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Customer-centered co-design modularization: the skirt design on mobile application

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ABSTRACT
With the development of mobile technology, customer-centered co-design modularization (CCCM) has been studied by researchers and brand operators. In contrast, in the field of skirt design, CCCM on mobile application has been largely ignored. The purpose of this study is to develop a customer-centered co-design modularization on skirt that enables customers to co-design skirt on mobile application. On the basis of analytic hierarchy theory and interactive genetic algorithm, CCCM is consisted of two categories, such as skirt parts (design attributes) and communicating parts (behavior attributes). Skirt parts are determined by knowledge classification. Communicating parts are supported by recommending, consulting, evaluating among customers, consultant, and expert. The customer-centered co-design modularization was conducted and proved by a mathematical model. Compared to online shopping, the proposed CCCM is a good approach to involve stakeholders (customer, consultant, and expert) to design together who can communicate on mobile application.

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KEYWORDS
Customer-centered co-design; modularized design; skirt design attributes; communicating attributes

1. Introduction
E-marketing is becoming increased globally. Brands have to handle the conflicts between customers’ requirement and variant products. The uprising product variety and personalized need results in an increase of the design process complexity. Brand managers have to find a solution to provide a good and wide service while meeting customers’ requirement and keeping their repurchase intention greatly.

A proven customer-centered co-design for this is a way to setup the modular in mobile application. Co-design is an approach that customers are regarded as co-designers, who co-work with stakeholders from the brand in the design process, which is involved multi-individuals (customer, expert, and consultant) to work together so as to satisfy their needs and increase the willingness to pay for the clothing extremely (Herd, Bardill, & Karamanoglu, 2007; Kongprasert, 2012; Senanayake, 2004). Online shopping and clothing co-design are studied by researchers in the area of co-design, co-creation, design knowledge modularization, product co-design, users, and designers co-work (Centeno & Wang, 2017; Koutsabasis, Vosinakis, Malisova, & Paparounas, 2012; Liao & Lee, 2009; Taffe, 2015; Vogiatzis, Paliouras, Jenkyn-Jones, & Possen, 2012; Yenicioglu & Suerdem, 2015; Zhang, Hu, Xu, & Zhang, 2012). Meanwhile, there are some brands that develop the co-design system in operation so as to meet customers’ personalized requirement in the product design process, such as Dell, IKEA, Threadless.com, Zazzle.com, Nike ID, Vans Costume, Spread Shirt, and Cotte Yolan. Therefore, customer-centered co-design on mobile application has been regarded as the currency of brand development, which contributes to the communication between customers and product providers.

This study presents an overview of the modular product development in recent years, which is related to product attribute and communication. The visualization is adopted in this study so as to present the design attributes. The methodical modularization of the product attribute is used to simplify the communication among customers, consultant, and expert. The mobile application structure of skirt design demonstrates its application and identifies the potential usability. The proposed customer-centered co-design modularization approach, which is adapted interactive genetic algorithm and analytic hierarchy theory is presented in the Sections 2 and 3, applied with a case study in Section 4, discussed and concluded in Section 5.

2. Theoretical foundation and related works
The literature relevant to this study has its basis in the modularization and interactive genetic algorithm. The theory supports the modular function and the structure of the co-design application. In accordance with analytic hierarchy theory and interactive genetic algorithm, this study primarily build the structure for how customer, expert, and consultant co-design on a skirt, can be reserved for the application of skirt design attribute and behavior attribute. To expand the co-design structure, the present
customer-centered co-design modularization has been conducted in the skirt design on mobile application.

### 2.1. Relevance of modularization in system setup

It is widely studied in the literature that modularization plays an important role in the product development. The key points of the modularization structure are to compose the product via simple units of the optional parts of the product (Ma & Kremer, 2014). Zhou, Xu, Wang, and Chen (2016) concluded that customer-oriented garment parts modularization is composed by essential parts and non-essential parts. Mok et al. (2013) setup the dress design database that is constructed on design elements decoding with three-level design model. The modularization is regarded as an approach to offer good services and products. Jiang, Kwong, Liu, and Ip (2015) report that design attribute set is considered to support the customer satisfaction model, meanwhile, product’s color and shape influenced customers’ emotion and satisfaction. There are some findings on the relationship between design and modularization (see Table 1). The above studies recommend modular to facilitate e-service so as to enhance the design process.

