Product Design Scenario Modeling and Its Application

Guoshu Yuan, Sun Hui, Qingsheng Xie, Jian Lyu, Weijie Pan

Key Laboratory of Advanced Manufacturing Technology, Ministry of Education, Guizhou University, Guiyang, 550003, China

Abstract

Aiming at the imperfect knowledge acquisition in the current product design and incomplete representation of design requirements in the design process, this paper proposes a method of modeling based on the scenario of the design process. The product design process is divided into knowledge acquisition scenario, knowledge materialization scenario and feature verification scenario. In the process of knowledge representation, the concept of extenics primitives is introduced. Firstly, the design information is transformed into the requirement primitives by the knowledge acquisition scenario. In the materialization scenario, the requirements primitives are merged with the designer's thinking to form the conceptual plan primitives, and the preliminary design plan is formed by information materialization. Finally, the effect of production design plan is maximized by constructing a model of verification scenario and judging if the preliminary design plan is reasonable. What is more, the design scenario model is validated with a piece of logistics sorting equipment as the object of study. The results show that, the product features are efficiently expressed as the process evolves which effectively guides the product design process and verifies the feasibility of the method.

Keywords: product design; scenario model; narrative; feature verification

1. INTRODUCTION

With the development of information industry and manufacturing, people are increasingly concerned with the services associated with products rather than satisfied with the convenience brought by product functions. Apart from functions, product design focused on the attractiveness of appearance in the past. Nowadays, however, customer-oriented product experiential service is extensively studied and applied. In particular, knowledge acquisition, representation, materialization and feature verification have become the research focus in the field of design. The core of design is gradually shifting from the tangible appearance to the intangible experiential service.

Scholars have paid more and more attention to the method of design scenario modeling. Based on cognitive psychology, Tan et al., (2006) propose a concept of design scenario, subdivided into problem scenario, problem-solving scenario, and the solved scenario. Luo et al.,(2008) put forward a research method of knowledge-driven product design, dividing the design process into such 3 dimensions as problem scenario, problem-solving scenario and the results scenario. Hui et al.,(2014) suggest integrating knowledge with specific scenarios, and analyze concepts like scenario dimension, scenario space, scenario tree, and scenario nodes. Integrating knowledge, knowledge process and scenarios, Pan et al., (2006) advocate a knowledge management method in consideration of scenarios, and look at the technology of knowledge modeling, scenario recognition and knowledge retrieval and acquisition. Liu et al., (2010) set up a framework of knowledge maps with the method of building knowledge maps, mainly through the establishment of design process models with different abstract granularities through the investigation and analysis of industrial design process. Putting forward a method of exploring the design DNA of visual identification product family design, Zhu et
al., (2010) study the system construction and key technologies of product family design under production visual identification. Lu et al., (2014) make a systematic summary of the status quo and progress of product design DNA research at home and abroad, introduce the expression structure, application research progress, key technologies and the defects of existing research, and point out the research hot spots and trends of product design DNA.

In light of the research progress on design scenario, the method of design scenario modeling is widely applied to the modeling of various product design processes (Su et al., 2004). For logistics sorting equipment, the modeling of knowledge acquisition, demand representation, feature materialization and plan verification is particularly strict and clear. The model construction and expression of product family design process boast clear hierarchy and relevance, especially for the design of intelligent product systems. The superiority of the method is displayed in the completeness of product and user information system, and the mining and representation of hidden information of the user.

Taking design process representation as the research object, this paper proposes a method for design scenario modeling on the basis of mining user knowledge: Firstly, acquire design knowledge to form information primitives; secondly, build a user demand model through information analysis and summarization; finally, verify the preliminary product’s performance in different verification scenarios by constructing feature scenarios based on the user’s experience in using the original product, thereby providing effective support and support for the design.

2. DESIGN SCENARIO ELEMENTS

Design scenario describes the problem solving process from “raising a problem, solving the problem to verifying the solution”. The key to construct a scenario lies in correct identification of the relationship between the user and the product. From the perspective of design psychology, it is found that the user’s experience of a product is affected the user’s operating mode of and attitude towards the production (Pan et al., 2007; Luo et al., 2010; Luo et al., 2010; Lin et al., 2005; Wu et al., 2008). During the use of the product, the user is more willing to get feedbacks more quickly. Therefore, the crux of product design and optimization is to dig out the hidden demand and intention of the user and obtain the usage scenario elements.

