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TWO TYPES OF DESIGN APPROACHES REGARDING INDUSTRIAL DESIGN AND ENGINEERING DESIGN IN PRODUCT DESIGN

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1. Introduction

'Product design' is broadly mentioned in various disciplines involving product development. For example, engineering design books usually talk about product design when they explain engineering design, and occasionally practitioners are even mentioned as product designers. In many cases, industrial designers also claim that they are doing product design and they are product designers. Moreover, product development itself is frequently referred to as product design. The meaning of the product is also different from discipline to discipline. In engineering design, mechanical components and industrial plants are included in the product category, however these are not generally considered part of the product design process for industrial designs. On the other hand, industrial design considers crafted artefacts as products, though these factors are almost not considered in engineering design. This dichotomy may be because product design actually involves integrating different disciplines to accomplish a common goal, developing a new product. From this point of view product design should be studied as an interdisciplinary subject rather than being dealt with under a sole discipline whether it be engineering design or industrial design. Otherwise, an abstracted perspective of product design would not be significant. For such a perspective, disciplines related to product design should be identified and studied. Since different disciplines have their own natures, there can be different ways of executing product design according to different conditions in the process, for example developing different types of products under different market situations. In the following research, we will refer to these as 'design approachs'.

In this study, we reviewed what product design is in terms of industrial design and engineering design, we assumed that there were suitable design approaches for certain types of products and designers could selectively use one of them for designing a type of product in a specific condition. As the initial study involved looking at the correlation between design approaches and product types, we explored what types of design approaches can be possible and why these approaches are possible by reviewing existing literature. To address this issue, we reviewed the definition of product design and its relationship with adjacent design disciplines. As two major design activities in product design, engineering design and industrial design are explored, we compare several factors including their definitions, characteristics, products they cover and their roles in product design activities. Based on reviewing current product design processes, we introduced two types of design approaches; the *'inside-out approach'* and the *'outside-in approach'*, which can explain how two different types of product functions; *product-working function* and *human-using function*, introduced as notions developed in the product design process. Definitions of the two approaches are made and cases applying the approaches are briefly discussed. As we assumed that these approaches had close relationship with product types; we tried to connect these approaches to product types. To do that, we

briefly reviewed several product classification models. Finally we ended up with a summary and addressing issues to be researched in the future study.

2. Product design

The term product design itself causes confusion to people in the same way the generic term *'design'* does. When we talk about product design, it usually has an implied relation with *'engineering design'* and *'industrial design'*. In many cases, product design means engineering design [Haik, 2003, Hollins, 1990, Pugh, 1996, Ullman, 2004], and in the other many cases, it is dealt as the subject in industrial design [Lorenz, 1986, Tjalve, 1979].

[Roozenburg, 1995] defined product design as the process of devising and laying down the plans that are needed for the manufacturing of a product. [Horvăth, 2004], on the other hand, illustrates that product design is placed between industrial design and engineering design while these two designs are overlapped with product design (Fig.1). In this sense, engineering design and industrial design are involved in the product design process to some extent, even though they have their own defining characteristics and area. Hence neither industrial design nor engineering design on its own can fully describe the product design process.

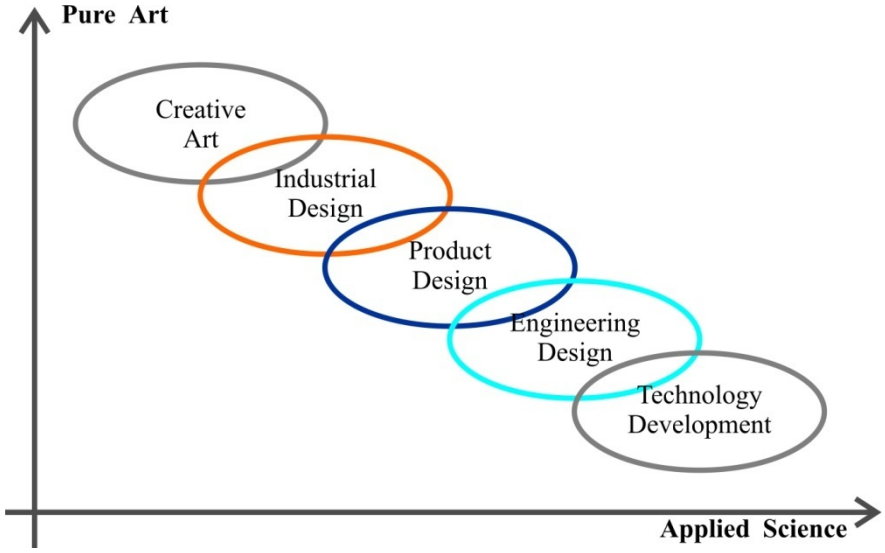

Figure 1. Position of Product design (by Horvăth 2004)

