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Shape Design of Products Based on A Decision Support System

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Abstract— **From a historical perspective, two fundamental issues are observed for industrial designers: (1) what is the shape design process within the context of a modern product design process, and (2) how shape design theories, methods, tools and computer aided software can be effectively utilized for creating product shapes. A framework is proposed to resolve the issues by describing the relationships of the product design problems, product design processes, shape design processes, shape design methods and tools with consideration of the functional, ergonomic, emotional and manufacturing requirements. The framework implemented here is a new type of decision support system (DSS) - an object-oriented decision support system to assist the designers in designing product shapes.**

I. INTRODUCTION

Modern products are designed and manufactured for a particular market through a product development process which involves a team of people with diverse expertise to develop products for satisfying human needs. In a highly competitive market, the design of products becomes more and more challenging due to diversified customer needs and the complexity of technologies. Industrial designers are obligated to create product shapes that meet all the requirements from engineering functions, aesthetics and emotions, ergonomics and usability, to manufacturing. Even more, the products should comply with environmental friendliness. It is observed that each mentioned requirement created new problems, and then the major design movement for solving the problems emerged as a paradigm shift in the history of industrial design. Design theories, design tools, and design methods have been continuously developed in response to the new design problems [1-3]. These observed transitions from one assertion to the next are followed by the development of all kinds of design theories, design processes, methods and computer aided tools. From the historical respective of product design, developing modern products in changing social and cultural contexts leads to two fundamental issues for industrial designers for creating product shapes.

What is the shape design process within the context of product design?

The product shape design can be considered as a problem-solving process to create the final product shape from the initial requirements [4]. According to the various design problems, industrial designers need to think about how to design the product shapes with appropriate steps, methods, and tools, because it is related to product quality, cost, and time-to-market. The shape design activity is not a routine which is applicable to all kinds of design problems and products in diverse industries. All kinds of processes for product design, engineering design, industrial design, interaction design, ergonomic design, and Kansei design for different design situations have been proposed [5-13].Industrial designers are faced with the difficulty of planning the whole shape design process within the context of the product design process due to the various design tasks in developing modern products, and to the many options for product design process in practice and literature. The decision on the shape design process for the current design task cannot rely on the industrial designers' intuition and experience.

How can the shape design knowledge be effectively applied to solve the problems of creating product shapes?

Design of product shapes is usually considered as a black box, because the required thinking and knowledge for designing are inside the designer's brain. In this paper, the approach is explicitly decomposing the shape design problem into many sub-problems which can be more easily solved by industrial designer and synthesizing a final product shape from the solutions of sub-problems. Each sub-problem can be easily dealt with using appropriate tools and knowledge. It also becomes feasible to utilize artificial intelligence and technologies in computer science to assist designers in solving the sub-problems.

Figure 1 illustrates the discussed fundamental issues: transforming the initial requirements into the final product shape design by planning the right shape design process and using appropriate methods, tools as well as knowledge. This paper presents a framework describing the relationship of product design problems, product design process, shape design process, shape design methods and tools. Accordingly, designers can use the framework for their own shape design processes, choosing the shape design tools, methods, and using knowledge for their own design problems.

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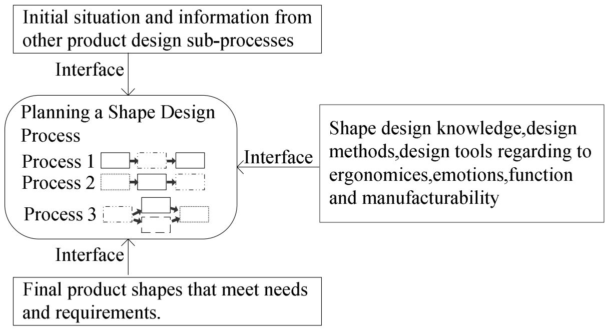

Figure 1. The schema describing the fundamental issues in product shape design

II. THE FRAMEWORK FOR PRODUCT DESIGN PROCESS

The purpose of the framework is to integrate the design processes across different disciplines as well as the design methods for product shape design under different design tasks in a precise manner. Two features, completeness and flexibility, are considered for designing the framework. The completeness indicates that the framework can be adapted to all kinds of product design tasks. The flexibility allows the framework to be easily expanded with newly developed design processes, methods, and tools. The approach of building the framework is described as follows:

(1) A comprehensive survey is conducted on product design tasks, all kinds of design processes from different disciplines, and their associated methods and tools.

