WEB BASED DO-IT-YOURSELF DESIGN USING VIRTUAL PROTOTYPES

OON YIN BEE

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DEDICATION

To my beloved parents

Oon Chu Ngok and Chan Wai Ying

And

My lovely sisters

Yin Kee, Yin Wee and Yin Lee
ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to my supervisor, Professor Halimahtun Mohd. Khalid, Director, Institute of Design and Ergonomics Application (IDEA), who has guided me along the whole research project, read my numerous drafts and helped me make sense of the confusion in my research. I would also like to show my special thanks to Yan Lee, Tek Yong and Kang Leng, for their help, stimulating suggestions and encouragement throughout the duration of the research and writing of this thesis. Many thanks to Terrin Lim, and Choo Chiaw for their advice and help in understanding complex technical knowledge for the design and development of the configuration system on the Web. I am also indebted to Professor Martin G. Helander and my supervisor, for being expert evaluators in the usability evaluation.

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This thesis is an investigation into the human factors and usability issues of implementing a Do-It-Yourself Design (DIYD) on the Web using virtual prototypes. Four studies were conducted. The first experiment evaluated the usability of available commercial DIYD Web sites that offered customers the opportunity to design their own product using an electronic product catalogue-cum-configuration system. Three DIYD Web sites were compared, and the ANOVA was performed on the data. The results showed significant effects of specific Web site attributes and electronic product catalogue on user satisfaction. There were also significant differences between genders in user preferences for different Web sites. Male subjects preferred designing bicycles compared to female subjects who liked designing dresses. Using factor analysis, three generic factors were extracted for Web site attributes namely: holistic design, navigability, and timeliness, while for product catalogue the factors extracted represent design procedure, aesthetic preferences, information display, and design pleasure. In the second study, users' preferences for the product that was selected for study were obtained based on a target user group. The data were applied in the development of prototypes on the DIYD Web site-cum-configuration systems with 2-dimensional images and 3-dimensional virtual prototypes. The third experimental study investigated usability issues concerning two different types of configuration systems, and the design procedure preferred by users. Data were collected and analysed using ANOVA. The study confirmed that users preferred to design their own product in an e-configuration system using 3-dimensional virtual prototypes rather than 2-dimensional images, suggesting that the use of 3D virtual prototypes in a configuration system can increase customer satisfaction. Furthermore, the ordinal data, analysed using Spearman’s Rank Correlation, showed that users preferred to design the product flexibly rather than following a proceduralised top-down hierarchical approach. The main complaint from subjects for both system types was the limited design choices given for each product part. This then implies that developing an online configuration system requires greater understanding of customer needs, and the requirement for a good size database on design options. A post hoc study on the 3D configuration system found that participants enjoyed designing their own product in the Web site as it was not only a novel experience but easy to do. The various findings have implications for designing usable Web sites that meet customer needs, and for specifying the design task to support DIYD activity in future mass customization systems.
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CHAPTER 1
INTRODUCTION

1.1 Overview of the Thesis
Rapid development in new technologies drives customers to demand high-quality and low-priced products that meet their needs (Tseng et al., 1998). Manufacturers have to compete to overcome factors such as product variety and the speed to market. To be agile in product development, manufacturers need to understand customer needs, and to seize quickly changing market opportunities, as well as build products speedily in response to those needs (Anderson, 1997). In light of this development, the customer profile has changed—customers today are more liberated, choosy, informed and demanding (Tseng, 2000). Keeping customers satisfied requires manufacturers to mass customize their products. Mass customization is the selling of highly individualised products on a mass scale. Products are built to order, and manufacturing takes place only as and when there is an order from a customer (The Economist, 2001). The advantage of mass customization over mass production is that products are designed to customer specifics through direct communication with the manufacturer (Tseng and Jiao, 1996; Helander et al., 1998) via the World Wide Web (Web). The Web offers many types of services; one emerging service is getting customers to design their own products online.

