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UNDERSTANDING THE WORLDS OF DESIGN AND ENGINEERING - AN APPRAISAL OF MODELS

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ABSTRACT

Using product innovation models as reference, this study presents barriers preventing integration between the worlds of industrial design and engineering design. Models illustrating workflow within both communities are compared, with the intention of revealing parallels and incompatibilities. Findings from research in design, cognitive theory, and innovation theory are then applied, seeking to explain why barriers exist. The study indicates a tendency in the design community towards seeing product development in a wider perspective, while engineers appear more concerned with technical detail. Furthermore, designers and engineers tend to have their own opinions about what design really is, what documentation forms are needed, how to tackle a problem, and why innovation models are needed. Seeking to develop mutual understanding, which is necessary for balancing 'soft' qualitative attributes and 'hard' performance requirements in product development, is challenging, since both groups possess limited capabilities in terms of recognizing or understanding what attributes are important to the other party.

Keywords: Design engineering, Engineering design, Product development, Models, Paradigms, Collaboration, Innovation, Integration, Cognitive Theory, Product requirements

1 INTRODUCTION

The term 'industrial design' was coined in the 1920s to describe the work of specialist designers, and is today generally used to describe the activity of improving aesthetics of mass-produced products to increase their marketability [1]. Krippendorff [2] suggests that 'design is making sense of things', a definition that despite its ambiguity provides a broader view of the industrial designer's role in an innovation process. Engineering design on the other hand, is generally concerned with the technical workings of mechanized products as opposed to aesthetics [3] or usability issues.

Significant contrasts exist between the worlds of design and engineering. Differences in education, mindsets, responsibilities, general guidelines, ways of addressing a problem, and work methods are only a handful of factors making up the big picture. Tackling the complexity of comparing the two communities requires a framework. The study reported on in this paper is therefore positioned where dimensions of both worlds do coincide, yet there is enough variation to point out differences. Models documenting product development workflow are commonly used among designers and engineers. At the highest level, these models can be used in two settings:

1. At the descriptive level, serving as a tool for describing the process, improving our understanding of workflow and information flow in product development activities, and
2. At the prescriptive level, serving as a means for teaching work practices by illustrating processes in a visual manner.

The objective of this study is to compare product innovation models developed within the communities of design and engineering with the purpose of identifying where the two worlds coincide and where they oppose each other, as well as where they may contribute to each other. Subsequent analysis seeks to provide pointers concerning the nature of these differences, and why they exist. It is our hope that a better understanding of the differences deeply grounded in design and engineering can set the stage for a dialogue between the two parties, which ultimately can result in more successful collaboration within industries. The study starts with a review of developments within the European design community, where the evolution of two well-known representative models from the industrial design and engineering design communities are used as basis.

2 BACKGROUND

2.1 Innovation model development in the industrial design community

The concept of modeling product innovation processes originates from the 60s, as design researchers sought to develop a systematic approach to product design, product development and product innovation [4]. They decided to follow a rigorous structure based on logical reasoning in order to establish a serious image comparable to more traditional academic disciplines. This resulted in efforts towards analyzing experiences from a working environment and presenting the process by a set of distinct steps organized in a logical order. Roozenburg [5] was among the first to rethink the waterfall representations of previous models, and he presented the design cycle as an alternative way of modeling innovation processes. Realizing that very few, if any, ideas arise out of the blue, the design cycle starts with an analysis of the current situation. Solution alternatives are then synthesized, simulated, and evaluated against the original design situation. The cycle is repeated as partial design solutions are assembled into a complete product. Each stage is made up by a divergent activity followed by a convergent activity, with the intention of exploring the solution space by getting as many alternatives as possible and then identifying the most promising of them. Roozenburg and Eekels [6] developed the design cycle into the first Delft Innovation Model, named after the Dutch university at which they were both employed at the time. The model employed three parallel stages, production development, product design, and marketing planning. Realizing that the market introduction of a new product will lead to reactions from competitors as well as user feedback, the company will have to introduce new products on a continuous basis in order to stay competitive over time. The end of one innovation process represents for this reason the beginning of the next. Introduced in 2003, the detailed circular model of the product innovation process (DCMPIP) [7] illustrates this point by retaining a circular form.