(2) Each design process may be divided into sub-processes to the suitable level of detail. The relationships among the different design processes from the literature are investigated.

(3) The framework of the design processes is built.

(4) Finally, the design methods and tools are associated to the design processes in the framework.

The framework is discussed from two aspects: the shape design process within the context of product design and its associated shape design methods and knowledge.

A. *Basic Type of Product Design Process*

The first decision situation in planning the product design process is choosing the product category. Products can be classified into one of three categories: technology-driven product, technology-and-user driven product, or user-driven product. The technology-driven product is focused on the engineering functions while the user-driven product focuses on human-factor functions. The product strategy determines the category of the product. The technology-driven approach is usually adopted for developing the product in the infant and growth stages of its life cycle – S curve. When the product is mature, the user-driven strategy is used [7].

Each product category is associated to three common types of product design processes as shown in Figure 2. For technology-driven products, the engineering design process is followed by industrial design process. The engineering process is parallel with industrial design process for technology-and-user driven products. The industrial design process leads the engineering design process for user-driven products [7]. An engineering design process dealing with the design of engineering functions in a broad range includes mechanical engineering, electronic engineering, and software engineering. The industrial design process is related to the human factors, interaction and aesthetics. The following sections will describe the design processes for each product category in detail.

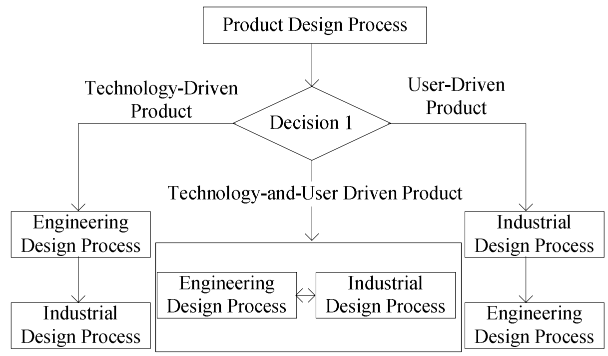

Figure 2. Product design process for different categories of products

B. *Design Process for Technology-driven Product*

The design process for technology-driven products consists of two sub-processes: (1) engineering design process and (2) industrial design process. First, the feasibility of the engineering concept is validated. Next, the product form is created by the industrial design process. The detail of engineering design and industrial design processes depends on the type of design task: original design or redesign. The determination of design tasks as an original design or redesign depends on the corporate strategy for disruptive innovation or continuous innovation. Original design refers to the use of new physical principles to realize the engineering functions, significant change of system architecture, or finding new applications for existing platform technologies. The original engineering design process consists of four phases: engineering concept design, configuration design, parameter design, and engineering detail design. Redesign is related to improving the engineering function with the change of component level or the dimension of the products, or modifying the product shape. Redesign can be further classified into three types – part configuration design, variant design, and selection design which only has fewer phases as shown in Figure 3. For each phase of engineering design, previous studies can be referred to for details [6-11].

The industrial design process can be decomposed into four phases of the shape design process: organization, surfacing, detail (industrial detail design), and graphics from Wallace's model [14-15]. The organization phase in Wallace's model is the same as the configuration design which has been performed in engineering design process under original design task. Surfacing phase is to generate enclosures in different styles, Details phase is to add details such as local surface alterations or new elements to complete the exterior surface, and Graphics phase is to apply graphical elements such as color, screening, decals, hot stampings, and texture to the outer surface of the product. Only three phases follow the engineering detail design as shown in Figure 3. The design principles from ergonomics and Kansei engineering can be applied to each phase.