This thesis is an investigation into the human factors of implementing a Do-It-Yourself Design (DIYD) on the Web using virtual prototypes. Four studies are reported in the thesis. The first experiment evaluated the usability of available commercial DIYD Web sites that offered customers the opportunity to design their own product using an electronic product catalogue-cum-configuration system. In the second study, users’ preferences for a product that was selected for study were obtained from a target user group. The data then were applied in the development of a prototype on the DIYD Web site-cum-configuration system. The third experimental study investigated usability issues concerning two different types of configuration systems, and the design procedure preferred by users. A post hoc study, conducted among the public, is aimed to prove further that users prefer designing the cell phone using the 3D configuration system with virtual prototypes. This introductory chapter gives an overview of the thesis, the research problems, study objectives, and the conceptual framework underlying the work.

1.2 Human Factors of Web-based Do-It-Yourself Design
Human Factors is a scientific discipline that is concerned with the understanding of interactions among humans, systems, and design methods in order to optimize the human well being and overall system performance (IEA, 2000). It takes a multi-disciplinary approach involving disciplines such as anthropology, psychology, medicine, physiology, engineering, computer science and education (e.g. Tillman and Tillman, 1991). According to Chapanis (1985: 2) "Human factors discovers and applies information about human behavior, abilities, limitations, and other characteristics to the design of tools, machines, systems, tasks, jobs, and environments for productive, safe, comfortable and effective human use."

Human factors research on the usability of Web sites is a growing field of specialization. This is due to the increasing use of the Internet in e-commerce. Human factors knowledge
supports the design of a product, tool or environment for human use. In order to make the product easy to learn and to use, the designer is expected to understand human abilities and limitations. Poor designs can influence human performance leading to failures or errors in a task (Tillman and Tillman, 1991).

Consideration of human factors issues is important for Web development (Forsythe et al., 1998). To stay competitive and create more business opportunities in the global market, mass customization, combined with electronic commerce (e-commerce), can help manufacturers to reach their customers directly. A Web-based DIYD system allows users to design their own product online while the company assembles the product (Khalid, 1999). This gives customers an opportunity to express their needs to the company. The introduction of an electronic product catalogue via a configuration system gives added advantage to companies who develop e-commerce on the Web. A configuration system that employs 3-dimensional (3D) virtual prototypes provides an effective way of presenting a product relative to a 2-dimensional (2D) image. Despite this advantage, there are several research issues surrounding the use of virtual prototypes that warrants investigation.

1.3 Do-It-Yourself Design (DIYD) on the Web
Despite the opportunities provided by new technologies, companies are still designing products in the conventional way. Through market surveys, they try to predict potential customer needs and design for the customers. Understanding customer needs in this rapidly evolving world of technologies can be difficult. Therefore, the DIYD approach is aimed at enabling companies to be more sensitive to what the customer really wants. By interacting directly with the customers, manufacturers can gather customer requirements, and giving them opportunities to express their choices from what the manufacturers can offer (Khalid, 1999; Khalid and Helander, 2001), thereby enhancing customer satisfaction. The final product too is expected to meet customers' needs. However there are limits to mass customization, as the options offered may not be afforded by the technology or the type of product to be designed. For example, a product with detailed engineering features may be too complex to be designed online by customers with no technical knowledge. Therefore, only simple consumer products, such as watches, dresses, cell phones, are typically offered to customers to be designed online (Khalid, 1999).

1.4 Electronic Product Catalogue-cum-Configuration System
Electronic catalogues such as the Pro-Quest periodical system (Pro Quest Company, 2001) were first delivered offline to users in compact disc (CD) format in 1995. The CDs not only increased the cost of the product but they were also limited to subscribers only since a copy of the CD would be provided to them. Libraries were usually their customers. In 1996, with online electronic catalogues (e-catalogues), users could search for the periodicals in their library through an online system before looking for articles in the library. This saved users' time since they need not queue to use the limited copies of electronic catalogues in the library. Moreover, e-catalogue provides better communication between companies and their customers, since the customers could access and search for the needed product easily rather than wait for the paper product catalogue which might not be up-to-date (Pro Quest Company, 2001).
There are several types of Web-based electronic catalogues that can be found today. Products can be presented in various media such as: text, 2D images, and 3D images. With the increasing use of the Internet, many developers such as Idtown.com and Voodoo-cycles.com have started to build customizable electronic catalogues in a component base for customers to select and configure products effortlessly via a configuration system that helps to increase the functionality of electronic catalogues on the Web. A few configuration systems offer e-catalogue in the form of virtual prototypes.