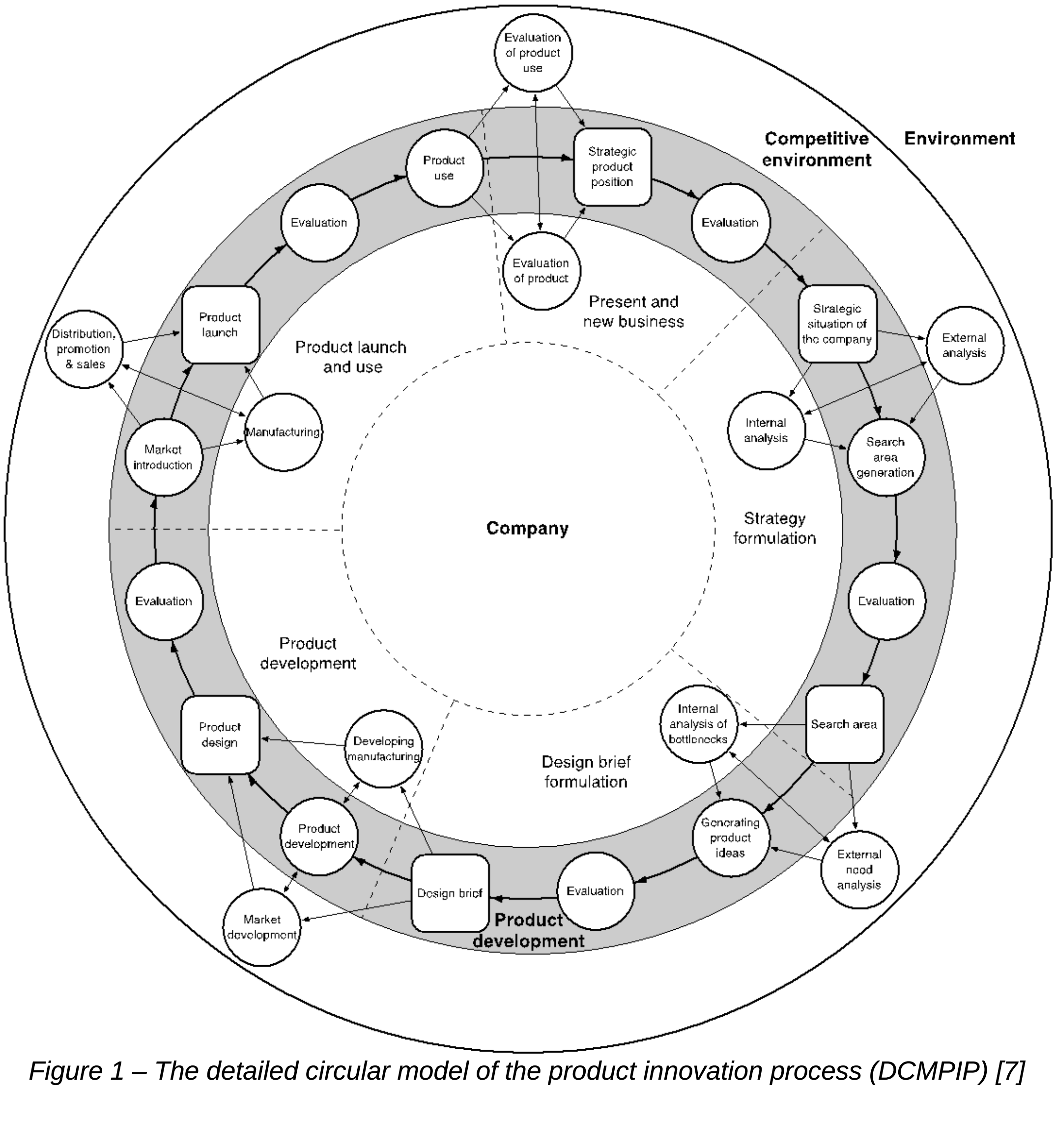

Figure 1 – The detailed circular model of the product innovation process (DCMPIP) [7]

While linear models are useful in structuring projects by presenting activities in a chronological fashion, they do not necessarily reflect the actual workflow of day-to-day practice. According to Buijs [4], most practitioners tend to present their design process through circular models or loops indicating a large degree of iteration. The knowledge building process, which represents a significant part of product development, can be described using Kolb's model of experimental learning [8]. According to this model, learning starts with a concrete experience. A person reflects upon that experience, determining whether he or she is satisfied with status quo. If yes; there is no need for learning. If no; there will be a need for learning in order to improve the situation. The person develops a new concept and conducts experiments, leading to new experiences. This enables reflection over whether the new situation is acceptable. If so, there is no need for additional learning, and the concept will be applied in future situations. If not, another concept must be developed. Although intended to describe the learning of individuals, Kolb's model can be applied in group settings. Buijs argues that a product innovation process is similar to a learning process, since "coming up with new products or services is the answer (learning) of a company reacting on its changing competitive environment" [4]. Realizing that:

1. Unpredictable outcomes prohibit logical sequence in the innovation process [9]
2. Feedback from industrial innovation projects suggests that divergent and convergent activities are conducted in parallel [10] [11]
3. Re-iterations occur as information from activities concerning internal aspects affect activities related to external aspects, and vice versa [4]
4. Sequential steps of a logical innovation model may be conducted in parallel as different team members concentrate on different activities [4],

the community at Delft University developed their first circular innovation model (Figure 2). The 'heart' in Figure 2 represents leadership and organizational culture driving the fuzzy front end-elements and ensuring progress. The process may start with any activity depending on the innovation team's analysis of the company and its competition. Depending on the outcome of one activity, the 'heart' decides the activity to proceed with, resulting in a process that follows a seemingly random pattern.