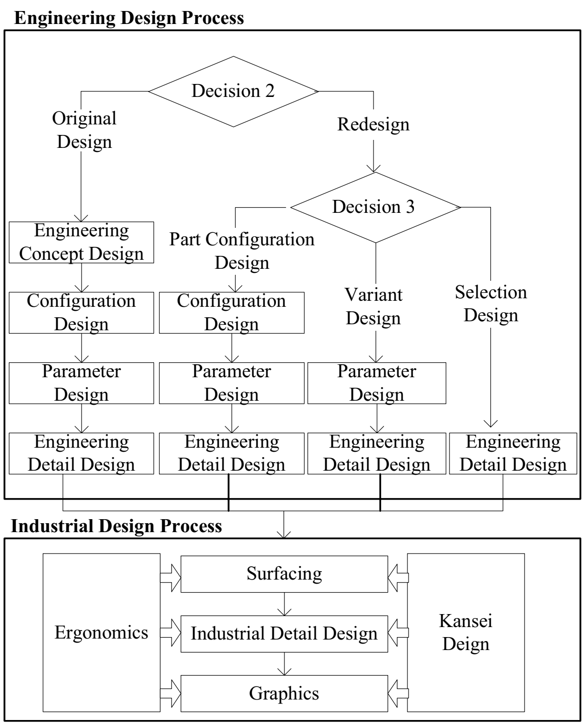

Figure 3. Original design and redesign processes for technology-driven products

C. *Design Process for User-driven Product*

The development of a user-driven product can be referred as a market-pull strategy. The development concepts always start from user scenarios, not from technological ideas. The design process for the user-driven product is usually led by industrial designers. The decision of product category is followed by two design situations: original design and redesign as shown in Figure 4. Figure 5 shows the detailed processes for original design and redesign respectively. The industrial designers develop the product concepts by industrial conceptual design process in original design case. Then the designer can consider the spatial arrangement of components from the viewpoints of ergonomics and Kansei in the phase of organization design. At the same time, the project team should consider the feasibility of engineering solutions from current proposed ideas. If there is a need to innovate a new engineering solution, engineering concept design and configuration design should be followed. Otherwise, the industrial designer can proceed to surfacing phase. The engineering parameter design related to the dimension of product can be performed before the surfacing phase, or engineers can perform it with consideration of surfacing design from industrial designers.