1.5 Virtual Prototypes
Virtual prototyping is a technique that could be integrated into DIYD to create a more comprehensible and innovative product catalogue (Tseng et al., 1998). With the virtual prototyping system, developers can produce high quality products within a short span of time. Given that manufacturers with a wide range of products have to generate product catalogues from time to time, electronic product catalogues help to reduce both production and distribution costs. Manufacturers too can easily change the data in e-product catalogues to cope with the short innovation periods and short spans of product lifecycles (Tseng et al., 1998).

1.6 Theoretical Framework of Web-based DIYD Using Virtual Prototypes
The conceptual framework for this thesis focuses on two main concerns: (1) human factors, and (2) Web-based DIYD process.

1.6.1 Human Factors Concerns
Investigation into Web-based DIYD using virtual prototypes requires identifying the human factors involved. Figure 1.1 summarises the main components of human factors, namely: Customer, Web Technology, Web Environment and Design Task.

The Customer (or user) component relates to the target customers of DIYD Web site. The cognitive aspects of the customer/user towards the Web site, and user perception could influence task performance and decision making. There are two types of visual information processing that could influence users’ perception while doing the DIYD task: bottom-up data driven processing and top-down conceptually driven processing (e.g. Lindsay and Norman, 1977; Marks and Dulaney, 1998). The bottom-up visual information processing refers to the extraction of information based on the characteristic and properties of a proximal stimulus (e.g. colour, shape, orientation and size) without the necessity of previous knowledge. This is unlike top-down visual information processing that is driven by the perceivers’ concept in determining perception. Perception refers to the meaning and organization given by the interpretation of sensory events based on previous knowledge.

Because most Web sites are loaded with information, the user will pay attention to certain selected information only. Usually the user’s prior knowledge or experience supports in perceiving the meaning of the information to be selected. At the same time, top-down information processing, which involves target and goal setting, helps to fine tune the process of selection and decision making. Therefore, the design of a Web site should not overuse too many distinctive features or animated images that may confuse the user, and
that there must be design consistency throughout the Web site (Marks and Dulaney, 1998).

![Diagram of Human Factors Approach of Do-It-Yourself Design on the Web](image)

Different individuals have different characteristics. Factors that may differentiate customers when they visit the online Web site include their attitudes, preferences, needs, gender, age or experience towards the task and/or purchasing a product online. Attitudes are made up of three components: cognitive, affective and behavioural (Rosenburg and Hovland, 1960). The cognitive component consists of a person’s beliefs towards an issue or object, the affective component consists of feelings towards an issue/object, while the behavioural component shows the tendency or disposition of a person to react in certain ways towards the issue/object (Radford and Govier, 1980). Applying this theory to Web-based DIYD means that users may have prior knowledge or belief towards Web sites on the basis of their browsing experience. This information leads to form certain opinions and feelings about what constitutes a good or bad Web site, and subsequently reacting either positively or negatively on the basis of the evaluative feelings. If positive, user may become addicted to the Web site, or if negative, user may just click away. The theory of Web addiction is often used to explain a user’s behaviour in spending hours on end on the Internet (e.g. playing freecell game), driven by challenging and motivating aspects of the task, rather than the Web site features (Helander and Khalid, 2000). The attractiveness of the Web site, navigation efficiency, helpfulness and learnability may also affect users’ attitudes, and the latter can influence their feeling of security towards the Web site and pricing of the product (Kirakowski et al., 1999; Helander and Khalid, 2000).

Modelling customer behaviour for the customization process may be done using theories such as living system theory (Kurniawan et al., 2001). This model is intended to explain
customer buying behaviour process in relation to the collection of components and organization similar to the mechanism of neurons in the brain. The customer involved in the customization process has to perform 2 types of cognitive activities, namely: product component selection and modification. For example, in component selection, whether the options fulfill customer needs in the customizable product, the customer would still have to perform certain processes to select their best final product. These processes included reading the information or options given, moving through all the options, comparing the options, selecting their desired options and eliminating the options chosen. These processes would be recorded and the company might know customer preferences on the basis of options that have been selected the most (Kurniawan et al., 2001).

The Web technology component defines the toolkits, both hardware and software, that have been developed in order to enable DIYD. The toolkits include the online configuration system, e-product catalogues, and virtual prototypes, as discussed previously.

