Trends and Research Issues in Customer-Oriented Product Conceptualization

Chun-Hsien Chen

Director of Design Stream
School of Mechanical & Aerospace Engineering, Nanyang Technological University
50 Nanyang Avenue, Singapore 639798
*Tel: +65 6790-4888, Fax: +65 6791-1859, E-mail: mchchen@ntu.edu.sg

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1 Introduction

With the increasing impact of global manufacturing, enterprises now must be able to adapt to the intensified collaboration among different parties that are involved in design, manufacturing and support services. Such collaboration is deemed critical for the timely realization and distribution of cost-effective and reliable products in the global market. In this respect, manufacturing enterprises now need to go beyond conventional practices to novel integrated activities encompassing product design and development, manufacturing, service supports, etc. Among these integrated activities, product design and development (PDD) activities, which are considered high value-added in the manufacturing industry, are becoming highly strategic to business success. The PDD activities encompass distributed, collaborative, innovative, knowledge-intensive, high value-added and customer-focused demands so as to promote productivity, serviceability, shorten time-to-market and compensate high resource and/or labor costs. As product design commits more than 70% of the total costs incurred in product development, it is imperative to pay more attention to the design phase, especially in the early product conceptualization stage.

In recent years, more and more industries begin to realize the importance of the needs of customers in product conceptualization, no matter the product is tangible or intangible, such as services. Only effective customer-oriented strategies are able to assist a company to gain a prominent competitive edge over its competitors. However, state-of-the-art solutions currently cannot address effectively the dynamics in customer-oriented product conceptualization. Without further advances and research into the critical methods and tools needed, companies will not have the means to develop their own strategic capabilities for product conceptualization and to participate in global product development programs. Conversely, methods and systems that support an effective customer-oriented environment for coordinating and visualizing
collaborative product conceptualization and for managing customer-driven requirements so as to achieve greater time- and cost-efficiencies, would assist companies in carving a niche in product design and development.

Recent research work reveals that rigid design systems and excessive specializations are no longer responsive enough to meet the rapidly changing customer demands and much shorter product life cycle (Yan et al., 2001a; Chen et al., 2003). Organizations are becoming aware that an optimal balance of product standardization (rigidity) and customization (flexibility) is the key to staying ahead of competitors in the globalized marketplace. To ride on this trend, the ultimate purpose of product conceptualization is to realize a product to the market effectively and efficiently (Yan et al., 2002). For this purpose, there are two fundamental design phases that need to be emphasized in product concept development: (1) Product definition: It aims at establishing a generic product platform and relevant product family as well as typical design alternatives; and (2) Product customization: It emphasizes on transferring specific customer information into the generic product platform established. Basically, product definition and customization can be represented as a list of product specifications or target values, which is often a mixture of qualitative descriptions and quantitative values of a product.

Usually, a design team starts with exploring a combination of customer needs, corporate objectives, product ideas and related technological capabilities, and then concluding the process with a set of product definition (Chen et al., 2000). In this respect, Hauge and Stauffer (1993) developed the taxonomy of product requirements as an initial concept graph structure for questionnaires used for the construction of an expert system. Tseng and Jiao (1997) presented a product family architecture (PFA) containing what a company can offer to customers in terms of various product variants or extensions derived from base product designs to satisfy a spectrum of customer needs. A well-designed PFA provides a generic architecture for product families, which comprised a base product, i.e., a substantiated core of a product family, and building blocks customizing the base product with a PFA. Fung et al. (1998) rendered a so-called analytic hierarchy process (AHP) as well as a fuzzy inference system (FIS) to analyze and prioritize customer requirements prior to their being employed as customer attributes in a quality function deployment (QFD) matrix for product definition. McAdams et al. (1999) suggested a methodology to perform functional explorations in design prior to the existence of a specific product architecture. In this approach, a clear connection among customer needs, functions and forms can be mapped into an interdependent product hierarchy. Chen et al. (2001) established a concurrent product design evaluation system that contains an engine of fuzzy inference system (FIS) for wood golf club head design. In developing this system, a graph decomposition algorithm (Chen & Occeña, 2000) and a knowledge sorting process (Chen & Occeña, 1999) based on hierarchical sorts were employed for the analysis of knowledge attributes, such as the customer needs, standards and ease of use.
Although these approaches have preliminarily provided some motivations to the customer-product interaction during product concept development, there is still lack of a systematic product conceptualizing strategy that spanning form design knowledge acquisition, representation and organization. The difficulties in generating product definition/customization include:

1. For product definition
   (1) A single and effective design knowledge acquisition technique, which is able to elicit design knowledge from such knowledge carriers as designers or domain experts, is lacking.
   (2) A comprehensive design knowledge representation scheme, which can possibly help in organizing the multidisciplinary knowledge such as diagrammatic, psychological, semantic, mathematical and logical domains, is scarce.