From another perspective, product design is not an isolated process but a part of a product development process. Some researchers use 'product design' as an equivalent term to product development or view it as an embedded process in product development [Hollins, 1990, Pugh, 1996, Roozenburg, 1995, Ulrich and Eppinger, 2008]. Several different disciplines are involved in the product development process. [Ulrich and Eppinger, 2008] said that the core team members for product development are the industrial designer, the mechanical designer, the electronics designer, the purchasing specialist, the manufacturing engineer, and the marketing professional. In their argument the product they mention was an electro-mechanical product of modest complexity, which covers a significant portion of the consumer product market these days. [Roozenburg, 1995] also claimed that engineering design, industrial design, ergonomics, marketing and innovation management are the disciplines nearly always involved in product design.

However some of the above mentioned professions are not the people who directly engage in design practice. They are rather people supporting design activities. For example, marketing people are those who support design activity by providing market and consumer data. Purchasing specialist and manufacturing engineer are the people who mainly work in manufacturing process and their work focuses on the realization of already-determined product forms and functions by engineering designers and industrial designers. Hence, among the experts who are said to be involved in the product development process when referring to 'product design', those who actually engage in practical design

activities are engineering designers and industrial designers. [Lindbeck, 1994] also pointed this out by mentioning the importance of the role of engineering designers and industrial designers in product development -*"manufacturers who are properly concerned with product quality will engage teams of engineering and industrial design people to create artefacts that work, look nice, and are easy to produce."* Thus engineering design and industrial design are viewed as the major elements of product design that take effort in the practical design activity.

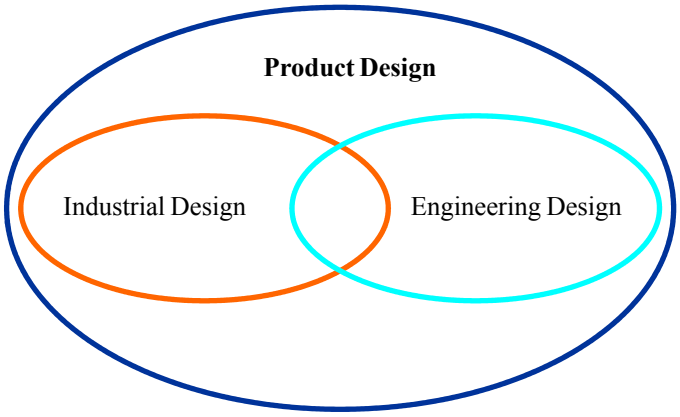

Figure 2. Two major parts in product design

3. Two types of designs in Product Design

As reviewed in the previous section, engineering design and industrial design are main components of product design. Thus to understand product design and see what kinds of different design approaches are in product design process, the characteristics of these two disciplines should be reviewed. Since these two disciplines include the common term 'design', they share common things; common design principle and process. However they have their own defining aspects.

Historically, engineering design as product design refers to mechanical design [Haik, 2003, Lindebeck, 1995, Pugh, 1996]. In this perspective, engineering design is defined as the process by which a need is met with a solution that is transformed into an actuality or product [Lindebeck, 1995]. In this process, a system, component, or process are devised to meet desired needs. And its process is relatively precise, systematic, mechanical, and even mathematical [Lindebeck, 1995, Ullman, 2008]. Typical examples showing the characteristic of engineering design methods are 'Quality Function Deployment Method (QFD)' which enables the transformation of customer needs into engineering value for a product and 'Axiomatic Theory' which is about the transformation of customer needs into functional requirements and design parameters.