The Web environment component implies the representational environment for customer’s interactivity, either a 3D virtual environment or a 2D environment. These environment types can influence customer’s visualization of the task. The DIYD task refers to the configuration of product parts from an e-catalogue. The procedure for performing DIYD can influence customer’s attitude, depending on the level of task difficulty. Conceptually, if the performance requirements of the task (e.g. difficult design procedure) exceed user’s limitations (e.g. inability to implement the design procedure), the outcome could be negative (e.g. user abandons the task). If the toolkits are easy to use, then users may be able to perform the task easily. If the technology requirements exceed user’s performance capabilities (e.g. inability to use the toolkit easily), user’s ratings on system usability could be negative as well. Other Web site criteria may also influence user’s satisfaction towards the Web site, such as ease of navigation, aesthetics, and downloading time.

1.6.2 Web-based DIYD Process
The life cycle of Web-based DIYD is illustrated in Figure 1.2. The first step in product development life cycle is uncovering customer needs (Khalid, 2000). Information on customer needs can be obtained from market surveys or field research. Such information enables a company to understand the customer’s requirements better, and match its offers to what the customer prefers. The company is then able to specify the functional requirements for the product accordingly. These functional requirements are then mapped onto design parameters to produce design options that are provided to the customer in the DIYD process (Helander et al., 1998; Tseng et al., 1998; Helander and Khalid, 1999).

A Web site, comprising an e-catalogue-cum-configuration system, is developed to enable communication between a company and its customers. If the Web site as a medium satisfies the customer, the designed product may be ordered online. The purchase by customer is an indication of customer satisfaction and acceptability of the Web site. A customer who is not satisfied may just click away and leave the Web site, thereby terminating the interaction between the customer and the DIYD service provider.
To a customer, satisfaction is likened to a goal to be attained from a consumption of products or patronization of services, and it may be a reinforcing, pleasurable experience (Oliver, 1997). This can reaffirm the customer's decision-making prowess. To the company, making a profit is the ultimate goal. Therefore repeat purchasing is essential to a continued stream of profitability. Even for long purchase interval products, such as automobiles or appliances, customer satisfaction is very important; thereby, organizations keep track reports of customer satisfaction over time (Oliver, 1997).

Satisfaction is defined by Oliver (1997: 13) as "the consumer's fulfillment response. It is a judgment that a product or service feature, or the product or service itself, provided a pleasurable level of consumption-related fulfillment, including levels of under-fulfillment or over-fulfillment." Satisfaction could result at the end of a customer's processing activities. A customer's satisfaction does not only depend on the final product or services received. The satisfaction level can be viewed from singular events leading up to a consumption outcome, and finally the collective impression towards these events. A customer can also be satisfied or dissatisfied with the level of satisfaction received throughout the whole consumption process, as described in Figure 1.3. In the case of DIYD, downloading time of the Web page, navigation in the virtual environment, and manipulation of the virtual prototype are examples of events that can lead to user satisfaction or dissatisfaction. These need to be evaluated to determine system usability.
Introduction

Satisfaction with the Complete Consumption Experience

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<td>Finding</td>
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<tr>
<td>Information</td>
</tr>
<tr>
<td>Action</td>
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<table>
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<tr>
<th>Satisfaction with Final Outcomes</th>
</tr>
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<tbody>
<tr>
<td>Enjoyment</td>
</tr>
<tr>
<td>Excitement</td>
</tr>
<tr>
<td>Involvement</td>
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</tbody>
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<table>
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<tr>
<th>Satisfaction with Level of Satisfaction Received</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inadequate</td>
</tr>
<tr>
<td>Adequate</td>
</tr>
<tr>
<td>Excessive</td>
</tr>
</tbody>
</table>

Figure 1.3: Variants of “Satisfaction” (after Oliver, 1997)

1.7 The Research Problem

Several issues drive this research. First, from a brief survey of the Internet, there are only a few DIYD Web sites that enable users to design their own product online based on the company’s offer, namely: Squash Blossom, the first fashion design studio online (Khalid, 1999); Global Customization Services Limited (1999), the first company to allow users to design their own watches online via Idtown.com; and Voodoo Cycles for designing bicycles (Voodoo Cycles, 2000). Other Web sites do not address DIYD as defined in this thesis. Some Web sites let users choose their product parts based on options given in a form or questionnaire; for example, Computer Supplies (Wales) Limited (2000) which provides users with a form on options for designing their own computer online (see http://www.designapc.com/design.cfm).