2. For product customization
   (1) To deal with the abstract and qualitative nature of product platform, it is imperative to conduct design knowledge reasoning and design decision-making in a quantitative and normative manner.
   (2) To embody the role of customers in design decision-making, it is necessary to transfer customer voices to a product platform in a simple and logical fashion.

Based on these understandings, from a design knowledge-handling viewpoint, the proposed approach aims at establishing a novel product definition and customization system (PDCS) for organizations to meet the demand of an efficient and flexible strategy for product concept development. The proposed prototype PDCS comprises two phases, namely, product definition using the laddering technique and a novel design knowledge hierarchy (DKH), and product customization using an integrated methodology of Kohonen association (KA) techniques and conjoint analysis (CA). Accordingly, this system offers a method of making design decisions on the basis of customer voices, i.e., a strategy for transferring customer information into a specific product concept. A case study on wood golf club design has been used to illustrate and validate the PDCS. The details of the validation are discussed.

2 A Prototype Product Definition and Customization System

A prototype PDCS, which emphasizes the merging of a generic product platform and a specific customer-oriented product concept, is proposed in this paper. The prototype PDCS consists of two phases: (1) a product definition phase (i.e. product platform formation) that solicits a generic product platform and presents it via a so-called design knowledge hierarchy (DKH); and (2) a product customization phase (i.e. product concept generation) that customizes the DKH through customer involvement. It attempts to integrate both product
definition and customization together in a time-saving and accurate way to adapt to the rapidly changing customer needs and short product life cycle. The details of the system implementation are presented in following sections.

2.1 Product Definition

2.1.1 Design knowledge acquisition

From a design knowledge-handling viewpoint, the design properties within a product platform, such as design specifications of a product, can be solicited from designers via a process of handling product information. However, there still exist a number of imperatives in acquiring designer’s knowledge in the early stage of product conceptualization. These include:

1. Under the circumstances of rapidly increasing competitiveness in today’s business climate, product development has become more and more complicated. In addition, a number of complex knowledge carrier’s behaviors, such as perceptions, motivations, attitudes, and personality, influence the way in which designers organize and interpret a company and its products. As such, an effective technique to acquire the designer’s knowledge is highly desired in establishing a product platform.

2. It is necessary to employ a simple and effective technique to deal with the bespoke complex knowledge acquisition problem during product platform formation. The technique should be able to elicit broad designer’s knowledge and be conducted in a controllable process.

3. The knowledge acquisition technique should possess a seamless integration with subsequent designer’s knowledge representation scheme, such as a widely-accepted hierarchical structure, in both theoretical orientation and format.

Based on these understandings, a well-established knowledge acquisition technique, the laddering (Rugg & McGeorge, 1995), presents a logical alternative for knowledge acquisition in product platform formation, and is accordingly employed and specified for designer’s knowledge acquisition in this study. Laddering is a structured questioning methodology derived from Kelly’s repertory grid technique (Kelly, 1955). It was initially developed by Hinkle (1965) for classifying the relation between the constructs and organizing them into hierarchical relations. Similar to other ‘contrived’ knowledge elicitation techniques such as sorting techniques (Rugg et al., 1992), it was originated in psychology. It has also been applied and improved with increasing frequency in the field of knowledge and requirements acquisition for product conceptualization in recent years (Chen et al., 2002; Chen et al., 2003; Khoo et al., 2002; Yan et al., 2001a; Yan et al., 2001b). Compared with other knowledge acquisition techniques, there are a number of advantages of using the laddering technique for designer’s knowledge acquisition as follows:
1. Psychological orientation. The laddering technique assumes that designers or domain experts know their design goals and are able to group them into different categories. It provides a novel way for transforming cognitive psychology factors into useful inputs for design issues.

2. Effective elicitation. The laddering technique is able to generate more rules and relevant clauses, has a wider coverage of domain, and requires less ‘effort’ in terms of mean total time for elicitation and coding. Moreover, it possesses more focused ‘control’ in terms of the signal/noise ratio over the direction of elicitation for process automation.

