branding and Manufacturing (OBM) stage. Therefore, product innovation contains human factors that gradually replace the scrutiny that is placed merely

on technology or functionality. Moreover, the education factor is a key driver for the market growth of stationery products such as pens, notebooks, and pen holders. When we studied the college student as a consumer, the perceived quality and service quality of education provided explained the varying degrees of satisfaction differences. Therefore, the perception of college students influences the design of bamboo stationery.

### *3.2. Emotional Preferences*

With the continuous development of society, college students' consumption demands are positively correlated with their emotional values. Education-related products have shown a trend of marketization [41]. Moreover, student spending is strongly linked to educational products as well as the educational environment [42]. In terms of educational products, the literature [43] suggested that college students deserve to be seen as 'co-producers' rather than single 'consumers' of educational products. The trend of students' emotional value is a valuable bridge for the KE–DT framework of stationery products. The bamboo stationery product belongs to cultural tools and its advancement and design ought to focus on two points: shape optimization and user emotional impression. Generally, the users' perceptual evaluation of the products can be transformed by extracting Kansei images related to the products. Ref. [44] argues that the degree of attractiveness of the product is related to the perceptual value of the user. Perception of the product affects the consideration of filtering costs in the market [45]. Therefore, the optimization of the bamboo pen holder can not only optimize the design process of stationery products but also facilitate the development of its sustainable design.

According to [46], perception consists of three components: a subjective experience, an emotional response, and a behavioral or expressive response based on the person's complex psychological condition. The importance of students' emotional preferences has been demonstrated in previous research, such as the emotional value of students in the arts [47], associations between student personalities and job preferences [48], and students' use of affective terms to describe the factors influencing feedback [49], etc. Particular attention to the emotions of specific user groups is conducive to creating products with emotional links from designers. This is not only considered as a way to alleviate the cognitive problem between users and designers but also a manifestation of the combination of emotion and design. Therefore, the emotional preferences of users are the driving force for designers to innovate [50]. The individual's effect is the external manifestation of the psychological state of their subjective needs. In order to focus on the connection with the product, the KE method is defined as the product development method best suited to transfer the users' emotional value and expression into the specific design elements. The present study proposed the KE–DT framework, integrating the KE method into the DT process (Figure 1). In the field of stationery design, evaluating users' perceptual preferences is an effective way to establish a long-term relationship between consumers and bamboo pen holder products. The perceptual aspect such as sensory characteristics [51] requires a lot of publicity by designers.