The apparent gaps between customers and designers are the product exterior features, such as color and materials (Shieh, Yeh, & Huang, 2016), there needs further studies on the design knowledge modularization. Visual, verbal and narrative are main methods in study individual knowledge (Wolfel, 2014). It is possible to categories the design knowledge of product attributes. The visual form of the product conveys information and knowledge to customers effectively (Crilly, Moultrie, & Clarkson, 2004). In order to identify users’ requirements, researchers conclude the problems in the design process that are the lack of interaction between customers and product information (Huang, Deng, & Chuang, 2013). The multiple users have been worked as a team in computer supported co-works environment, users exchanged information without the limitation from locations (Sarjoughian, Nutaro, & Joshi, 2011). Multidisciplinary expertise is encouraged to share ideas with team members in user-centered collaborative design approach, but they could not meet users’ admire (Chammas, Quaresma, & Alvao, 2015). From above literature, design knowledge is recommended to customers. However, a further study should be needed on how to adopt communication and interaction in the design process.

### 2.2. Application of interactive genetic algorithm on system

On the basis of fashion design knowledge, Kim and Cho (2000) apply interactive genetic algorithm to fashion design system, encode details and show design parts on 3D models. Gong et al. (2007) and Gong, Guo, Lu, and Ma (2008) adopt interactive genetic algorithm in fashion design system so as to improve the fitness. From the above literature, the design knowledge and design system are studied that the gap lies in the customer-knowledge-system interaction. There still need more study on the evaluation from customers, consultant and expert on system structure and its application.

There are some findings on visual information and system setup. Considering the product configuration and visual design features, Dou, Zhang, and Nan (2016) prove that collaborative product design system reflects knowledge value on that improving design efficiency, that is supported by interactive genetic algorithm. Mok et al. (2013) study the design elements by interactive genetic algorithm. Li and Chen (2018) setup a model of e-customized system so as to provide good service to users, that is supported by evolutionary algorithm and fuzzy theory. Farooq and Siddique (2014) find the future direction of interactive genetic algorithm is to adopted with the visualization technology. As seen from the literature, there still exist gaps in the co-design system development, even though they have many remarkable findings. The communication is not studied fully, which influence customers’ satisfaction directly.

The main problems in the existing co-design system are described as follows: (a) Communication gap. Communication, interaction, and design knowledge modular are not studied fully. (b) Limitation on categorized selection. The knowledge is recommended to customers without transforming parts. (c) Low system usability. There is no evaluation modular in the system that the feedback could not be collected quickly.

### Table 1. Main points of design modularization.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Main points of design modularization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gebhardt et al. (2014)</td>
<td>The module interface graph is developed with the modular product families and component variety. The boundaries of module interface are defined in the modularization.</td>
</tr>
<tr>
<td>Williamsson and Sellgren (2016)</td>
<td>The physical and functional modular is adopted as module driver so as to identify modules, that integrated the technical complexity.</td>
</tr>
<tr>
<td>Zhou et al. (2016)</td>
<td>Modularized design is developed and supported by garment design attributes. A binary decision variable is used to determining the garment parts.</td>
</tr>
<tr>
<td>Mutingi, Dube, and Mbohwa (2017)</td>
<td>Modular product design is an effective optimization method, which could work in fuzzy environment. It combines of the components to achieve sustainable manufacture.</td>
</tr>
<tr>
<td>Sun, Chai, Pi, Zhang, and Fan (2017)</td>
<td>To support the personalized requirement, modularization plays a key role in product service system development. Products and services are supported by the function sets.</td>
</tr>
<tr>
<td>Bruun, Mortensen, Harlou, Worosch, and Proschowsky (2015)</td>
<td>The modular design is supported by product lifecycle management, which could be measured by the properties and product family. Product family could be visualized so as to achieve functionality.</td>
</tr>
</tbody>
</table>
This study pointed out the knowledge sharing between communicating attribute and skirt design attribute on mobile application. CCCM is proposed to meet the customers’ requirement through the skirt design knowledge classification and the communication among individuals. The skirt parts are categorized by essential parts and optional parts. The communicating part is achieved by consulting and evaluating. A mathematical model is developed to analyze the relation between design attributes and behavior attributes in the co-design process. The skirt specific knowledge is supplied in the modularizing operation. Customers are able to select the skirts parts following their preferences and assisted by fashion consultant.