3. Hierarchical structure. The laddering technique requires less effort to transform output into alternative formats of ‘part-of’ or ‘is-a’ hierarchies, and imposes more categorical hierarchies or discrete classes. As such, it can be employed to bridge the knowledge carrier space (e.g. designers) and the design space (e.g. a hierarchical structure for representing the designer’s knowledge).

2.1.2 The laddering technique

Laddering resembles a form of structured interview in which the interviewer uses a limited set of standard questions to elicit respondent (customer) requirements. It is based on the assumption that respondent requirements are organized as a polyhierarchy, i.e., a multidimensional or multifaceted set of hierarchies. Laddering provides a structure for the elicitation of information using a ‘facet’, which is a convenient way to describe individual hierarchy and decomposition requirements. The procedure of the laddering technique is summarized as follows (Rugg & McGeorge, 1995).

**Step 1. Selecting / faceting a seed item**

An interviewer first selects a seed item, which is a point within the domain in question, from any level within the hierarchy. It is recommended that several sessions be conducted, each time for a ‘facet’ or ‘dimension’.

**Step 2. Preparing / phrasing the probes**

The interviewer uses probing questions to move around the structure embedding the seed item. Some of the frequently used probes or phrasings include ‘is-a’, ‘has-goal’ and ‘part-of’. Note that the nature of the probes (phrasings) can be rephrased according to the types of elicited hierarchy. In general, a wide range of links between the nodes of the hierarchy is advisable while the basic question format (as opposed to phrasing) remains the same.

**Step 3. Directing / leveling the semantics**

Although laddering proceeds simply and recursively, different prompts are recommended to alter the direction once laddering is not possible to go any further in a particular direction.
Moreover, the so-called ‘bottoming out’ (or ‘topping out’) is reached when it is not possible to proceed any further downwards (or upwards) in that line of questioning.

**Step 4. Decomposing/classing the explanations**

As the depth of explanations can be treated as an indication of requirement complexity, also known as elucidatory depth, explanations are then decomposed recursively until terms such as classes, attributes and entities have bottomed out. Basically, the maximum elucidatory depth is domain dependent. Flexibility that allows terms to be classified into relevant domain features, such as observable and unobservable ones and directly and indirectly measurable ones is provided.

**Step 5. Recording/coding the sessions**

Several coding methods are available for laddering; including paper record, graphical representation and pseudo-production rule. Appropriate labeling that displays the names of classes and attributes is advisable. In general, abbreviations of terms should be avoided.

**Step 6. Analyzing/post-processing the results**

This enables the elicitors to gain insights into the results of laddering. Quantitative analysis can be employed to post-process the results obtained.

**2.1.3 Design knowledge representation**

Although researches on product concept formation have realized that the product concepts should be postulated across different abstraction levels, the following limitations still existed.

![Figure 1: Representation of the design knowledge hierarchy.](image-url)
1. Most techniques are so narrowly used for the embodiment or detail design process (Reich, 1995).
2. The geometrical or physical assembly modeling rather than the functional or abstract leveling is employed prevailingly (Rosen & Peters, 1996).
3. A large number of models have focused much on the decomposing rather than the re-composing functionality for product platform representation (Kusiak & Huang, 1996).
4. Researchers have attempted to explain the hierarchical or topological architecture using the set theory. However, these expressions are not so intuitive and simple enough as to efficiently represent the product platform rather than search methodologies (Oommen & Loke, 2001).

Based on these notions, the basic requirements of representing the designer’s knowledge are likely to involve:

1. A simplified way to represent the designer’s knowledge acquired in different abstraction levels within a uniformed knowledge representation scheme.
2. A more abstract way to decompose the product platform, rather than in a physical or assembly fashion that is not suitable for product conceptualization stage.
3. A logical formulation of the initial product platform as well as relevant design properties and design alternatives.
4. A further possibility of convenient quantitative evaluation of the design structure.