Second, most electronic product catalogues on the Web are 2-dimensional (2D). Although there are a few Web sites that allow users to perform the DIYD task, the options provided are 2-dimensional. Users often have difficulty in visualising the real product just by looking at 2D images alone. Although Jaguar Company shows their products in 3-dimension using simulation techniques, users can move the Jaguar car model to the left or right only. Other electronic catalogues present their products using photo-realistic panoramas technique to enhance presentation of the product to the customer (http://www.realtor.com). Companies like Nokia (2002) provide interactive multimedia using Flash or QuickTime Virtual Reality (VR) for users to view or move around the hand phone. Such graphical information might not be enough to give customers details of the real product that they might buy. There is still a lack of 3D implementation of virtual prototypes in electronic product catalogues. With better technology support for 3D design and development, integration of 3D virtual prototypes into e-catalogue-cum-configuration system could enhance user visualization of the intended product, leading to greater understanding of the product’s functionality (Tseng et al., 1998).

Third, from the Internet review, some Web sites that allow customers to design their own product offer a standard and inflexible design procedure in designing the product online (Oon and Khalid, 2001). The design procedure may not be what customers expect. The norm is to design following a hierarchical approach (Khalid, 1999), that is, selecting first general features on product functionality, then the detailed features. Although this may be
the norm, companies may want to explore flexibility in the design sequence so as to increase usability.

Fourth, while many companies have conducted surveys and market research on potential customer needs, the final product may not necessarily meet their needs. Satisfying customer needs has been a major concern of companies, especially in e-commerce and mass customization (Khalid and Helander, 2001). Besides uncovering the average needs of customers, developing a product family architecture in a fast changing global economy (Tseng, 2000) requires much analysis and effort.

Fifth, the usability of the Web site and configuration system is an important issue in improving ease of use and increasing user satisfaction. Various guidelines exist to support better design of Web sites (Forsythe et al., 1998; Nielsen, 2001). Past studies on the usability of Web sites have shown that poor usability will only drive customers away (Khalid, 2000). Design of the Web site should not frustrate users, especially if they find it hard to get information, are confused about the displays, or are hard to navigate (Goonetilleke et al., 2001).

Finally, the issue of gender bias may influence the customer's attitude whether to design a certain product and/or to purchase it. Studies have indicated that male and female customers react differently to certain products (e.g. Yun et al., 2001). Therefore, the effect of gender in product design is important to ensure the success of DIYD and mass customization.

1.8 Research Objectives
The main objective of this research is to investigate and document human factors and usability issues in Web-based Do-It-Yourself product design using virtual prototypes, and to identify the design procedure preferred by users in DIYD. These objectives are achieved through the following sub-objectives:

1) To document usability issues for currently available commercial DIYD Web sites and configuration systems. As such, to identify the main factors which influence user satisfaction towards the DIYD Web sites and configuration systems;

2) To investigate the design procedure preferred by users in DIYD;

3) To develop a prototype of a DIYD Web site using a configuration system with virtual prototypes; and

4) To compare and evaluate the usability of the derived DIYD Web site using 3D virtual prototypes with that of a 2D DIYD Web site.

These objectives set to define the design of experiments and field studies undertaken in this thesis.

1.9 Research Framework
The research problem and derived objectives are investigated in a series of research activities. Figure 1.4 describes the main activities undertaken in the research: (1) survey and evaluation of customer needs, (2) design and development of an e-configuration system, (3) usability evaluation of the prototype system, and (4) post hoc assessment of the said system.
1. Usability evaluation on current DIYD Web sites using questionnaires
2. A sample survey on customer preferences towards cell phone attributes using questionnaires
3. Review of past studies

**Survey and Evaluation of Customer Needs**

**Design & Development of e-Configuration System**

**Configuration System:**
- Using 3D virtual prototypes
  1. Web layout design
  2. Design of system structure
  3. Virtual prototype modelling using Catia 5.0 and 3D Studio Max 4.0
  4. Integration of e-configuration system in the Web page using Catia 3D, Java Script, Java and HTML
  5. Setup Web server