The aims of this study are: customer-consultant-expert communication is needed in the co-design; the evaluation is conducted to assess the final design works by the customer and the expert; the final co-design work finished, there is a feedback board for customers, that collected data could be used for the product co-design system future studies; the co-design modularization could meet consumers’ personal requirement and reduce the clothing stocks.

### 3. Process of modularized skirt design

Essential parts and optional parts composed the skirts design attributes. Each of the parts can be adopted to skirt design, and the transforming contains the usability of enlarging, saving, posting. Communication is related to the interaction between customer and professional consultant. In this study, the co-design modularization supports the decision making among customer, design attribute and stakeholders. The flowing CCCM is designed in Figure 1. The skirt parts are supported by database.

The system is set up on the professional consultant’s support and connected with customers’ preference who select and transform the parts. The co-design process includes (a) communicating with consultant; (b) fashion trends are provided to customers; (c) the new comer guidance is set following the start, which could be skipped; (d) the final design work is scored by the customer (50%) and the expert (50%); (e) if the final design works could not meet customers’ need, the process can be returned to selecting and communicating; if the customer was satisfied, the co-design process can be turned to finished. Then the customer would be asked to comment on the co-design process and services.

### 3.1. Composition of skirt parts (design attributes) and communicating parts (behavior attributes)

Pattern outline was the key point in body measurements (Gill & Chadwich, 2009). The basic functional requirements were defined as the wearer was able to meet the required movement, no binding and no limited body moving (Gill, 2011). The skirt design attributes composed by essential

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**Table 2. The composition of skirt parts.**

<table>
<thead>
<tr>
<th>Part type</th>
<th>Coding</th>
<th>Sub-part name</th>
<th>Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Essential</td>
<td>I₁</td>
<td>Skirt body</td>
<td>Position of waistline, hipline, hemline</td>
</tr>
<tr>
<td></td>
<td>I₂</td>
<td>Waist</td>
<td>Waistline, level</td>
</tr>
<tr>
<td></td>
<td>I₃</td>
<td>Hip</td>
<td>Width, level</td>
</tr>
<tr>
<td></td>
<td>I₄</td>
<td>Hem</td>
<td>Width, level</td>
</tr>
<tr>
<td></td>
<td>I₅</td>
<td>Color</td>
<td>Hue, brightness, pureness</td>
</tr>
<tr>
<td>Optional</td>
<td>J₁</td>
<td>Pocket</td>
<td>Type, level, width</td>
</tr>
<tr>
<td></td>
<td>J₂</td>
<td>Pleat</td>
<td>Type, level, width</td>
</tr>
<tr>
<td></td>
<td>J₃</td>
<td>Dart</td>
<td>Type, level, width</td>
</tr>
<tr>
<td></td>
<td>J₄</td>
<td>Accessory</td>
<td>Type, level, width</td>
</tr>
</tbody>
</table>

---

**Figure 1.** The flowing approach of customer-centered co-design modularization (CCCM).

**Figure 2.** The skirt co-design running board.
parts and optional parts. The essential parts are related to skirt function; the optional parts are unnecessary ones that are not related to the measurable body point. Thus, the instruction is as follows.

a. The essential parts should meet wearer’s requirement and own basic function.
b. The optional parts should play a role as decoration and/or some unnecessary function.
c. The two parts types should meet the skirt design attribute function, that should be produced by manufacturers and worn by customers.