In this work, a so-called design knowledge hierarchy (DKH) is proposed as the basis of representing designer’s knowledge for product platform formation. Figure 1 shows the architecture of a generic product platform (or design space) for establishing the DKH using laddering technique. The DKH, which organizes the designer’s knowledge registered, comprises a four-level top-down designer-directed architecture for decomposing a specific product concept. In this multilevel taxonomy, each design specification, which is stemmed from the high-level product platform, can be decomposed into several sub-specifications, and each sub-specification contains several alternative values. Typical design alternatives can be selected from different combinations of alternative values using the DKH to form a specific product family. As such, this hierarchical structure can be employed to represent the product concept in different abstraction levels from the generic (e.g. the designer-perceived product platform) to the specific (e.g. the design alternatives) conception. The results from the DKH and the selection of typical design alternatives may differ from one another due to different designers or domain experts involved. In this respect, the DKH can be viewed as a designer-perceived product concept (or product family) mapping from the generic product platform to the specific design alternatives as shown in Equation (1).

\[ \exists P_{ll} : P_{ll} \rightarrow C^g \quad \forall C = \{C^g\} \] (1)
where $\exists$ is the existential quantifier, $P_{1,1}$ is a designer-perceived product platform, $C$ is a designer-perceived product family (or product concept), $C_q$ is the typical design alternatives of a product family, $q$ is the sequential number of the typical design alternatives ($q = 1, 2, ..., Q$).

The tree-like hierarchy of the DKH is constructed in a top-down fashion, with the root on top (i.e. a designer-perceived product platform) and linkages spread downward to other nodes (or design properties). A symbolic characterization of the depth of a node in a hierarchy is its level. Proceeding inductively, the root of a hierarchy is, by definition, on Level 1. Subsequently, the subsequent levels starting from Level 2 can mathematically be expressed as shown in Equations (2) – (5).

For a designer-perceived product Platform:

$$L_1 = \{P_{1,1}\}$$

(2)

For design specifications:

$$L_2 = \{P_{2,1}, P_{2,2}, ..., P_{2,k}, ..., P_{2,K}\} = \{P_{1,1}^1, P_{1,1}^2, ..., P_{1,1}^k, ..., P_{1,1}^K\}$$

(3)

For sub-specifications:

$$L_3 = \{P_{3,1}, P_{3,2}, ..., P_{3,j}, ..., P_{3,J}\} = \{P_{2,1}^1, P_{2,1}^2, ..., P_{2,k}^1, P_{2,k}^2, ..., P_{2,k}^K\}$$

(4)

For alternative values:

$$L_4 = \{P_{4,1}, P_{4,2}, ..., P_{4,i}, ..., P_{4,I}\} = \{P_{3,1}^1, P_{3,1}^2, ..., P_{3,j}^1, P_{3,j}^2, ..., P_{3,j}^J\}$$

(5)

where $L$ and $P$ denotes respectively the level and node of the DKH, $k, j, i$ is the sequential node number in Level 2, 3 and 4, respectively ($k = 1, 2, ..., K; j = 1, 2, ..., J; i = 1, 2, ..., I$).

Besides the expression of each level, the design alternatives are obtained from the various combinations of the alternative values in Level 4 with respect to each design specification in Level 2. Based on a generic product platform, the typical design alternatives can be expressed in Equation 6 as a subset of a product family.

$$C^q = \{(P_{4,r})_{P_{2,s}}^1, (P_{4,s})_{P_{2,s}}^2, ..., (P_{4,t})_{P_{2,s}}^r\}$$

(6)

where $r, s, t$ stands respectively for the sequential number of alternative values with respect to each design specification.

The potential advantages of employing the DKH involve:

1. Comprehensive representation. The DKH represents both the decomposition relationship and the inheritance relationship within a product platform.
2. Multiple abstraction-level. The DKH is an effective means to provide a high-level overview of the entire product architecture. By so doing, the categorization at different abstraction levels of product platform, and their relationships and interactions can be easily formulated.

3. Scope limitation. By exploring the DKH, design alternatives can be easily and intuitively generated from different combinations of alternative values. In addition, design alternatives extracted from an initial product platform take into consideration of avoiding operational difficulty in handling a large number of possible design alternatives.

4. Quantitative process. The DKH possesses the properties of descriptive, such as a design specification, and normative, such as an alternative value. Accordingly, it is suitable to quantify the design properties via such information as customer ratings in the heuristic design evaluation.

### 2.2 Product Customization

#### 2.2.1 Design knowledge reasoning and design decision-making

![Diagram](attachment:diagram.png)

**Figure 2: Representation of the product customization phase.**

The design knowledge reasoning and design decision-making play an important role in narrowing down the design solution (or design decision) space on the basis of design criteria and constraints. This is because each design space (or product platform) is only dependent on a finite set of entities, whereas infinite possible design solutions exist. Thus, while
represented by a hierarchical structure alone, product concept becomes quite qualitative and uncertain. This is due to (1) the nodes of the hierarchy contain semantic or nominal values; and (2) there are few uncoupled relations between the properties of the product platform during product concept development, in particular. As such, a typical measurement from design knowledge carriers (e.g. customer importance ratings) is required to offer the numerical values to the properties of the hierarchy and to handle the product conceptualization more normatively and quantitatively (Chen et al., 2003).