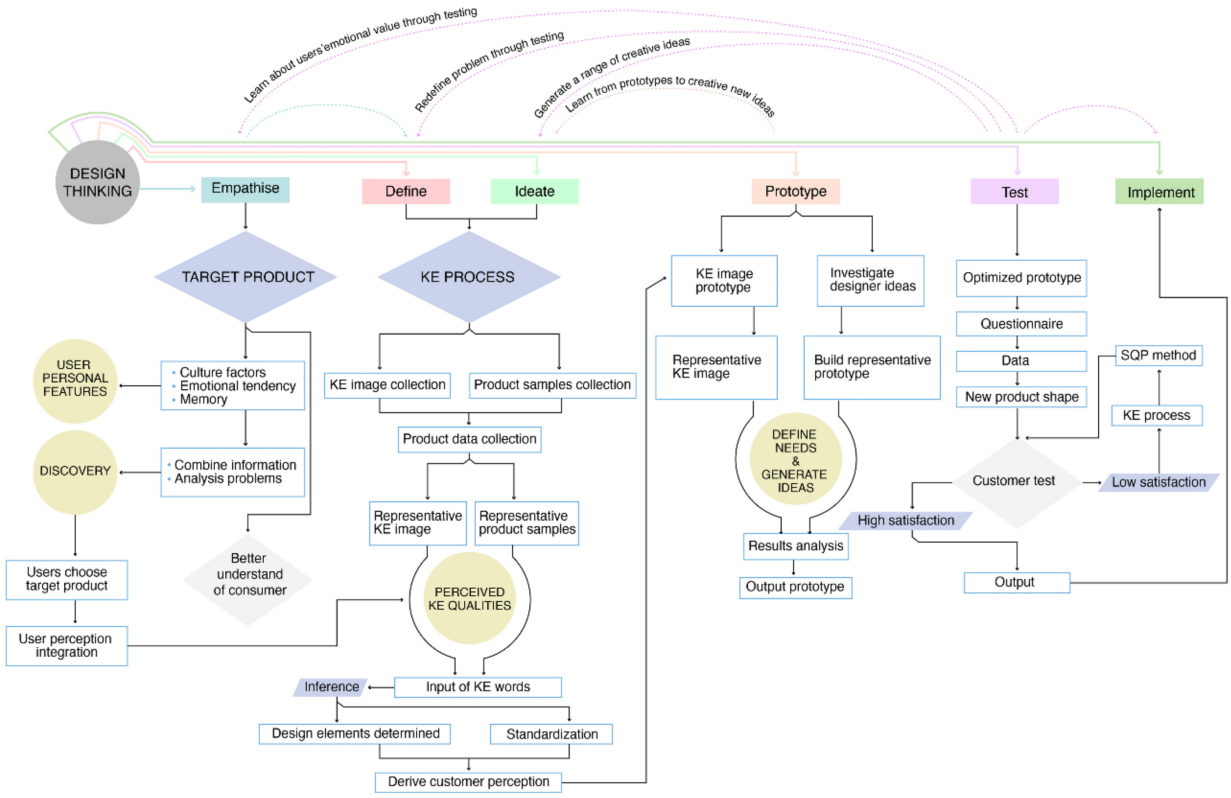



**Figure 1.** The KE–DT framework for the product design process.

## 4. Experimental Elements and Design

### *4.1. Participants*

The participants included designers and consumers. Six universities were involved in this experiment. A total of 37 university students (19 female) volunteered for this experiment as potential users of the target product. Their average age was 25.47 years old (SD = 3.72 years old), extending from 19 to 31 years old. Among the college students, 16 had used bamboo pen holders, 11 had used pen holders made from other materials, and 10 had not used pen holders. We then selected 6 designers (3 females) as participants in the design thinking perspective. They were between the ages of 24 and 36 years old. All participants had university study experience.

As mentioned earlier, the educational factor has become an important factor in the development of the stationery market. There is a positive correlation between students' emotions and stationery. In [52], poverty-stricken students will suffer a double impact in terms of emotions and study due to lack of stationery. Designing stationery products for students' needs ought to capture their psychological needs and transmit positive visual signals [53]. Therefore, university students were selected as the participants. None of the students possessed professional design expertise.

Besides, as a bridge between products and users, designers are obliged to use creative thinking skills to understand the real perceptual needs of users, rather than focusing only on aesthetic values [54]. However, designers are often caught in an empirical loop in the design process. Utilizing the single design mindset will limit the path for designers to identify solutions to a certain extent [55]. Thus, it is necessary to include designers in the experiment. When we find differences between the designer and the user in this process, we can handle the problem early in the design process and optimize the product via the KE–DT framework.

### *4.2. Selection of Typical Samples*

For this study, various types of bamboo pen holder products have been chosen from Amazon (https://www.amazon.com/; accessed on 6 March 2022) and Alibaba (https://world.taobao.com/; accessed on 6 March 2022), which are the largest shopping platforms. Since the current types of bamboo pen holders are relatively generic, we also added bamboo-carved pen holders from 17th to 18th century China into the experiment. Bamboo pen holders were the favorite products of the Chinese literati in that period and their designs and shapes are exquisite. As [56] recorded, the bamboo-carved pen holder was regarded as a significant tool of the Chinese study room. Even bamboo stationery in the 18th century has produced specialized bamboo stationery design genres [57] such as the Jinling genre and the Jiading genre, etc. Therefore, bamboo stationery contains both design and marketing significance. So, the selection of typical samples in this study includes the bamboo pen holder of the 18th century in China and the bamboo pen holder in the big data screening. Then, to avoid the pattern or other factors influencing the emotional preferences of participants, this study selected representative product shapes as the samples excluding factors such as patterns. Seventy-eight bamboo stationeries were selected and then the bamboo pen holder representatives with the smallest differences or homologous series of appearance were deleted. Therefore, we selected 66 distinct bamboo pen holder shapes as typical samples.