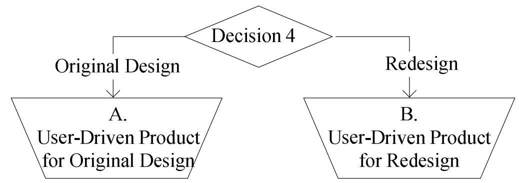

Figure 4. Design situations for a user-driven product

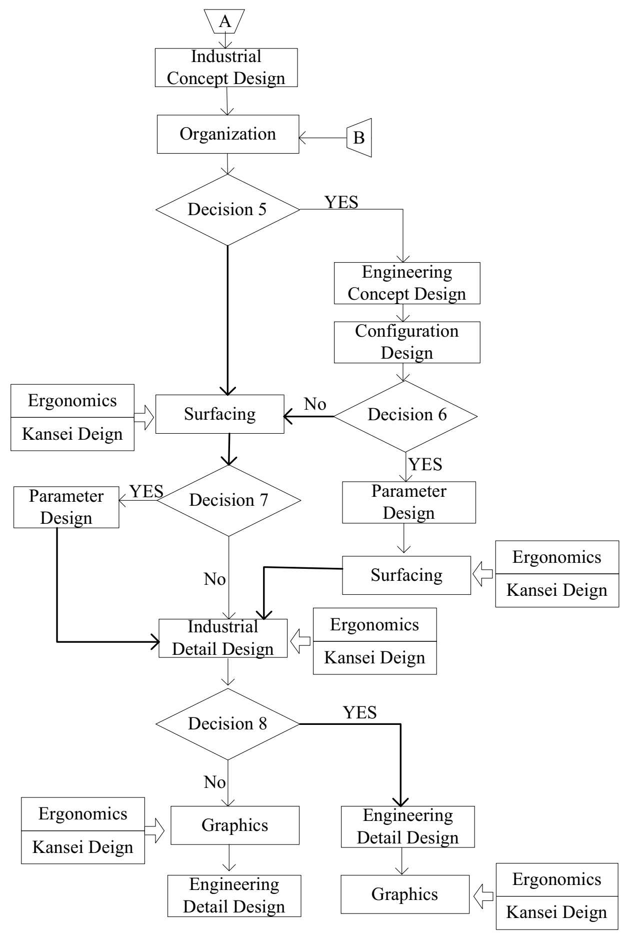

Figure 5. Original design and redesign processes for a user-driven product

The design principles from ergonomics and Kansei design can be applied to surfacing phase. After the surfacing phase, industrial detail design can be performed. When the industrial detail design is finished, the project team can decide if engineering detail design should be performed before or after the graphics design. During the graphics design phase, the designer can consider using the approaches from Kansei design and ergonomics. The difference of the design process between original design and redesign for the user driven product is that only industrial concept design is included in the design activity of original design process.

D. Design Process for Technology-and-user Driven Product

The design process for technology-and-user driven products is not specifically discussed in the literature. Many complex technology products demand high-touch user interactions for lowering the learning curve and reducing frustration with the operations of technology products. Thus the design process for this product category can be analogically described by an interaction design process. Interaction design deals with hardware/software integration, software application design, and interactive media and content [16]. IDEO proposes a five-stage process for interaction design: understand, observe, visualize and predict, evaluate and refine, and implement [17]. During "understand" and "observe" phases, the client is interviewed and the real users' behaviors are observed. The key problem can be found. Next stage is "visualize and predict" about the concept generation for the key problems. Interdisciplinary team members brainstorm to create concepts. All the requirements from engineering, ergonomic, Kansei, etc are considered at the same time by a group of people. Then detailed design and implementation follow. This design process is quite successful for developing many excellent products in IDEO. Following IDEO's processes, this design process for a technology-and-user driven product is shown in Figure 6.

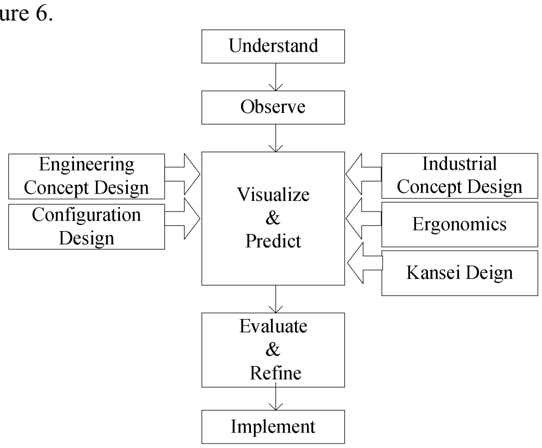

Figure 6. The design process for a technology-and-user driven product

III. METHODS AND TOOLS FOR SHAPE DESIGN

After the framework of the product design processes is fully built, each sub-process can be effectively associated with the design methods which are proposed in many studies. Figure 7 shows the schema of using design methods and tools. For example, product matrix, structure grammar and morphological method can be used for the configuration design. Style design process can use the tools of shape grammars, and Kansei engineering methods [17-21]. According to the structure of the framework, new design methods and tools can be easily added to the proposed framework. For example, when developing next-generation creative products, the designers usually sketch the product shapes from void. Then the engineers try to bring the sketches to life. They usually need and find the inspiration from fashion, architecture, and so on to create new shapes for new products. Instead of wandering around the imaginary world, creative thinking methods such as synectics have become popular for the designers to open their imagination. On the other hand, Bentley's book asserts that evolutionary computation for arts initiates the interest of researches in the 1990s [22]. We can add these new tools into the framework as shown in Figure 7.