In this study, an integrated methodology based on the Kohonen association (KA) techniques and conjoint analysis (CA) is proposed for design knowledge reasoning and design decision making during product customization. The framework of this design phase is shown in Figure 2. The KA method is employed to solicit the customer desirability, i.e., the correlation levels (e.g. weak or strong relationships) between the design specifications and design alternatives stemmed from the aforementioned DKH. On the other hand, the CA strategy is used to obtain the customer preferences with respect to various design alternatives based on the customer utility values.

2.2.2 Kohonen association for customer desirability generation

In previous work, the bespoke customer desirability between the design specifications and design alternatives was frequently determined by a specific designer or domain expert, for example, in marketing (Cattin & Wittink, 1982) and engineering (Tseng & Du, 1998). Nonetheless, it appears that those methods could hardly handle and reveal the actual desirability levels from the customers. In this respect, a method known as Kohonen association (KA) (Beale, 1993) has been employed in this work to improve the CA technique. The KA algorithm, which is extended from that of the Kohonen learning (Kohonen, 1989), is implemented as part of the proposed system to further process the information obtained from the DKH for product customization. In the KA algorithm, the connection between the input and the competitive layer for the self-organized competitive learning is specified using a set of instar patterns, i.e., the winner of the competitive layer is the pattern that has the weights closest to the current input. Here, the Kohonen association specifies the Kohonen learning in a manner that the density of the weight vectors assigned to an input region approximates the density of the inputs from customer voices associated with that region. It is also employed to detect the cluster centers of customer ratings for soliciting the customer desirability during product customization. The advantages of adopting the KA algorithm for this purpose include:

1. The solicitation of customer desirability is complex in product customization. It cannot be effectively handled by a simple function such as simple statistical functions.
2. As a self-organized algorithm, it possesses simple input features and properties such as fast learning and effective clustering.
3. It is comparatively easy to be updated. New customer data can be easily input into the input database.
In this study, the KA algorithm for the identification of cluster center of customer input samples are implemented as follows.

\[(R_k)_{Cv} = [x_k]\]  

\[(W_k)_{Cv} = [w_k]\]  

where \((R_k)_{Cv}\) is the customer importance ratings for design specifications \(P_{2,k}\) with respect to each design alternative \(C_q\); \((W_k)_{Cv}\) is the customer desirability between design specifications \(P_{2,k}\) and design alternatives \(C_q\); \(x\) and \(w\) are respectively the input node and weight in the KA algorithm; and \(k\) is the sequential number of design specifications \((k = 1, 2, \ldots, K)\).

**Step 1**: Initializing the network. Select \(w_k\) \((1 \leq k \leq K)\) as the weight for input node \(x_k\) in relation to output node \(y\), where \(K\) is the dimension of the input features of a certain sample. Let the number of training iterations equal to a priori, \(N\). Noted that the initial weights are set to small random values, and \(N\) is the pre-determined number of respondents (or customers).

**Step 2**: Calculating the Euclidean distance. Sequentially select an input pattern \(x(n)\) from the training data of input features. Compute the Euclidean distance of this input pattern from each weight vector associated with the output node.

\[d(n) = \sum_{k=1}^{K} [x_k(n) - w_k(n)]^2\]  

where \(n\) is the sequential number of each multicultural customer group in relation to input samples \((1 \leq n \leq N)\).

**Step 3**: Adopting the Instar rule. Especially in this work, the Kohonen rule is identical to the Instar rule, i.e., the output is either 1 or 0. Hence, the Kohonen learning is more efficient because of its convergent trend. That is

\[y(n) = \begin{cases} 1 & \text{if } d(n) \geq b \\ 0 & \text{if } d(n) < b \end{cases}\]  

where \(b\) is the predefined bias that controls the size of neighborhood.

**Step 4**: Adapting the Weight. Update the weight according to Equation (11). Especially,

\[w_k(n+1) = w_k(n) + \eta y(n)[x_k(n) - w_k(n)]\]  

where \(\eta\) is the learning rate \((0 < \eta < 1)\).

**Step 5**: Checking the terminating criterion. If \(n = N\), Stop. Otherwise, select the next input.
sample and repeat Steps 1 – 4. Finally, the weight vector can be treated as the cluster centre for all input patterns.