## 5. Methodology and Analysis

### *5.1. Determination of the Representative Kansei Words*

To set up the Kansei words toward the bamboo pen holder product, we obtained the 45 perceptual words in the KE images of the target stationery products by combining 8 expert interviews and 89 online evaluations. After that, we conducted a semantic similarity survey and analyzed it with 45 Kansei words. A similarity matrix was used for cluster analysis as follows:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1l} \\ \vdots & \ddots & \vdots \\ a_{l1} & \cdots & a_{ll} \end{bmatrix} \quad (1)$$

where $a_{ll}$ is the similarity evaluation value. This study used the multi-dimensional scaling method and two-dimensional Euclidean distance model to obtain the Euclidean distance of the 45 most commonly used Kansei word pairs as shown in Figure 2.

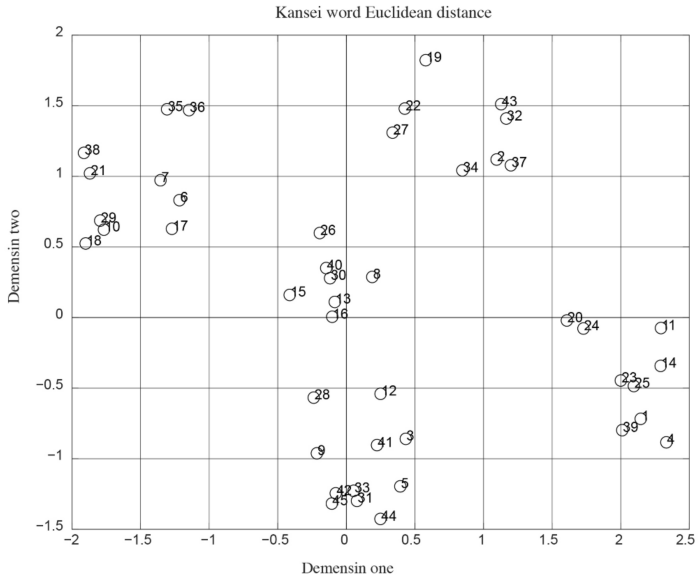



**Figure 2.** Grouping of five groups of KE words.

In Figure 2, the 45 Kansei words are classified into 5 groups. Then, to construct the KE image set by Euclidean distances, the 7 most representative Kansei word pairs are selected in Table 2. Some codes are shown as follows:

```
# Euclidean distance
def get_distance (X,Y):
        return np.sum((X − Y)^2)^0.5
def calc_mean (X):
        l = len(X[0])
        list_mean = []
        for i in range (l):
            s = 0
            for j in X:
                s+=j[i]
             m = s/len(X)
            list_mean.append (m)
        return list_mean
def k_means(x_train,k,max_iter):
        num_iter = 0
        # Initial cluster center
        cluster_center = x_train[:k]
        pre_cluster_center = copy.deep_copy(cluster_center) # Last cluster center point
        # Starting iteration
        while num_iter < max_iter:
            clusters_data = {}
             for i in x_train:
                cluster_dists = []
                 for index,cluster in enumerate(cluster_center):
                    distance = get_distance(i,cluster)
                        cluster_dists.append((index,distance))
                cluster_dists.sort(key = lambda x:x[1])
                 min_index,min_dist = cluster_dists[0]
                if min_index not in clusters_data:
                    clusters_data[min_index] = []
                clusters_data[min_index].append(i)
            # Update the cluster center point
            for index in clusters_data:
                cluster_center[index] = calc_mean(clusters_data[index])
            if pre_cluster_center == cluster_center:
                break
            else:
                pre_cluster_center = copy.deep_copy(cluster_center)
return cluster_center
```

**Table 2.** The representative KE word pairs.

| Number | Representative KE Word Pair |
|---|---|
| 1 | Fashionable—ancient |
| 2 | Rounded—upright |
| 3 | Concise—complex |
| 4 | Rough—exquisite |
| 5 | Noble—vulgar |
| 6 | Unique—ordinary |
| 7 | Desired—undesired |

A questionnaire survey method was conducted to ascertain whether the pen holder form influences the view of university students regarding the seven identified attractiveness factors of bamboo pen holders. According to [58], the questionnaire is a more suitable method to evaluate the emotion component than other self-report methods. Solutions

related to Kansei words were scored via a seven-point Likert scale. Specifically, each Kansei word pair is given a score axis (−3, −2, −1, 0, 1, 2, 3). The higher the number evaluated by the target group, the higher the recognition of the Kansei word of this KE image. Next, a KE questionnaire about 66 KE images of bamboo pen holder samples was established in this study. Herein, the Kansei image evaluation is constructed as follows:

$$R^{\varphi} = \begin{bmatrix} r_{11}^{\varphi} & r_{12}^{\varphi} & \cdots & r_{1j}^{\varphi} \\ r_{21}^{\varphi} & r_{22}^{\varphi} & \cdots & r_{2j}^{\varphi} \\ \vdots & \vdots & r_{xy}^{\varphi} & \vdots \\ r_{i1}^{\varphi} & r_{i2}^{\varphi} & \cdots & r_{ij}^{\varphi} \end{bmatrix} \quad (2)$$

where $R^{\varphi}$ is the Kansei image recognition evaluation matrix. $\varphi$ is used to distinguish between users and designers, and $\varphi = 1$ and =2 denote users and designers, respectively. $r_{ij}^{\varphi}$ represents the evaluation value of the φ-th design subject on the *j*-th Kansei image of the *i*-th sample. In this way, the questionnaire information could be recorded and detailed.

### *5.2. Gathering Data and KE Image*

The design elements that were selected for the experiment were the aforementioned curved shape bamboo pen holders. We abstracted the outlines of 66 typical samples as KE images (see Figure 3) to control the variables. Based on the material advantages of bamboo, its curvature has a relatively proper performance, which can produce more beautiful curve changes. Therefore, this study only conducts experiments on the shape, excluding the factors of pattern, combination form, and material. We also informed respondents of this standard in our subsequent screening process and questionnaire survey.

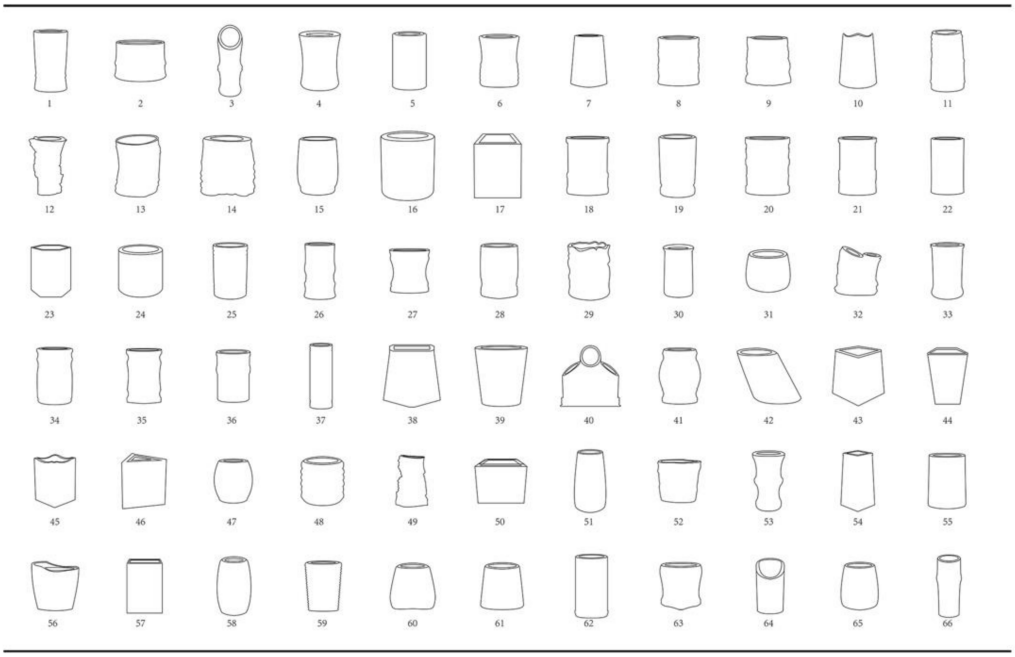


**Figure 3.** The typical KE images.

As mentioned above, 37 university students and 6 designers were asked to take the questionnaire and give their scores based on their own emotional experiences. All the valid scores we collected were clustered in Matlab.