2.1 Design Scenario

From the perspective of design scenario, “raising a problem” refers to putting forward design requirements based on the user’s experience and attitude. As the results of the problem-solving process, product features are expressed by the product’s external form C and the operating flow S, which is further divided into user’s habit T, signifying the potential behaviors of the user, and the use path of the product E, focusing on the user’s operating mode of the product. Because the Sand C expressed by the product do not necessarily satisfy the user’s demand of the product in actual use, the author designs a verification scenario D in the scenario model, which consists of technical scenario and usage scenario. Emphasizing on the representation of the product in hypothetical usage scenario, the usage scenario sends the verification information F to the designer to redefine the product. See Figure 1 for the framework of the design scenario model.
2.2 Design Elements

Design scenario model includes three design elements: knowledge acquisition, knowledge materialization, and feature verification. With the product as the carrier, the modeling of the design process goes through 3 different stages. See Figure 2.

(1) Knowledge acquisition: Starting from user’s demand, obtain product-related information by tapping the potential demand of the user through communication, and construct information primitives by analyzing and summing up the acquired information.

(2) Knowledge materialization: Starting from the knowledge reasoning in the design process and combining the information primitives and the emotion of the designer, materialize the knowledge into product design features to construct the preliminary design plan.

(3) Feature verification: In light of the usage scenario and the user’s demand of the product, judge if the product features meet actual use by providing feedbacks to the problem-solving process. Targeted at the judgment of and feedbacks on product features in the problem-solving scenario, the author simulates all possible usage scenarios to observe the performance of the preliminary design plan, unlock the potential problems of the plan and feedback the problems to the designer so that he/she could redefine the design plan.
3. DESIGN SCENARIO MODELING

Design scenario model stands for the information framework constructed with logical factors and on the basis of cognitive thinking in design. The modeling process is made up of two parts: model framework construction and model information construction.

3.1 Framework Construction of Design Scenario Model

The model framework includes three parts: knowledge acquisition and classification, knowledge materialization and feature verification. See Figure 3.

Figure 3. Framework of design context model

(1) Knowledge acquisition: According to user’s demand, design information is divided into: user, demand, market, and technology. Obtained from the information by category, information primitives $P_n$ and $S_n$ are divided into different levels based on the relevance between informative primitives and user’s demand.

(2) Knowledge analysis: the creative thinking by the designer on the basis of the information primitives he/she has acquired. During the process, the designer analyzes and summarizes the information primitives he/she has acquired in accordance with the relationship $f$, and forms the demand for product design ($N_n$).

(3) Feature verification: a detailed analysis and optimization of the preliminary design plan. Various design verification scenarios $K_n$ and $M_n$ are constructed in light of the user’s experience of the product in the scenarios. After materialization, the product features are verified and screened and the features which do not meet actual demand are removed. The results are fed back to the designer.
The concept of scenario model integrates the acquisition, summarization, and verification of knowledge into a vector composed of objects, scenarios, and variables. The model vector can be simply expressed as:

\[ C_v = (C_p, C_q, C_i, T) \]

Where,\( C_0 \)--Design scenario;

\( C_p \)-- Knowledge acquisition scenario;

\( C_i \)-- Knowledge materialization scenario;

\( T \)-- Design process parameter.

To sum up the discussion of the product design process, the product design process is represented in Figure 4.

![Figure 4](image-url)

**Figure 4.** Situational expression of product design process

### 3.2 Information Construction of Design Scenario Model

From the perspective of design methodology and scenario approach, the design scenario model is the process of problem solving and verification. During the innovative thinking over the knowledge he/she has acquired, the designer’s own subjective emotion is integrated and materialized to form the preliminary product design plan. Thus, the design process can be simply expressed as a four-stage process: acquire knowledge, summarize knowledge, materialize knowledge and verify the features. The scenario model is illustrated in Figure 5.
Knowledge acquisition is the original point of the scenario model construction. The designer analyzes and summarizes the design knowledge \( P_n \) he/she has acquired to form the design demand, and materialize the knowledge into product features \( u \) in combination with the product appearance. Based on the verification scenario model \( K_{nr} \), it is judged if the designed product meets the user's expectation of the product. The knowledge verification process is also a process of design thinking and screening.

### 4. DESIGN SCENARIO MODEL REPRESENTATION

Based on user’s demand and targeted at the production design process, design scenario model is a method to improve the design plan by materializing the user’s perceptual demand (Suri et al., 2000; Shi et al., 2007; Ghafurian S and Javadian N, 2011; Danjou et al., 2013). In traditional form design, the design plan is sometimes optimized locally instead of generally because it is prepared on the basis of the designer’s subjective feeling.

As a solution to represent the design process in a model, design scenario model verifies if the features of the product formed as per plan meet the user's demand, identifies existing problems and makes improvements by constructing the scenario verification model.