**2.2.3 Conjoint analysis for customer utility generation**

A DKH represents what a company can offer to its customers in terms of product variants and extensions (i.e. design alternatives) that can be defined from a generic product structure (i.e. product platform) to satisfy a spectrum of customer needs. With a DKH, each individual design alternative, i.e. a specific case of a product family, may contain several attributes of the design specifications. Conjoint analysis (CA), which was coined by Green and Srinivasan (1978), is based on the assumption that individuals can evaluate multi-attributes in such a way that their responses are approximately intervals in a measurement level. Specific in the proposed approach, it is assumed that a generic product platform, \( P_{1,1} \), can be described as a vector of K functional attributes or design specifications, i.e. \( P_{2,1}, P_{2,2}, \ldots, P_{2,k}, \ldots, P_{2,K} \), as shown in Figure 2. The utility function representing the customer preference on design alternatives is shown in Equation (12). For each typical design alternative,

\[
U^n_q = \sum_{k=1}^{K} \left( R^n_k \right)_{n,j} \left( W_k \right)_{C^q}
\]  

(12)

where \( U^n_q \) is the customer utility for a specific design alternative \( C_q \), \( n \) is the sequential number of respondents \( (n = 1,2,\ldots,N) \), \( \left( R^n_k \right)_{n,j} \) is the importance rating from a specific customer with respect to design specifications \( P_{2,k} \) within a product platform \( P_{1,1} \), and \( \left( W_k \right)_{C^q} \), which was obtained using KA, is the customer desirability between the design specifications \( P_{2,k} \) and design alternatives \( C_q \) in relation to various multicultural customer groups regarding such demographic factors as gender or age. This agrees with the conception that both similarity/typicality (i.e. customer desirability regarding multicultural customer groups) and variability/difference (i.e. individual customer importance ratings) amongst the diversity of multicultural customer groups are seriously considered.

Therefore, the customer information is input into this technique in terms of customer importance ratings and customer desirability, which will affect the final results of design decision-making in terms of the customer utility. For instance, the design alternative, \( C^q \), which is ranked first as the customer preferred choice, is related to the maximum utility value as shown in Equation (13).

\[
C^q \rightarrow \text{first ranking} \quad \text{if} \quad U^n_q \rightarrow \text{max}
\]

(13)
3 A Case Study on Wood Golf Club Design

Product concept development is an important stage in the development of successful wood golf clubs. Few decades back, the wood golf club manufacturers and distributors enjoyed a quite comfortable business climate thanks to less competition and lower quality and performance requirements from the customers. However, this situation has changed dramatically since late 1980s owing to rapidly increasing golfing population and intensive competition from both domestic and global manufacturers. As a result, for a golf equipment manufacturer to survive, strategic decisions are imperative to focus on corporate requirements, market share and profit margin. Moreover, a number of companies have realized that it is crucial to meet individual customer requirements via product customization, such as wood golf club fitting. For this purpose, the prototype product definition and customization system developed in this work is proposed to ride on this trend.

3.1 Product Platform Formation

This case study involved the design of a wood golf club. During the laddering process, an expert golf equipment designer was asked to contribute his voices upon probes by an interviewer (or elicitor) during a total of eight sessions of laddering (each session using a specific seed item at one time). Figures 3 and 4 present the graphical user interface (GUI) of product platform formation and the graphical representation of laddering for the design of a wood golf club, respectively. A four-level design knowledge hierarchy (DKH) was obtained, together with eight (8) design specifications, nineteen (19) sub-specifications and thirty-four (34) alternative values. It was observed that a large number of design specifications, sub-specifications and alternative values elicited possess overlapped (high-commonality of distribution) facets. For example, Design Specification ‘Total weight’ and ‘Head volume’ are largely shared. On the other hand, conflicts (adverse correlation) between design specifications such as ‘Head material’ versus ‘Estimated price’ can also be detected.

Figure 3: Graphical user interface of product platform formation.
Further processing on the DKH with a collection of selected alternative values (Table 1) yields the patterns of product portfolio known as design variants (or design alternatives) of a product family. The six design alternatives listed in Table 1 are determined using predefined marketing analysis. The KA technique can then be performed to evaluate the customer desirability between design specifications and design alternatives.