Next, to select a representative KE image for each perceptual imagery, this study averagely compared 6 Kansei word pairs, except for the Kansei word pairs "Desired—undesired". Intuitively, the characteristics people most care about would significantly influence purchase intention. Hence, to determine the most interested Kansei word pair of

users and designers, we made a correlation comparison between each Kansei word and purchase intention. The Partial Correlation Coefficient (PCC) of the design elements was used to calculate the relationship between the shape elements of the bamboo pen holder and the product image. PCC is a measurement mode [59] of the correlation coefficient on a scale without units, which goes from −1 to +1. If the sign of the correlation coefficient of the tested object is positive, it is a positive correlation. The scoring trends of respondents are deemed to be vectors in the PCC. Then, the correlation between the scoring trends is obtained according to the PCC. We normalized the data first and then computed the PCC. The PCC is defined as the quotient of covariance and standard deviation between purchase intention and other Kansei words:

$$\rho_{X,Y} = \frac{\sum_{i=1}^{n} (X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{n} (X_i - \overline{X})^2} \sqrt{\sum_{i=1}^{n} (Y_i - \overline{Y})^2}} \quad (3)$$

where $X_i$ and $Y_i$ are the evaluation values of the purchase intention and other Kansei words, respectively. $\overline{X}$ and $\overline{Y}$ average values of the purchase intention and other Kansei words, respectively. Note that, all of the data contains the evaluation of students and designers. In this study, it is interesting to note that the Kansei word pair of "Noble-vulgar" had the highest correlation with the purchase intention, that is, users care about "Noble-vulgar" the most, as shown in Table 3. Similarly, the designers preferred "Noble-vulgar" the most with a score of 0.7817. According to the PCC, it has been concluded that the "Noble-vulgar" Kansei word is the factor that most affects the user's evaluation of the bamboo pen holder.

**Table 3.** The PCC of respondents' scoring.

| KE Word | User | Designer |
|---|---|---|
| Fashionable—ancient | 0.7909 | 0.7416 |
| Rounded—upright | 0.6936 | 0.5530 |
| Concise—complex | 0.6380 | 0.4825 |
| Rough—exquisite | 0.7825 | 0.7514 |
| Noble—vulgar | 0.8863 | 0.7817 |
| Unique—ordinary | 0.7544 | 0.6859 |

### *5.3. Result*

After the average score calculation, the KE image with the highest score corresponding to the word is Number 38. As shown in Figure 4, the KE images 45, 4, 1, 64, 38, and 25 are the most representative KE images of the 6 Kansei words, respectively.

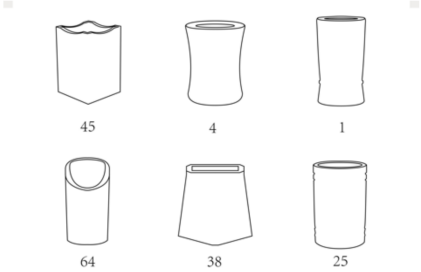


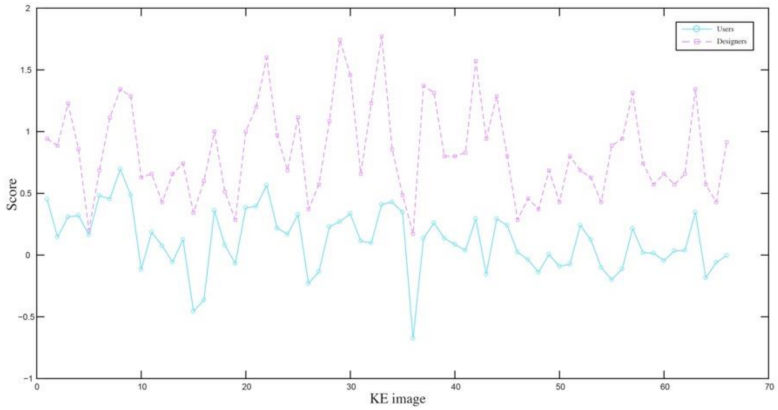

**Figure 4.** The most representative KE images of each KE word.

## 6. Optimization and Analysis

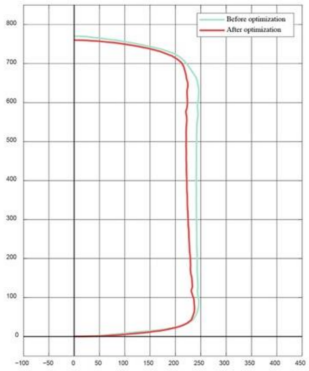
### *6.1. Optimized Prototype by SQP*

In the previous section, this study has identified 6 representative KE images and the optimized KE image by user scoring. Next, the user and the designer ratings are