**Using 2D images**
- 1. Web layout design
- 2. Design of system structure
- 3. Images editing using Adobe Photoshop 6.0
- 4. Integration of e-configuration system in the Web page using Java Script, Java and HTML
- 5. Setup Web server

**Usability Evaluation of Prototype System**

1. Usability evaluation on effectiveness and user satisfaction using questionnaire
2. Comparison between e-configuration system using 2D images and 3D virtual prototypes (using questionnaire)
3. Interviewed subjects
4. Video recorded subjects’ design history

**Post hoc Assessment of System**

1. Follow-up evaluation on e-configuration system using 3D virtual prototypes at S&T Expo, KL.

**Outcome:**
1. Usability data as guidelines
   - User preferred design procedure – top-down hierarchical approach
   - There are gender differences
2. Customer Preferences for cell phone attributes.
   - Anticipated User preferred design procedure – top-down hierarchical approach
3. Usability guidelines

**Outcome:**
1. e-Configuration system on DIYD Web site using 3D virtual prototypes
2. e-Configuration system on DIYD Web site using 2D images

**Outcome:**
1. Findings based on the experimental study stated in the left box:
   - Subjects enjoyed designing cell phone on the Web.
   - Subjects preferred e-configuration system using 3D virtual prototypes rather than 2D images.
   - Subjects preferred design procedure using a flexible top-down hierarchical approach.

**Outcome:**
1. Subjects satisfied with the performance of the e-configuration system using 3D virtual prototypes.

Figure 1.4: Summary of Research Activities on Web-based Do-It-Yourself Design Using Virtual Prototypes
Introduction

As mentioned in Figure 1.1, customer needs and individual differences influence customer satisfaction. The first step in the research is uncovering customer needs and preferences for the DIYD Web site, and to understand their preferences for product attributes to be used in development of an e-configuration system. In the first study, three existing commercial DIYD Web sites were evaluated on usability. This was followed by a sample survey of customer preferences for cell phone which was chosen as the product to be designed online. Then two e-configuration systems were developed for another experimental study, one using 2D graphics in a 2D representational environment, another system using virtual prototypes in a virtual environment. A follow-up study was conducted among the public at a Science and Technology Exposition in Kuala Lumpur in November 2002. This post hoc analysis evaluated the e-configuration system using 3-dimensional virtual prototypes only.

1.10 Definition of Concepts

There are several concepts used in this thesis that require both normative and operational definitions, as referred to in the context of the study.

1.10.1 Usability

The International Standards Organization (ISO 9241-11) defines ‘usability’ as the extent to which particular users can attain particular goals with effectiveness, efficiency and satisfaction in a particular environment (Jordan, 2001). Effectiveness measures the accuracy and completeness with which users achieve specified goals. Efficiency considers the amount of effort needed to achieve a goal measured by the time spent on a task or errors in task performance. Additionally, the effort needed for mental workload (Jordan, 1998), human resources and equipments should also be taken into consideration. User satisfaction refers to the level of cognitive comfort or pleasures that users experience in using the product and their acceptance of the product in accomplishing their task goals. A person's feeling of pleasure or disappointment can be estimated by comparing the perceived performance of a product with that expected. Subjective evaluations can provide estimates of user satisfaction, thereby usability.

In this thesis, only measures of system effectiveness and user satisfaction are taken. The ability of the Web-based DIYD configuration system to enable performance of DIYD task determines system effectiveness. Web site features such as downloading time, design procedure, and so forth define the measures. User satisfaction is determined from subjective evaluations of Web site design, such as design options, colour and so forth. Both types of measures are obtained using a 5-point Likert scale in the first experiment and 7-point Likert scale in the second experiment. In this thesis, the attributes of the Web sites and e-configuration system are defined in Table 1.1 (see Appendix 1.1). The measurement is via a questionnaire using Likert Scale.

1.10.2 Do-It-Yourself Design Concept

The Do-It-Yourself Design (DIYD) concept as used in this thesis was first proposed by Helander, Khalid and Tseng (1998). It means that users 'design' a product using options offered by the company while the latter assembles the product. The 'Design by Customer' term as proposed by Tseng and Du (1998) is used synonymously with DIYD to mean the same thing. The term 'design' as defined in the dictionary (Longman Asia Limited, 1998)