#### 4.1 Knowledge Acquisition Model Representation

From the perspective of the representation of scenario model, the product knowledge is divided into \( n \) information primitives in 4 different categories. The model composition can be expressed as:
User knowledge

<table>
<thead>
<tr>
<th>$P_1$</th>
<th>$P_2$</th>
<th>$P_3$</th>
</tr>
</thead>
</table>

Demand knowledge

<table>
<thead>
<tr>
<th>$P_4$</th>
<th>$P_5$</th>
<th>$P_6$</th>
<th>$P_7$</th>
</tr>
</thead>
</table>

Market information

<table>
<thead>
<tr>
<th>$P_{8a}$</th>
<th>$P_{8b}$</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>$P_{9a}$</th>
<th>$P_{9b}$</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>$P_{10a}$</th>
<th>$P_{10b}$</th>
</tr>
</thead>
</table>

$P$ stands for the knowledge primitives obtained under different knowledge categories, if $O$ stands for the knowledge acquisition sub-module, and $A=\{A_1, A_2, ..., A_n\}$ represents information features, when product knowledge acquisition $A_i(O)$ happens, there is a feature set:

$$\{M_i\} = \{M_{ij}, \ i = 1, 2, ..., n; \ j \in \{1, 2, ..., k_j\}\} .$$

Where $M_{ij} = (C_{ij}, V_{ij})$, $V_{ij} = <a_{ij}, b_{ij}>$ is the primitives related to $C_{ij}$ and $V_{ij}$ when $A_i(O)$ happens; $C_{ij}$ is the obtained information primitives; $V_{ij}$ is the design element. Then, the event of knowledge acquisition $O$ can be expressed as:

$$M_i = \begin{bmatrix} A_i(O), & c_{i1}, & v_{i1} \\ c_{i2}, & v_{i2} \\ \vdots & \vdots \\ c_{ik_i}, & v_{ik_i} \end{bmatrix}$$

After the information is obtained, define the relevance between the information primitives and product demand, and determine the level of information primitives based on the degree of relevance, thereby constructing a more intuitive and richer knowledge acquisition sub-model to achieve a more accurate solution to the design problem.

4.2 Feature Materialization Model Expression

On the basis of knowledge acquisition, construct a scenario model of the knowledge materialization process in combination with the expression method for externics primitives. In this scenario, the creative thinking is formed and transformed into the product. This process can be expressed as follows:

$E_{mn}$ represents the design plan, $u(x_{mn})$ represents information primitives, and $P_i$ represents product features. If the product $M_i = \begin{bmatrix} A(O), & c_{i1}, & v_{i1} \\ c_{i2}, & v_{i2} \\ \vdots & \vdots \\ c_{ik_i}, & v_{ik_i} \end{bmatrix}$, there are $n$ features $P_1, P_2, ..., P_n$.

The corresponding information primitives are described with $u(x_1)u(x_2), ..., u(x_n) (i = 1, 2, ..., n)$. Then, the product features can be expressed as:
In light of the process of scenario modeling, the knowledge materialization consists of two parts: one is the materialization of the acquired knowledge, and the other is the materialization of the form factor. The former uses product to expressing the design demand generated in the previous step, and the latter focuses on the sensory interpretation of the product and the addition of the subjective feeling of the designer.

4.3 Verification Model Expression

In logical thinking, there is the mechanism of “raising a problem, solving the problem to verifying the solution”. The focus of the process is the verification of the preliminary plan. Based on possible scenarios of the product in actual use, virtual usage scenarios of the product are constructed to judge if the preliminary plan meets the demand. The virtual scenarios consist of two parts: one is the product operating scenario, and the other is the product materialization technology. Because the preliminary product features partially come from the user’s experience of the original product, the operating mode is a hypothetical scenario constructed on the basis of the marginal condition of product operation (i.e. the usage scenario which may occur during the use of the product, but always occurs with a small probability.)

The technical scenario is divided into: the existing achievable technology, non-existing but developable technology demanded by the design, and future technology.

<table>
<thead>
<tr>
<th>Technical context</th>
<th>Experience situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_n$</td>
<td>$M_n$</td>
</tr>
<tr>
<td>$K_1, K_2, \ldots, K_n$</td>
<td>$M_1, M_2, \ldots, M_n$</td>
</tr>
</tbody>
</table>

Starting from the assumed value $u_j$, define the relevance of each feature of the preliminary product. Determine whether a product feature should be retained by calculating the distance between the product feature and the mean value.

The product feature is represented by $[W_n, Q_i, T_i]$ and $U_j$ each describes a kind of verification scenario. $u$ stands for the mean value of feature relevance. The value of $k$ reflects the standard distance from the feature value that meets the demand to the mean value. The features within the value of $k$ are necessary and sufficient features. Otherwise, the features should be discarded. The verification model can be expressed as:

$$W_n = \{ (Q_i, T_i, U_j) \mid D(X) \}$$

$Q_i$: form factor;

$T_i$: usage scenario;
\( U_i \): technology;

\( D(X) \): product feature distance.