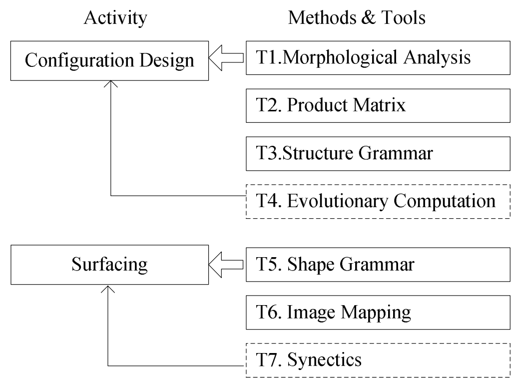

Figure 7. The schema for associating a design process with design methods and tools

IV. DSS FOR PLANNING OF DESIGN PROCESS

The proposed framework resolves the issues conceptually, but it may not provide a friendly way for practical use due to lack of support of storing and reasoning design knowledge. DSS has been widely applied to engineering design, industrial design and product design. To implement the framework, a DSS is considered for the following reasons:

(1) A DSS can facilitate the interaction between an industrial designer and computers to generate alternative plans for design processes.

(2) A DSS can provide unstructured design knowledge stored as rules or any kind of knowledge representation methods for making decision.

(3) A DSS can implement the framework more easily due to the available commercial software programming tools and research efforts in this area.

During the survey of DSS on product design, several types of applications have been found. Besharati et al. use a generalized purchase modeling approach to develop an expected utility metric on customer basis that forms the basis for a DSS to support the selection in product design [23]. Toben and Leo built DSS for selection of manufacturing processes in product design [24]. Giachetti aggregates the decision on material selection and manufacturing process selection into a DSS [25]. Masubana and Nagamachi proposed a hybrid Kansei engineering system to support customers and designers in deciding the kansei of the products [26]. Jindo et al. use semantic difference to find the relationship between customers' kansei evaluation of office chairs and design elements. The office chair can be created by their proposed DSS [27]. According to the present authors' best knowledge, no relevant research on DSS for planning of product design process is found. It is assumed that the reason is that the latent need for a better method of planning design process is not revealed and people are satisfied with current approaches to planning the design process. Actually current planning approach is inadequate.

Now we are faced with a new problem: synthesis of a new type of DSS. Our approach is to find an existing type of DSS which is closest to meeting our requirements. Then a new concept of DSS is generated by improving the existing type of DSS until all the requirements are satisfied. According to Power's taxonomy of DSS, Power differentiates communication-driven DSS, data-driven DSS, document-driven DSS, knowledge-driven DSS, and model-driven DSS by using the mode of assistance as the criterion [28]. Due to the need of the complex and unstructured information in planning a design process, a knowledge-driven DSS is selected as a candidate system for improvement. On the other hand, from the past experience of the researchers, object-oriented programming (OOP) provides many advantages over other tools like C or Prolog in implementing DSS for the conceptual design of products. OOP can facilitate a great visual interface or easy maintenance of DSS. Another key consideration is that object oriented design thinking has been introduced into industrial and product design. Gorti created CONGEN, a decision support system for conceptual design. The CONGEN object is used as a template for constructing an artifact, a design process, and many other objects for recording the design activity from symbolic evolution [29, 30]. The computer support of conceptual design becomes feasible in generating new concepts rather than only for drawing. Bijan et al. used universal modeling language (UML) in OOP to describe the users' need, scenario of usage, product structure and related design knowledge in product design. The object oriented design leads to a new direction for computer support of product design [31]. OOP provides the advantages of modularization, flexibility and scalability. Integrating an object-oriented and knowledge driven approaches, an object-oriented knowledge-driven DSS is proposed in this paper. It provides a good architecture to support the decision of planning design based on complex design knowledge. The unique feature in the proposed DSS is the symbolic-description of the evolution of the planned design processes. More detail about DSS can be found in Turban and Aronson's book [32].

The object-oriented knowledge-driven DSS for planning a design process has three parts: an object-based decision model, an object-based representation of design process, and an object-based database of design methods. The decision model of planning a design process is described as a decision tree as shown in Figures 2 to 7. Each node in the decision tree is treated as an object of decision class. The attributes of a decision-class object consist of object identifiers, decision description, decision options and decision goals. A process-class object represents the product design processes and sub-processes which are manipulated by the objects of decision class. An object in class of design tool represents an available tool or method associated with many process-class objects. Figure 8 shows the interfaces and interactions with decision makers. The decision history records the transition and status of each decision node in the decision tree.