The skirt is divided into nine coding as shown in Table 2. The essential parts are provided with measurement, which could be revised and modified by customers, so as to meet their need easily. For the sub-part, if it is selected, the customer is able to communicate with fashion consultant. After the skirt co-design work is finished, the evaluation community is presented to a human-system. There are two steps for communication among individuals. (a) In the co-design process, the customer communicates with the fashion consultant. (b) The evaluation would be available between two stakeholders in the community once the skirt design has been finished.

3.2. Configuration and connection of garment parts and communicating parts

Through dividing the skirts into parts and determining behavior attributes and design attributes, the co-design system has a database which was setup by professional staff that enables the skirt co-design to meet customers’ personalized needs.

The various skirts have different essential parts and optional parts. In order to configuration the design attributes and behavior attributes, decision variable is presented in Equation 1.

$$\sigma_{mn} = \{0 \text{ if } m \neq n, 1 \text{ otherwise} \}$$  \hspace{1cm} (1)

Where $\sigma_{mn} = 0$ represents that $mn$ part is not configured, $\sigma_{mn} = 1$ represents that it is configured. In the co-design process, the essential parts, optional parts and communicating parts are represented in binary decision value. Meanwhile, skirt design attributes configurations are shown in Table 3. Different shapes of the skirt related to different optional parts. Following customers’ need, the optional part could be selected. For the communicating parts, the customer communicates with a consultant that is a kind of optional parts.

These parts are linked by simple stitch and be shown as co-design sketch works. The skirt making is supported by pattern makers, who are professional in manufacture. The skirt co-design process is consisted by fashion trends information and fashion consultant advice (see Equation 2).

$$R_{mn} = \{md, M, D, B, M_{at}, T, X, E\}, m = 1, 2, \ldots, r, n = 1, 2, \ldots, s$$  \hspace{1cm} (2)

Where $R_{mn}$ is the junction of the $m$ part, $md$ is the connecting junction, $M$ is the junction that is supported by $D = \{d_1, d_2, \ldots, d_m\}$ which is a set of design attributes (i.e. essential parts) that includes the junction of waist, hip, hem, and skirt body. $B = \{b_1, b_2, \ldots, b_m\}$ is a set of optional parts attributes. $M_{at} = \{M_{at1}, M_{at2}, \ldots, M_{atn}\}$ is a set of the part connection by simple stitch, $T = \{t_1, t_2, \ldots, t_m\}$ is a set of transforming design optional parts. $X = \{x_1, x_2, \ldots, x_m\}$ is a set of communicating with fashion parts.
consultant. $E = \{e_1, e_2, \ldots, e_m\}$ is a set of the feedback from customers that related to skirts co-design and communication.

Before connecting the parts, customers could check the fashion trends and communicate with fashion consultant on the platform. The design attribute is setup by the skirt knowledge. After finishing co-design works, the customer selects to save or delete it. After finishing the co-design works, there is a feedback board, the collected data is collected to enhancing the brand design and service quality.

In the co-design process, the communication is needed. The communicating is a part of the co-design process. Behavior attributes are maintained as shown in Figure 3 with gray color:

$$
\begin{align*}
\{X_m &= X_n \} \\
\{E_m &= E_n \} \\
&= m = 1, 2, \ldots, R, n = 1, 2, \ldots, S
\end{align*}
$$

Where $X_m$ and $X_n$ are the elements of communicating, consulting, inquiring with fashion consultant, that are sets of $X_1, X_2, \ldots, X_m$, $R$ and $S$ are the number of the set. Both of the $X_m = X_n$ indicate the communicating steps among customers, fashion consultants and design information recommending. $E_m = E_n$ indicates that behavior attributes on evaluation of the skirt design parts and communicating parts. The factors are correlated in the relationship among the customer, fashion consultant, expert, and design knowledge.