Table 1: Design alternatives with alternative values and design specifications

<table>
<thead>
<tr>
<th>Design Specification</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
<th>#5</th>
<th>#6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Material (Face/Body)</td>
<td>Ti Alloy/Casting</td>
<td>Ti Alloy/Forged</td>
<td>Stainless Steel/Forged</td>
<td>Ti Alloy/Forged</td>
<td>Ti Alloy/Forged</td>
<td>Maraging Steel/Forged</td>
</tr>
<tr>
<td>Length (cm)</td>
<td>115</td>
<td>112</td>
<td>115</td>
<td>115</td>
<td>115</td>
<td>112</td>
</tr>
<tr>
<td>Head Angle (Loft/Lie)</td>
<td>9°/55°</td>
<td>10°/56°</td>
<td>11°/57°</td>
<td>11°/57°</td>
<td>10°/55°</td>
<td>12°/57°</td>
</tr>
<tr>
<td>Total Weight (g)</td>
<td>270</td>
<td>250</td>
<td>300</td>
<td>290</td>
<td>280</td>
<td>270</td>
</tr>
<tr>
<td>Head Volume (cm³)</td>
<td>260</td>
<td>280</td>
<td>300</td>
<td>300</td>
<td>270</td>
<td>290</td>
</tr>
<tr>
<td>Shaft Material</td>
<td>L Carbon</td>
<td>L Carbon</td>
<td>Carbon</td>
<td>Carbon</td>
<td>Carbon</td>
<td>Fiberglass</td>
</tr>
<tr>
<td>Flex</td>
<td>X</td>
<td>SR</td>
<td>S</td>
<td>RS</td>
<td>S</td>
<td>R</td>
</tr>
<tr>
<td>Estimated Price ($)</td>
<td>1,100</td>
<td>800</td>
<td>500</td>
<td>700</td>
<td>900</td>
<td>600</td>
</tr>
</tbody>
</table>

Notes: Ti denotes Titanium, L denotes light, S denotes stiffness, R denotes reflex, X denotes extraordinary stiffness, SR and RS is respectively the level between R and S and between S and X.
3.2 Customer Desirability Generation

The respondents (or customers) were chosen from different multicultural groups. Such demographic characteristics as age, gender and skill level play a key role in product concept development of wood golf club design. In this case study, respondents of different age (i.e. young: < 35 and elder: ≥ 35), gender (i.e. male and female), and skill level (i.e. beginner and better amateur) were chosen to contribute their ratings on the design specifications with respect to each design alternative. Based on the combination of the three multicultural factors cum variations, eight multicultural customer groups, e.g. young male beginners, were formed with thirty respondents in each group. The respondents were asked to contribute their importance ratings according to a 1 to 10 scale, where 1 stands for the least importance and 10 denotes the most importance. Subsequently, the KA technique was employed for customer desirability elicitation (one set for each customer group). Figure 5 shows the input space of the multicultural customer group of thirty young male beginners.

Figure 5: Representation of example inputs (for young male beginners): (a) Customer input space; (b) 3D contour of input space.

Figure 6: Illustration of customer desirability (for young male beginners): (a) Customer desirability space; (b) 3D contour of customer desirability space.
Aided by the KA technique, the customer desirability in relation to a specific multicultural customer group can be acquired. Table 2 lists the customer desirability of the multicultural customer group of young male beginners. Figure 6 illustrates the desirability values three dimensionally. The GUI for customer desirability generation in the prototype PDCS is shown in Figure 7.

### Table 2: Customer desirability of young male beginners

<table>
<thead>
<tr>
<th>Design Specification</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
<th>#5</th>
<th>#6</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>4.1</td>
<td>5.4</td>
<td>7.6</td>
<td>7.3</td>
<td>5.0</td>
<td>6.8</td>
</tr>
<tr>
<td>II</td>
<td>6.9</td>
<td>4.0</td>
<td>8.0</td>
<td>8.2</td>
<td>7.3</td>
<td>4.1</td>
</tr>
<tr>
<td>III</td>
<td>3.2</td>
<td>6.1</td>
<td>7.7</td>
<td>7.5</td>
<td>4.9</td>
<td>7.9</td>
</tr>
<tr>
<td>IV</td>
<td>5.3</td>
<td>3.6</td>
<td>5.2</td>
<td>6.9</td>
<td>7.4</td>
<td>6.2</td>
</tr>
<tr>
<td>V</td>
<td>4.0</td>
<td>5.5</td>
<td>8.1</td>
<td>8.0</td>
<td>5.5</td>
<td>5.6</td>
</tr>
<tr>
<td>VI</td>
<td>4.5</td>
<td>4.8</td>
<td>7.5</td>
<td>7.3</td>
<td>7.1</td>
<td>5.7</td>
</tr>
<tr>
<td>VII</td>
<td>3.7</td>
<td>6.8</td>
<td>6.6</td>
<td>5.9</td>
<td>6.4</td>
<td>4.9</td>
</tr>
<tr>
<td>VIII</td>
<td>3.3</td>
<td>5.9</td>
<td>8.4</td>
<td>7.8</td>
<td>4.7</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Notes: I – VIII denotes the sequential number of design specifications; and #1 – #6 denotes the sequential number of design alternatives.