Product engineering design deals with has a very wide spectrum, from small mechanical components to large systems, called 'technical systems.' This nomenclature constitutes plants, equipment, machine tools, large-scale assembly and components according to their complexity [Pahl and Beitz, 1997]. Most of these products have been based on mechanical ones. In other words, most times engineering design is considered related to product design are times when it focuses on mechanical design. Because of the wide spectrum of product categories engineering design deals with, some products like plants and machines are not related to industrial designs and these are generally the only areas in which engineering design contributes without any collaboration with industrial designers in the design process. Thus products with which engineering design and industrial design collaborate together in design process are the main concern of the product design discussed in this paper. Nowadays engineering design commonly takes care of internal elements of consumer products which are not purely mechanical ones. This is the category where engineering design and industrial design are more widely overlapped than other categories. This is why designers from these two disciplines need to collaborate with each other in product design.

This situation is not only noticeable in the practical field but also in design research. Engineering design research dealing with consumer products like coffee makers and mp3 player is becoming

common these days [Nepal et al. 2006, Park. 2008]. To some extent, their research seems to be more related to industrial design because they deal with product form and style. This may be because of the overlapping of and close connection between engineering design and industrial design.

While designing a product, engineering designers solve design problems relating to product functionality. They are primarily concerned with technical devices and systems [Lindbeck 1994]. They think about how a component performs its function and how different components are integrated to accomplish a products core function in a product system. Therefore their work in product design is mainly focused on functional elements and their interactive arrangement which is called 'layout design' [Ulrich & Eppinger 2008]. In this process, they usually designed the inside parts of a product. They determine functional elements and arrange them into physical chunks inside of a product. This kind of design activity can be viewed under the design process of *'product-working functionality'* because their activity mainly focuses on how to realize a product's functions.

On the other hand, Industrial design in product design has different aspects from engineering design in various points. It is defined by the IDSA that this kind of design is "*the professional service of creating and developing concepts and specifications that optimize the function, value, and appearance of products and systems for the mutual benefit of both user and manufacturer*" [IDSA 2009]. The concept of industrial design originally started as 'industrial art' [Lindbeck 1994]. Traditionally industrial designers have been the people who take charge of aesthetic aspects of commercial products. They refine form, shape and color based on the customer needs [Lorenz, 1986, Ulrich and Eppinger, 2008]. So their background has been mostly art-based and their works have been closely related to methods to make products aesthetically appealing for consumers. This means that their concern involves understanding how people feel. According to technology development and the needs of developing various products based on new technology, the role of industrial design has been extended beyond aesthetic appeal. It has come to play an important role not only for aesthetic appeal but also in reducing production cost and increasing ease of use [Flurscheim, 1983, Lindbeck, 1994, Lorenz, 1986]. They use ergonomic knowledge to make products easy to use and apply their artistic skill and manufacturing knowledge to reducing production costs. In this way, industrial designers have a significant and positive influence on company performance in new product development [Gemser and Leenders, 2000].

Nowadays the role of industrial design is widening. Companies are increasingly using industrial design as an important tool for both satisfying customer needs and differentiating their products from those of their competition, because they are primarily responsible for the aspects of a product that relate to the user's experience [Ulrich and Eppinger, 2008]. Actually industrial designers are often relevant to the user's whole experience around the product, from the purchasing moment all the way to the moment a product is discarded or stops being used; not only the product's visual aesthetic appeal but also how it sounds, feels and smells, how the user interacts with the product and what the meaning of the product to the user is on a personal and even a social perspective. This comes with diverse consumer needs according to technology and social development. So, these days industrial designers are using various tools for user research like *'contextual inquiry'*, *'ethnography study'* and so forth. *'Emotional design'* and *'interaction design'* are emerging areas in which industrial designers actively devise tools for making products more attractive and easy to use providing improved experience for the user. Thus, industrial design activity can be understood as the *'human-using functionality'* perspective.

The products that industrial designers cover are also very wide. They work with all kinds of manufactured products from small crafted products like wooden toys to home appliances and to large machine systems. Some industrial designers concentrate on crafted products and wooden furniture and do not need engineering designers' effort in their process. These are the exclusive areas where only industrial design activity exists in design process. And for some design cases like designing large machine systems, industrial designers' contributions are limited because they simply do graphic work on the machine surface. Therefore when industrial designers work closely with engineering designers in a product design process it is likely that they design products composed of engineered components and the products are related to the user's experience in some way.