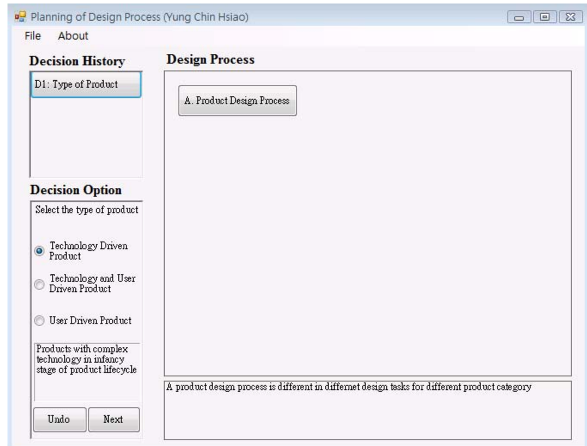

Figure 8. The interfaces of DSS for planning a design process

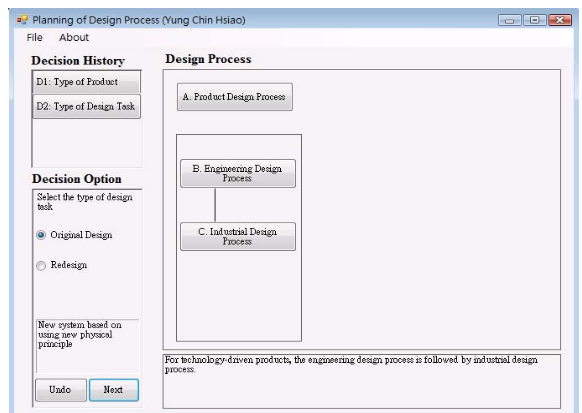

Figure 9. The planned design process for a technology-driven product

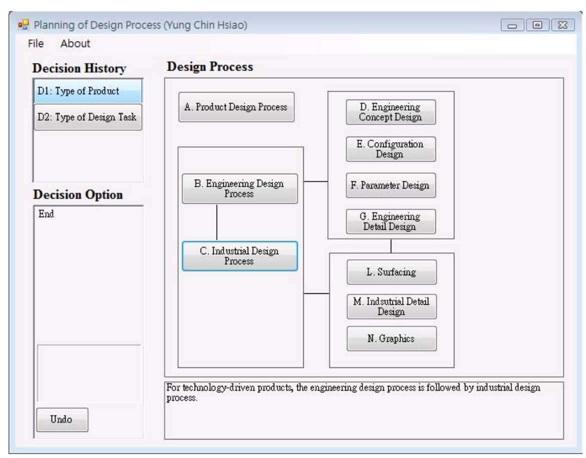

Figure 10. The planned design process for original design of a technology-driven product

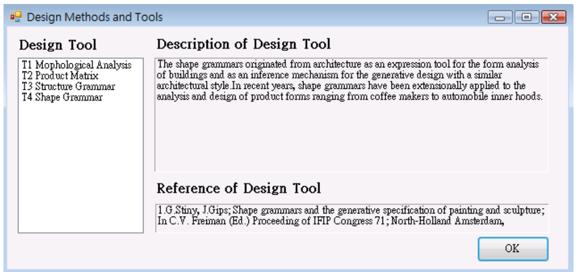

Figure 11. The interface of design methods associated to a design process.

The decision history allows the decision makers to store, retrieve, and modify the results of current planning activities in software. The decision option shows the options of decision for current decision node. The progress of the planned design process and relative information will be shown in the right part of the windows. For example, if the goal of the decision is finding the closest type of product in one of three product categories and technology-driven product is chosen, the software will next decision nodes and current planned design process as shown in Figures 9 and 10. Due to the huge information related to each design method and tool, the information should be managed by a database. Figure 11 shows the interface of design methods associated to the design process. The DSS is implemented in Microsoft Visual Basic 2008 first for user-interface design. Then Microsoft Visual C++ 2008 is used to create object-oriented DSS.