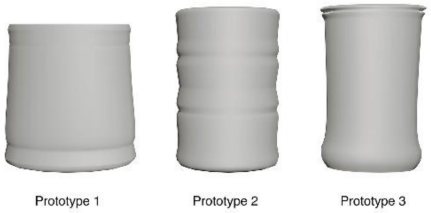
compared. Figure 5a shows the average scores related to the bamboo pen holder's form are measurably calculated and averaged. In general, designers and users have roughly the same emotional image of the bamboo pen holder. It should be noted that the Kansei word pairs "Desired—undesired" are listed separately and only the other 6 Kansei word pairs are calculated. Then, we find that users and designers have the closest evaluation in Number 5. The difference is only 0.0346. The largest rating gap occurs at Number 29 with a difference of 1.4722. After analysis, the most representative user KE image and designer's KE images are Number 8 and Number 33 as shown in Figure 3, respectively. This difference shows that in the process of design thinking, the designer should still pay attention to the emotional value of users.




(**a**)




(**b**)




(**c**)

**Figure 5.** The SQP optimizes the product's process. (**a**) The analysis of scores; (**b**) Comparison of SQP optimization results; (**c**) The 3D prototype.

The main purpose of this study is to design an optimal pen holder according to the response of the users and designers. To obtain the optimized prototype, we used the SQP to optimize the shape of the pen holder via 6 of the most representative KE images, i.e., Number. 45, 4, 1, 64, 38, and 25. From the product shape perspective, SQP proved an effective way to perform optimization of product design variables. The KE images 45, 4, 1, 64, 38, and 25 are all axisymmetric symmetrical shapes. Thus, we selected half of the product shape to take pixel dots for computation. Thereafter, 100-pixel dots were taken uniformly on each KE image and those pixel dots were coordinated. Here, we selected 100 coordinating points to be optimized. The optimized criterion is expressed as follows:

$$\min_{X,Y} \sum_{i=1,4,25,38,45,64} (a_i \|X_i - X\| + a_i \|Y_i - Y\|) \quad (4)$$

where $a_i$ is the weight coefficient of each KE image, and $X_i$ and $Y_i$ are the 100-pixel dots' horizontal and vertical coordinating values of these representative KE images, respectively. Note that, the initial value of each coordinating point is determined by averaging the 6 KE images' 100-pixel dots coordinating value. Next, the SQP optimizes this image, and the result is shown in Figure 5b.

This study transforms three product shapes on 3D product modeling software, including the optimized product shape, the product shape with the highest scores by users and designers, from 2D to 3D models as shown in Figure 5c.

### *6.2. Validation of KE–DT Framework*

The interaction process between the user's KE cognition and the product is the user's initial cognition of the product. In practice, the shape of the product lacks uniformity between the designers and the users [60]. The foremost critical demonstration of inventive considering is approximately rhombus considering proposed by extenics for the product design area. This could be a way of considering 'divergence-convergence' [61]. Designers' innovations are divided into many stages in the KE–DT framework, including brainstorming, design strategy transfer, user analysis, and convergent thinking, etc. DT provides designers with a way to study perception [62]. Moreover, using the KE method for the DT builds a systematic connection between the designers as well as users. The KE–DT framework optimizes the product design process such that the designers could focus on the social aspects of product sustainability.

This study verifies the feasibility of cognitive matching of the optimized prototypes. A new group composed of users and designers (46 students from different universities and 14 designers) were invited to evaluate the prototype. Note that, the previous pen holders together with the optimized pen holder are also conducted via a new questionnaire. The results are shown in Figure 6.

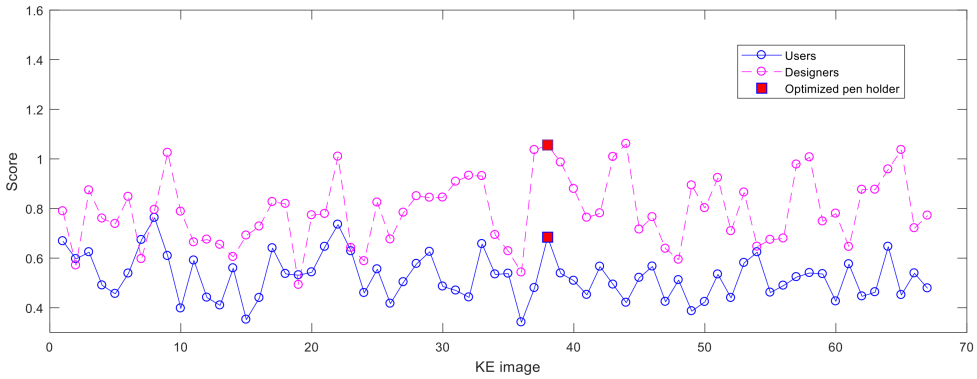



**Figure 6.** The average score for each product.

The optimized pen holder scored 0.6844 and 1.056 in users and designers, respectively, ranking third and second, respectively, in all products. Besides, the optimized product scored 0.1615 and 0.2683 higher than average among users and designers, respectively. Tables 4 and 5 show the variance of the five pen holders with the highest scores.