Based on the comparison of engineering design and industrial design regarding product design, we can make a conclusion that engineering design plays an important role in realizing *'product-working functionality'* while industrial design is responsible for *'human-using functionality'* of the product. In another word, engineering designers are the people who concern internal design; actualizing functions, working out performance and product architecture, and industrial designers are the people who are concerned with external design or user facing design components, such as the user experience; aesthetics, ergonomics and user interface.
Based on this review of the products types that both disciplines cover, we argue that the products that both disciplines deal with during their collaboration are those relevant to the study of product design.

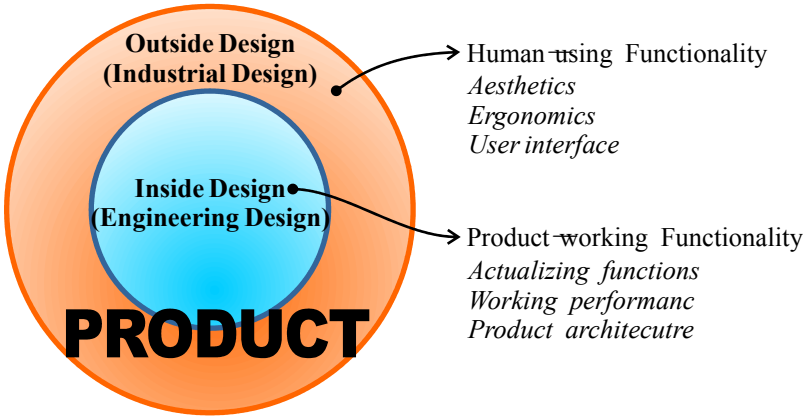

Figure 3. Industrial design and Engineering design in Product design

4. Design Approach

4.1 Product design process

There have been many design process models, some of which are from the engineering design field and some of which are from other design fields. As reviewed in the previous section, product design consists of industrial design and engineering design, and a review of the process of both disciplines is necessary. Design is said to be a human problem solving process. So every design process has common elements. That is, it starts with a perception of a problem and ends with some kind of related solution. The problem is transformed into a solution through the design process. However depending on the discipline, the design processes used is distinctive in specific way. For example an engineering designer calculates tension for a beam to verify structural safety while an industrial designer collects many colorful images to capture the user taste on product style.

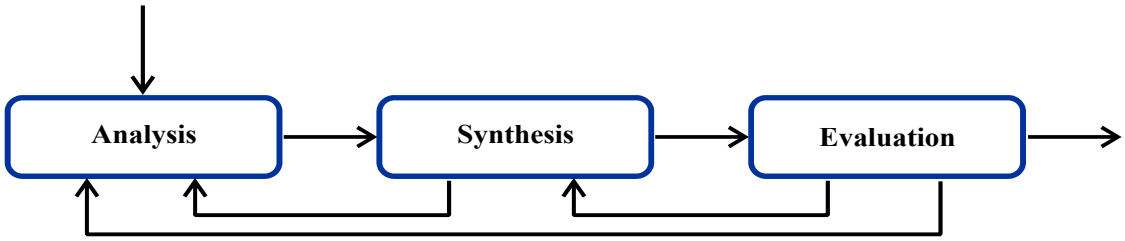

Figure 4. Design process model by Lawson

One of the very simplest and general design process models is explained in three iterative steps; *'analysis – synthesis – evaluation'* [Lawson, 1997]. In this process designers proceed to from the general to the specific, from 'outline proposals' to 'detail design'. This model describe common aspect of every design process across design disciplines and provide a general idea how a design idea is embodied through the general design process. However it is too brief and general to see what industrial design or engineering design does and in what stages.