The correlation with its intensity between each two functional requirements can be presented as the following (see Table 4):

As the element of matrix $M$, $a_{ij}$ denotes the correlation intensity between elements $i$ from $X$ and $j$ from $E$. $a_{ij} = 1$ when $i = j$ can be found in this step.

$$
M = \begin{bmatrix}
1 & a_{12} & \ldots & a_{1j} \\
a_{21} & 1 & \ldots & a_{2j} \\
\vdots & \vdots & \ddots & \vdots \\
a_{1i} & a_{2i} & \ldots & a_{jj}
\end{bmatrix}
$$

$$
a_{ij} = \frac{1}{9} (\omega_p A_p + \omega_q B_q)
$$

Where $\omega_p$ and $\omega_q$ are the weight with $\omega_p + \omega_q = 1$. According to the discussion of the expert, both $\omega_p$ and $\omega_q$ are assigned 0.5. $A$ and $B$ are the correlation intensity valued from 1 to 9.

### 4. Application of modularized co-design method

The skirt co-design method can be applied to e-customized apparel system. The modularized co-design method applied to skirt co-design process are shown in Figure 4. For example, the customer needs the flared skirt, without a hip line. According to the skirt type, the binary factors are shown as follows:

$$
\begin{align*}
\sigma_{in} &= 1e \quad n = 1, 2, 3, 4, 5 \\
\sigma_{jn} &= 0e \quad n = 6, 7, 8 \\
\sigma_{in} &= 1e \quad n = 1, 2, 3, 4 \\
\sigma_{jn} &= 0e \quad n = 6, 7, 8 \\
\sigma_{in} &= 1e \quad n = 1, 2, 3, 4 \\
\sigma_{jn} &= 0e \quad n = 6, 7, 8
\end{align*}
$$

The selected design parts are modularized supported by skirt design database and communicating parts. Figure 4 shown an example of flare skirt co-design. The finished design sketch works are presented to customers. After evaluating by the customer and expert, if the customer is pleased with the design sketches that can be saved and the co-design process could be finished. Then the service feedback step will be shown in the system. Otherwise, the customer could delete the works and be back to start. In this co-design system, the transformation could be given on the optional parts that follow Equation (2). The essential parts, optional parts, and communicating parts are available to customers (see Equation 6).

Co-design work could be shown that is supported by the steps of customer’s requirement, selecting skirt design information, fashion trends recommending, and consulting. The system can be operated until the customer satisfied. And the feedback can be collected that concluded by the customer’s self-experience.

### 5. Conclusion

This study is proposed to integrate the interactive genetic algorithms and analytic hierarchy theory with modularization to tackle the effect in the model of customer-centered co-design system. We proposed the model can make a better study of modularization and communication on mobile application than website. This study also shows that the evaluation and communication given in the paper are capable of covering the effects in co-design process, it is supported by stakeholders (customer, consultant, and expert). From the model, we can draw the conclusion about the model application of the flowing approach and design knowledge modularization.

The interactive genetic algorithm and analytic hierarchy theory were used to present the relationship among modular. Based on the communication and evaluation modular, the system could be provided to customers on mobile application. The co-design system is expected to apply in e-customization. The method could be adopted in the field of production design, which solve the problems between design knowledge and customers’ requirement. However, customers’ dynamic emotion need is not considered in this study. Future work should consider
how to follow customers’ dynamic emotional need simultaneously. Additionally, more stakeholders should be involved in the co-design system, who might play different roles in the design process.

The system would be conducted in the co-design mobile application. It has stronger predictive the updating electronic technology trends on clothing industry. This study contributes to the approach and method that can enhance the brands’ co-design services. Future research is encouraged to explore the customer virtual perception, preferences, design attribute knowledge categorization, and inter-brands design resources structure construction. We suggest that a wide consideration of customers’ experiences and feelings are possible to refine design knowledge and enhance service quality.

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