**Table 4.** The variance of users.

| Product | Number 1 | Number 8 | Number 22 | Number 33 | Number 38 |
|---|---|---|---|---|---|
| Variance | 0.7353 | 0.8314 | 0.6842 | 0.7021 | 0.5626 |

**Table 5.** The variance of designers.

| Product | Number 9 | Number 37 | Number 38 | Number 44 | Number 65 |
|---|---|---|---|---|---|
| Variance | 0.8719 | 0.6936 | 0.6012 | 0.9347 | 0.7564 |

Tables 4 and 5 indicate that the variance of the optimized bamboo pen holder is obviously lower than others. In other words, although the optimized pen holder does not score the highest either among users or designers, basically, everyone gave it a good review. All of these show that the pen holder, after our optimization, has wide consumer appeal. Meanwhile, the method of automatically optimizing the shape of stationery proposed by this study can significantly shorten the design period. In a business context, emotional value can be linked to building a corporate image through the KE–DT framework. It enables designers to take into account the real emotional tendencies of users earlier. Meanwhile, user groups can also indirectly participate in the design process through their emotional tendencies towards the product. Designers can also exchange ideas with users through this process. This provides an effective emotional connection between the product and the user. The KE–DT framework can accurately fetch the cognitive trends between users and designers and help designers build education-related product forms.

Additionally, the KE–DT framework proposed in this paper is intended to create more green products, such as bamboo stationery, which demands a high social duty for the designers. When designers are uncertain about the evaluation of the scheme, the breadth of design thinking will continue to widen and shift. Convergent and divergent thought models are iteratively transformed. Supplementary attributes including the SQP and KE method will effectively facilitate the iterative process of product design. Thus, applying the KE method to the DT process is an effective way for designers to integrate design elements and user-perceived value.

## 7. Conclusions

The purpose of this study not only aims to improve the purchase of sustainable products by college students but also aims to optimize the product design process and reduce resource waste through the proposed KE–DT framework. By optimizing the shape of the bamboo pen holder, this will further promote the entry of sustainable products into the market. After a new round of questionnaire surveys, the results showed that our optimized bamboo pen holder was very popular. We demonstrated how a KE–DT framework can increase students' consumption of bamboo products. Moreover, we also discussed the importance of the perceived value to users of related products. This KE–DT framework provides the basis for the redesign by designers. Thus, it can effectively narrow the cognitive gap between designers and youth and the appearance of the bamboo stationery product in this study. This provides an effective framework that prevents the single design model and provides products that better meet the psychological needs of its users. The combination of subjective DT and the objective optimization model can provide designers with more efficient and flexible design solutions, which, in turn, provides new ideas for the innovative optimization of sustainable product design. This study further develops the innovation of sustainable products by both designers and users.

This paper also attempts to replace part of the designer's work with computers. Using the digital virtual design of pen holders can free the designer, who does not need to repeat the revisions and multiple investigations of users, therefore, greatly shortening the design period. More importantly, the proposed KE–DT framework can also reduce the consumption of materials in the traditional product design process. This contributes to the development of sustainable product design. In this study, the KE–DT framework incorporated the KE and SQP as an effective method to help integrate perceptual matching between designers and users. An understanding of whether a particular population's perception of the target product's attributes is positive or negative is facilitated to a more rapidly designed product that is closely related to the actual needs of its users. In addition, the KE–DT framework can also be applied to complex technical product design processes and provide designers with potential solutions faster. In this KE–DT framework, consumers can become 'co-creators' of products rather than single purchasers. This is a positive interaction for enterprises, which not only reduces the waste of resources due to the design gap but also improves users' purchase of sustainable products. For designers, this result

not only efficiently optimizes product shape but also serves as a design guide for novice designers. Finally, it also enables designers to create stronger bonds between green design and users' perceptual value.

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