The industrial design process is said to be relatively holistic. [Hong, 2007] illustrates this design process in eight steps. They are 1. design initiate, 2. design research, 3. design analysis, 4. design concept, 5. design development, 6. design finalization, 7. design evaluation and 8. design communication. In his model, he mainly focuses on industrial designers' tasks as form making (styling), graphic working and user interfaces. In the 2nd and 3rd stages, Industrial designers analyse the market, competitors, consumers and so on. For that, they work with many images which is called 'image mapping' giving a holistic idea about current market situation and visual positioning of the product to be designed. Nowadays designers often conduct user research to capture customer needs. They observe the user's behaviour in context analyzing the user's unmet needs. They also deal with cultural and social issues related to human behaviour, because sometimes they critically affect the user's way of using or the meaning of the product. This process is relatively holistic and is followed by interpretation of the result rather than a systematic analysis method. In the 4th and 5th stages, designers generate design ideas mostly by producing sketches. Frequently they develop using scenarios which describe how the new product might be used in various situations. In these stages, product form and way of interaction are defined. After that, photorealistic product images are often generated with 3D CAID systems defining the outside form, shape and way of human interaction with the product. Through the next stages, the design is evaluated and finally design specifications including CAD data, drawings, graphic data, and definition of way interface are transferred to manufacturing team.

Another, industrial design process which is product-development-oriented has six phases; 1. investigation of customer needs, 2. conceptualization, 3. preliminary refinement, 4. further refinement and final concept selection, 5. control drawings or models, and 6. coordination with engineering, manufacturing, and external vendors [Ulrich and Eppinger, 2008]. This process is similar with the process mentioned above except the later phases which describe industrial designers' collaboration with other teams to produce real products. Even after designing the product's form and user interfaces, they should closely collaborate with engineers until the product is launched, because the product's form is definitely connected to internal parts and the way these interfaces should be defined then transformed into physical functions through an engineering process. To deliver their design idea correctly, the design team should co-work with the manufacturing team up until the end of the process. Based on the above review, we argue that the industrial design process proceeds around designing the outside of a product while interacting with engineering design as they define the internal aspects.

The engineering design process generally has similarity with the industrial design process but detailed tasks are different. In their design process model, [Pahl and Beitz, 1996] describe the engineering design process with four phases (see Figure 5); clarification of the task, conceptual design, embodiment design and detail design.

This model regards the engineering design process as the process of layout and form development. In the conceptual design phase, problems are identified and functions are structured while searching for a suitable design solution. When the concept is defined, functional elements are arranged. This is known as the layout design stage where engineering designers use systematic or mechanical method to determine the best layout. Accordingly layout becomes a decisive factor in determining the final form of the product. Through the embodiment design phase, layout and form are finally defined.

Another similar engineering design process model with the Phal & Beitz's model is made by [Dym, 1994]. He presents a design process consisting of four phases; a task formulation phase, a functional phase, a form design phase, and forming results (Fig. 6). In this model, functional phase is corresponding with the Conceptual Design phase in Phan & Beitz model. The form design phase is similar to the Embodiment design phase. One important thing that has to be pointed out is that the two presented design process models have a similar reliance on layout design to define the form of the final result (determination of functional structure). Most of the design processes from the engineering design discipline have a stance that layout design is prior to form design [Dym, 1994, Haik, 2004, Pahl and Beitz, 1996, Ullman, 2004], although layout and form design are described to be developed though an iterative and possibly reflective process. Thus the engineering design process can be said to be more related with the internal design of a product, and concentrates on the layout of functional elements.