Product feature distance can be expressed as:

\[
Q_i, x \in [0,1] \\
D(X) = \sqrt{(X - u)^T S^{-1} (X - u)} \\
T_i, x \in [1,2] \\
U_i, x \in [2,3]
\]

Where, \( S \) stands for the covariance of the product feature sample vector, \( u \) stands for the mean vector, and \( Q_i, T_i, U_i \) respectively describes the interval of different scenarios. \( i \) stands for the coordinate value of the feature on the environmental axis \( X \), \( P_0, P_1, ..., P_n \) stand for feature samples, and \( D(X) \) stands for the Mahalanobis distance from the feature value to the sample mean value. When \(-K + (u - u_i) \leq D(X) \leq K - (u - u_i)\), the product features meet design demand. Otherwise, the product features do not meet design demand.

5. PRODUCT APPLICATION EXAMPLES

Based on the richness of product information and the familiarity with product use scenario, the author takes the sorting equipment in logistics sorting system as the application example.

5.1 Obtainment of Sorting Equipment Information

In light of the corporate culture and product conditions of a certain company, the author acquires the design knowledge through communication with the user. See Figure 6.

![Figure 6](knowledge_acquisition_model_logistics_sorting_equipment.png)

**Figure 6.** Knowledge acquisition model of logistics sorting equipment

5.2 Equipment Knowledge Materialization

After analyzing and summarizing the acquired design knowledge, the author comes up with the design requirements and the design strategy. In view of the logistics sorting equipment, and targeted at the main design problems, the materialization model of product features can be expressed as:
The author analyzes the knowledge model of the logistics sorting equipment and designs the preliminary plan, provides the product design features and puts forward solutions to main problems. After the materialization of the sorting equipment, the product features can be expressed as Figure 7:

**Figure 7.** Characteristics of initial scheme

With the materialization model of the sorting equipment, the author develops the model of the preliminary design plan with the 3D design software SolidWorks. Figure 8 shows the three-dimensional view of the preliminary design plan for the sorting equipment.

**Figure 8.** 3D model of equipment
5.3 Equipment Feature Verification

With the verification scenario model, the author verifies the completed preliminary product, locates design problems, and sends the problems to the designer.

See Table 1 for the relevance of the design features of the sorting equipment.

**Table 1.** Initial scheme characteristic value of sorting equipment

<table>
<thead>
<tr>
<th>Product features</th>
<th>Value</th>
<th>Product features</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taiwan high: 900mm</td>
<td>p1=0.5</td>
<td>Easy to learn</td>
<td>P8=0.2</td>
</tr>
<tr>
<td>All-inclusive</td>
<td>p2=0.7</td>
<td>Easy to move</td>
<td>P9=0.2</td>
</tr>
<tr>
<td>Easy maintenance</td>
<td>p3=−0.3</td>
<td>Tilt angle (display)</td>
<td>p10=−0.3</td>
</tr>
<tr>
<td>LED display</td>
<td>p4=0.5</td>
<td>Product total height</td>
<td>p11=0.6</td>
</tr>
<tr>
<td>Brown glass material</td>
<td>p5=0.2</td>
<td>Wool glass material</td>
<td>p12=−0.3</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>p6=1.2</td>
<td>Open the way</td>
<td>p13=−0.4</td>
</tr>
<tr>
<td>ABS plastic</td>
<td>p7=1.3</td>
<td>Open mode</td>
<td>p14=0.1</td>
</tr>
<tr>
<td>Screw connection</td>
<td>p15=1.4</td>
<td>Screw connection</td>
<td>p15=1.4</td>
</tr>
</tbody>
</table>

The author calculates the Mahalanobis distance of each feature to its mean value according to the feature distance formula. After correction, the feature verification model of the logistics sorting equipment is displayed in Figure 9.

According to the feature model, the author determines that: product features like tilt angle (display), screw connection, and ground glass material should be discarded as they do not meet the actual demand of the user.

See Figure 10 for the revised design plan.
The product design is completed by design scenario modeling of the logistics sorting equipment. The results show that the design method achieves expected results. For example, the design is recognized by the company and spoken highly of among users. The successful selling of the product stands as a good testimony of the feasibility of the design scenario model.

6. CONCLUSION

Starting from the perceptual demand of the user, this paper constructs the scenario model of the design process block by block. Taking externics design and scenario approach as the basis, the author puts forward the scenario model in reference to relevant experiments and research, and studies the design process and form materialization.

The research demonstrates the complexity of the process from design demand acquisition to information analysis and summarization, which involves expression and judgment of design feature relevance, and the transformation of information to products. There are still many problems to be solved in this process. For example, further research is needed to calculate the relevance between design features and user's demand, to set up user models, and so on.

7. ACKNOWLEDGMENTS

This work was supported by the natural science funds (JYSZ [2014]004), LH[2014]7644, LH[2014]7645.

REFERENCES