V. CASE STUDIES

Three scenarios illustrate the shape design of products based on the decision support system.

A. Infra-Red Lamp

The infra-red lamp as shown in Figure 12(A) has several drawbacks: (1) the hinge of frame cannot support the heavy light bulb in secure position after several months, (2) the lamp falls down easily, (3) The glass light bulb heat up the surface of the case cover with high temperature, (4) The red glare may be emitted to the eyes of the nearby persons. According to the decision support system, a sequence of decisions is made for this case:

Decision 1: Technology driven product,

Decision 2: Redesign,

Decision 3: Configuration design

This case is related to redesign an existing product with many insufficient functions. Therefore, the design process should focus on engineering first. The progress of product shape for this case is shown in (B) (C) (D) of Figure 12.

B. Measuring Device

The device measures and displays the status of human body. The fingers should contact with the electrodes in specific posture and the hands should be capable of holding the device. The device is invented with new functions. The human factors are seriously considered. According to the decision support system, a sequence of decisions is made for this case:

Decision 1: Technology-and-user driven product.

The shape design process is coupled with engineering design. For example, the spatial configuration of parts should be arranged for easy operation. Figure 13 shows the layout of the measuring devices to explore the possibility of engineering function and human factors. Engineers and industrial designers work together to solve the problems.

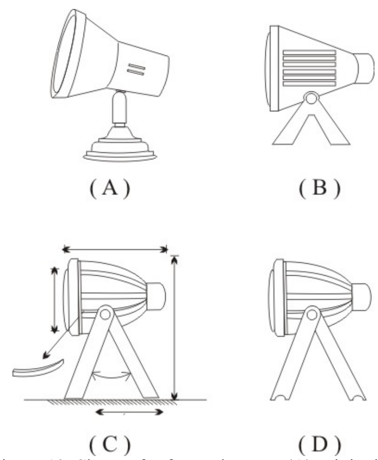

Figure 12. Shape of Infra-Red Lamp: (A) original design, (B) configuration design (C) parameter design, and (D) surfacing

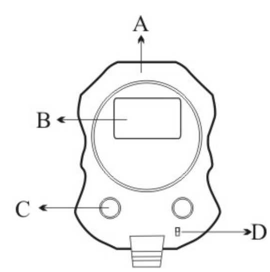

Figure 13. Shape of the measureing device: (A) Case, (B) LCD, (C) Touch Pad, (D) Switch

C. Scooter

The scooter has been developed for several decades. The market demands an outstanding looking of the scooter with its own identity. In this case, the major consideration is users' emotional reception. The decisions for the shape design process are made as follows:

Decision 1: User-driven product,

Decision 4: Redesign,

Decision 5: No engineering conceptual design, doing surfacing design with consideration of ergonomics, and using shape grammar for generating creative shapes,

Decision 7: No parameter design and doing industrial detail design,

Decision 8: No engineering detail design and doing graphics

Figure 14 shows the scooter shapes created from shape grammar [36].

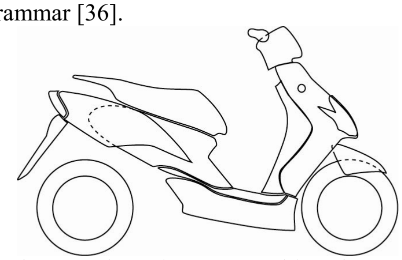

Figure 14. Shape of scooter created from shape grammar

VI. CONCLUSIONSE

Development of modern products is a challenging task subject to many constraints. Two fundamental issues for industrial designers are: what is the shape design process within the context of product design, and how the shape design knowledge can be effectively applied to solve the problems of creating product shapes. This paper proposes a framework integrating the product design problems, product design process, shape design process, shape design methods and tools with consideration of the requirement of function, ergonomic, emotional and manufacturing factors. The proposed framework is implemented using an object-oriented DSS that can completely integrate all the up-to-date design research into a knowledge base and provide an interactive interface. Therefore DSS can assist industrial designers to make a better decision on planning of design process and using design methods.

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