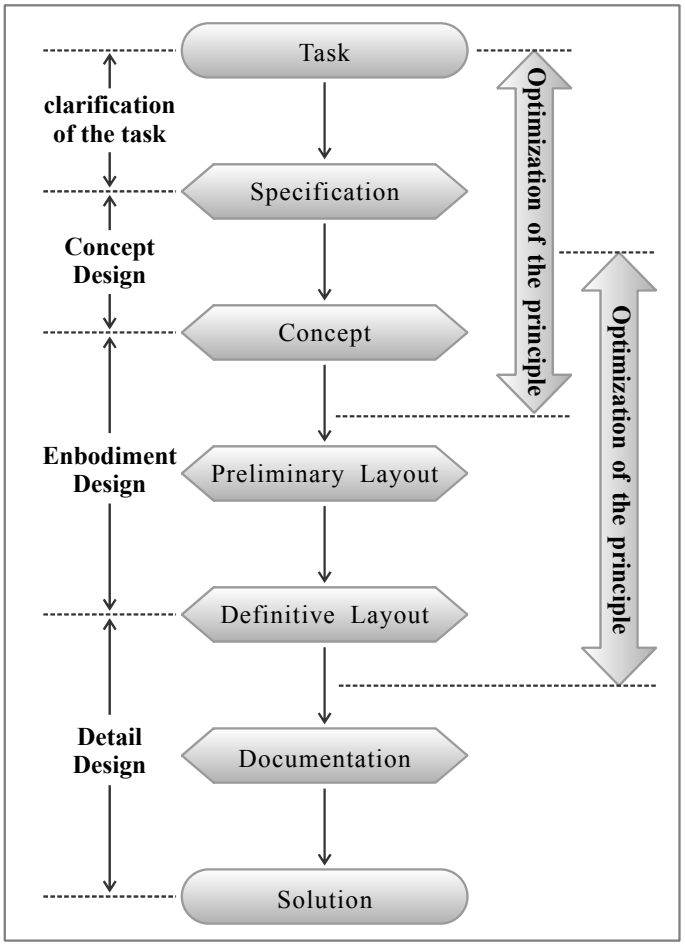

Figure 5. Engineering design process by Phal & Beitz

Other design process related to product design is product development process [Lindbeck, 1994, Pugh, 1996, Roozenburg, 1995, Ulrich and Eppinger, 2008]. Predominantly they don't divide industrial design activity and engineering design activity in their processes, however Ulrich & [Eppinger, 2008] present a process mentioning the implications of industrial design's involvement. They argue that industrial designers are involved after developing all the engineering design elements in the cases of technology-driven product development, and through the product development process in case of user-driven product development. This says that depending on product types industrial design is involved in the product design process differently. From this we can infer that there are different design approaches according to the style of interaction between industrial design and engineering design. For example, industrial design can firstly initiate product design and engineering design follows it or engineering design defines all the functional elements before outside design is defined.

In this section, we looked at the characteristics of design processes in product design. Industrial design process and engineering design process have common elements in general however their tasks and responsibilities are different. Industrial design process is specialized by designing the outside of a product regarding how the user interacts with it while engineering design concentrate on the inside of a product and is concerned with the product's functioning.

4.2 Two design approaches in design process

Most design process models from engineering disciplines explain the development of layout and form design. Many of which imply that layout design comes before proceeding to form design as reviewed from the previous section. This means that inside design is determined in advance, and as the result, outside design is defined. However from the industrial design point of view, this process can be

reversed. That is, the outside can be designed first and then the inside is designed by the engineers later. For convenience's sake, inside design can be viewed as design activity for defining and arranging functional components based on functional structure. This is one type of design activity based on a product functionality perspective and equivalent to layout design which is done by engineering designers. Outside design can be defined as designing the product's outside including form, shape and color and the way of interaction in terms of a user's experience, which is generally covered by industrial designers. This is another type of design activity based on the human-using functionality perspective.

Thus I can draw the conclusion that there are two distinctive design approaches; the *'inside-out approach'* by which inside design is defined prior to outside design and the *'outside-in approach'* by which outside design is defined prior to inside design.

The term 'inside-out' was used by Dreyfuss and Lorenz [Lorenz, 1986] to explain industrial designer's works. They used this term insisting that the exterior of product should be defined from the 'inside-out'. This has been a traditional industrial design approach where the fixed layout of