It can be observed that:

1. Quite different correlation levels are detected from the customer desirability between design specifications and design alternatives. For example, in Table 2 and Figure 6, the Design Specification ‘Estimated Price’ is highly/closely correlated with Design Alternative #3 as the desirability value reached 8.4 (intersection of Column #3 and Row VIII); while the Design Specification ‘Head Angle’ is loosely correlated with Alternative #1 according to the low desirability value of 3.2 (intersection of Column #1 and Row III).

2. As the listed values in Table 2 were limited to one of the multicultural customer groups, it is expected that different desirability values can be obtained with respect to different multicultural customer groups (Figure 7).

### 3.3 Customer Utility Generation

After the customer desirability elicitation is completed, the prototype PDCS can then be used for product customization for specific customers. For this purpose, a targeted respondent or customer is asked to contribute his/her importance ratings according to a 1 to 10 scale, where 1 stands for the least importance and 10 denotes the most importance, to the design specifications with respect to the product platform established. Subsequently, the customer utility is obtained using CA technique. Figure 7 shows the GUI for customer utility generation using CA technique in the prototype PDCS. Table 3 lists the customer importance ratings and the resulted utility values by two specific respondents of young male beginners.
It can be deduced that:

1. The customer utility with respect to design alternatives can be treated as the customer preference level to those selected alternatives.

2. The customer utility values obtained from the same multicultural customer group are quite similar (e.g. the utility values from Respondents 1 and 2 in Table 3).

3. Even though these two respondents belonged to the same multicultural customer group, they showed different preference in selecting design alternatives, i.e., Respondent 1 preferred Alternative #4, while Respondent 2 preferred Alternative #3. Furthermore, it appeared that both design alternatives might be the choices of a number of respondents from that multicultural customer group due to their high and close utility values.

Figure 7: Graphical user interface of product customization.
Table 3: Customer utility from two sample respondents of young male beginners

<table>
<thead>
<tr>
<th>Customer Rating</th>
<th>Design Specification</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
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<td>I</td>
<td>8</td>
<td>3</td>
<td>5</td>
<td>9</td>
<td>4</td>
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<td>5</td>
<td>8</td>
<td>6</td>
<td>8</td>
<td>2</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customer Utility</th>
<th>Design Alternative</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
<th>#5</th>
<th>#6</th>
</tr>
</thead>
<tbody>
<tr>
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<td>354.3</td>
<td>357.1</td>
<td>296.7</td>
<td>304.9</td>
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<tr>
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<td>260.9</td>
<td>357.2</td>
<td>354.4</td>
<td>280.4</td>
<td>296.6</td>
<td></td>
</tr>
</tbody>
</table>

Notes: 1 – 2 denotes the sequential number of respondents, I – VIII denotes the sequential number of design specifications; and #1 – #6 denotes the sequential number of design alternatives.

4 Concluding Remarks

A prototype product definition and customization system (PDCS) has been proposed in this work for successful product development. It aims at critically addressing the problems in product definition and customization during the stage of product concept development. The proposed prototype PDCS comprises two design phases, namely, product definition using laddering technique and design knowledge hierarchy (DKH), and product customization using an integrated methodology of conjoint analysis (CA) and Kohonen association (KA) techniques. The work has yielded the followings.

(1) For product definition, the laddering technique has been proven to be promising in eliciting the designer’s knowledge, from generic to specific abstraction levels, by the design knowledge hierarchy (DKH).

(2) For product customization, an integrated approach of CA and KA techniques has been employed and investigated for customer utility generation on the basis of intensive customer involvement.

(3) Based on (1) and (2), the prototype PDCS has been realized and its capability illustrated using a case study on wood golf club design. It is envisaged that the role of customers is expected to contribute more to product concept development in today’s competitive and globalized business condition.
References