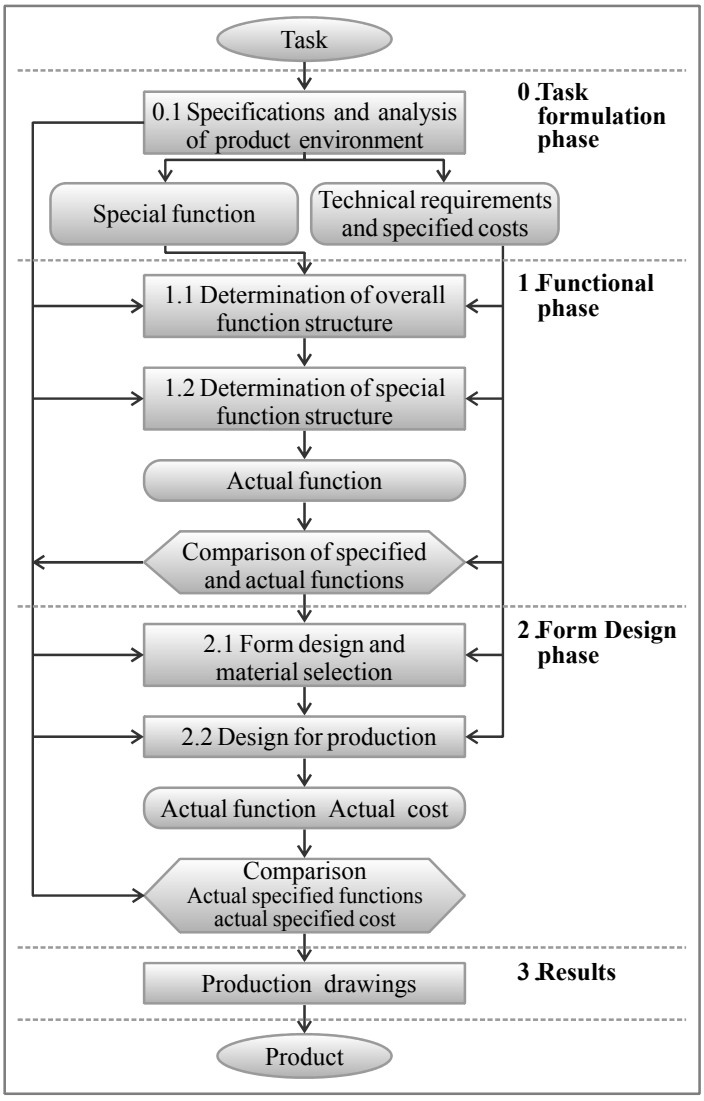

Figure 6. Engineering design process model by Dym

the inside functional components was given to the industrial designer who would then complete the outside form. This is closely related to the principle that form should follow function.

The difference with our definition of 'inside-out approach' from that proposed by Dreyfuss et al. in 'inside-out' is not significant, however the outside design referred to these days often includes more

activities than when they wrote, refereeing to solely the form design. Outside design as we use the term, is related to the user's experience with the product. It includes not only outside form but also all other aspects of the user facing design, even including emotional factors. That is, there are significant functions to be designed in the outside part regarding user experience.
The outside-in design approach is rare in practical cases. Inside design is barely completed in this approach because functional elements always needed specific space to be arranged and a specific way of interaction among them to accomplish a certain function. So it has been through non-practical field like design competitions that we generally see this kind of output. Industrial designers have publicized pure conceptual products with very simple and sometime even imaginary way of functioning for the purposes of conceptual design experiments and design competition. This kind of product often introduces totally new notions and would be very innovative if it was realized. However to realize these designs often is nontrivial and involves significant new process or technology development.
Recently, some companies show outside design should be prior to inside design to reach success in a competitive global market. One interesting case is the MP3 player manufacturer, 'Iriver'. They are now notable of their design and there is a famous story that the CEO of the company ordered the engineering designers to fit functional elements into the inside of an outside design; *"If functional elements are bigger than outside design, put them inside of it even by crushing them"* [Kim, 2008].
Nowadays this tendency seems to be increasingly common for manufacturers. They start product design by completing the outside design without setting any functional structure inside. This situation seems to be supported by technology, since many products regarding outside design first include electronic products. That is, functional elements of small electronic components have fewer limitations of arrangement than mechanical components might. According to the technology development level, this may also be possible for mechanical elements and products.

5. Design approach and Product type

Products composed of mechanical components are easier to design with an inside-out approach. This might be because a mechanical component can generally only take up specific space to be functional. Nowadays companies leading the market may use an outside-in approach as reviewed in the previous section. Based on this situation, design approaches can be differently applied according to the product type to be generated. Therefore it is necessary to classify products so we can explore these two approaches more deeply. There have been several product classification models. Doren classified product types into four categories for defining industrial design domain [Hong, 2007]. They are consumer products, commercial equipment, capital or durable goods and transportation. Another classification for industrial design has consumablee products, products for personal use, products used by groups of people and products having no connection with normal people [Löbach, 2000]. These models describe how people relate with products but don't say anything about design process. [Ulrich and Eppinger, 2008] propose another product classification model explaining how a type of product is developed. They also broadly classified products into technology-driven products and user-driven

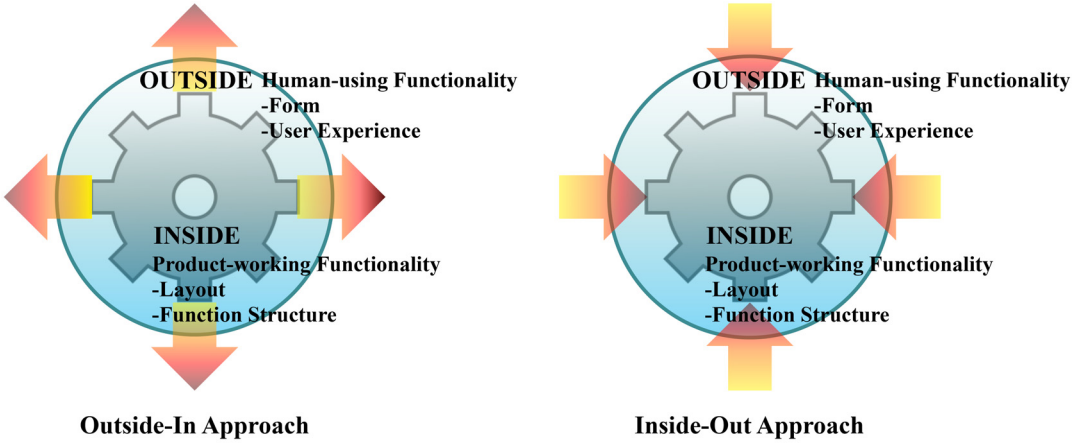

Figure 7. Two design approaches

products to explain how industrial design is involved in the product development process. This doesn't also tell us about the design approach. In the engineering design field [Eder, 2006] classified products into artistic work, consumer products, consumer durables, bulk or continuous engineering products, industrial products, industrial equipment products, special purpose equipment, industrial plants, configuration products, intangible products and software products. This differentiates the design process and deliverables according to products but doesn't say about design approach.
Reviewing several classification models shows that few studies have been done on product classification, attempting to explain design approaches for product design where industrial design and engineering design cooperate. To explore how inside-out and outside-in approaches affect product design, proper product classification models should be made. The starting point of this classification can be the identification of design elements of products which are dealt with by designers in some kind of design process. For example design property of a mobile phone is different from those of a bicycle. A mobile phone has separate interaction components for activating functional components, but a bicycle is controlled directly via functional components. This kind of difference may lead to different design approaches according to product types.

6. Summary and Conclusions

Product design consists of two types of designs, engineering design and industrial design. Mostly engineering design in product design has been referred to as mechanical design. Engineering design in product design is responsible for designing internal parts and its result is layout design. Industrial design in product design is responsible for designing the outside of a product and its result is an outside form and the related user facing interfaces. Because the two designs are core parts of product design, manufactures focus on incorporating engineering designers and industrial designers to develop successful products. Based on the task difference between the two designs, there can be two types of design approaches, the inside-out approach in which internal design precedes external design, and the outside-in approach in which the users' experience are outlined before the internal function of the product is defined. Most product design process follows an inside-out approach. Recently, however, some companies have shown that using an outside-in approach can lead commercial success. This implies that the design approach can have a close relationship with product types because most of these companies are manufacturers of electronic goods. The enabling factor for outside-in approachs may be technology generalization. This situation will be possible in not only electronic products but also mechanical products as mechanical technology advances or becomes electronically implemented. One possible result of this shift is that more innovative products will appear as both sides of the product design process become freer. These two approaches have close relationship with product types and this area requires a classification process. Although there have been several product classification models, few trials have been done to explore this factor in design approaches. Thus product classification for testing the two approaches should be done and to test them with product types, the current industry situation should be examined in depth. Design approaches may have been mostly determined by a design team's tradition in a company or a management style in practice. They will subsequently affect the design process and design results differently. These factors will be also characterized by product types and selectable based on product types and product development strategies.

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