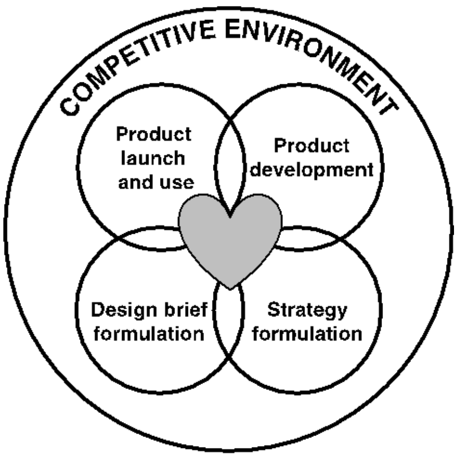

Figure 2 – The first circular version of the Delft innovation model [12]

2.2 Innovation model development in the engineering design community

'Engineering design, A systematic approach' by Pahl and Beitz [13] is an extensive guide to engineering design. It is used as reference in improvement programs targeted at working methods for practicing engineers as well as in teaching students. Much of the theory described in this book is based on external references, and the general working method is considered common engineering knowledge by many. Pahl and Beitz characterize an engineering design problem as something that often cannot be solved directly, but requires novel thinking at different levels of concretization. Methods for supporting engineering design must be developed for this reason to match people's thought patterns. Their reference to the TOTE-model (Figure 3) [14] shows how fundamental thinking can be considered a combination of two processes: modification, and testing. A test is applied for analyzing the initial state. An unsatisfactory result leads to a change operation, which is necessary for improving the situation. A new test is then executed and the cycle is repeated until the test yields a satisfactory result. Complex thinking processes are represented through chains of TOTE-models or models where several modification operations are executed prior to testing step.

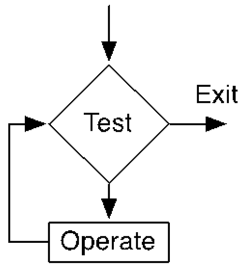

Figure 3 – Basic TOTE-model for organizing thinking processes [14]

The systematic approach uses systems theory in breaking down a complex product into manageable pieces, which can then be independently developed. The method is function-oriented, meaning that any solution concept can be represented by the means of a function model or function structure where the overall function is divided into sub-functions. A verb and a noun is usually applied in describing desired functions, for example ‘increase pressure’, ‘transfer torque’, or ‘reduce speed’. Sub-functions may be linked in different ways to create solution variants. The method involves step-by-step analysis and synthesis. Analysis concerns the resolution of anything complex into elements and relationships, which can then be studied. Synthesis involves combining elements to produce new effects and overall order. The workflow proceeds from qualitative to quantitative knowledge with each step being more concrete than the previous. Abided by the principles behind the TOTE-model, each step is divided into ‘work’ and ‘decision making’. Iteration loops can be implemented within each step or on entire steps whenever necessary for improving output value. Additional steps may also be added to the original plan in order to ensure satisfactory information quality. The essence of the systematic approach is summarized in Pahl and Beitz’ model illustrating the steps of the planning and design process (SPDP) (Figure 4).

3 PARALLELS AND INCOMPATIBILITIES BETWEEN MODELS

Comparing the DCMPIP with the SPDP, a number of similarities and differences can be identified. Given the aim of this paper; to understand reasons behind differences in order to promote understanding and integration between the communities of industrial design and engineering design, this chapter continues by highlighting six main differences.

3.1 Relevance of present and new business with regards to future product development

Introducing a new product in the market leads to reactions from competitors, often in the form of even better alternatives. Maintaining competitiveness therefore relies on continued innovation activities, as indicated by the DCMPIP. Buijs [4] refers to Cooper’s [15] declaration that the minimal new product development process will involve at least two sequential activities; product development and launch. Parallels can be drawn to the TOTE-model as well as Kolb’s model of experimental learning. The operation activity equals product development, whereas the test activity involves launching the product and receiving market feedback. If the market indicates that the product is satisfactory, the cycle ends. If improvement opportunities exist and are considered worth pursuing, the cycle is repeated. Considering that the DCMPIP is founded in part on Kolb’s model of experimental learning, there is little wonder why product launch and use holds such a strong position. Pahl & Beitz conclude that “to start a product development, a product idea is needed that looks promising given the current market situation, company needs and economic outlook” [13]. Market situation, company needs, and economic outlook are recognized as important factors determining the strategic situation of the company, but Pahl & Beitz do not appear to question the reasons behind status quo. Nor do they seem care about what happens after the product has been developed. Will it be a success or a failure? If the people involved in the development program do not learn about the response from markets and competitors, how can they improve their product development skills? Pahl & Beitz appear fully aware of the importance of learning from experience when dealing with problem solving. Still, their focus tends to revolve around the technical artifact without particular concern to how the new product will fit into a customer's lifestyle and social situation.

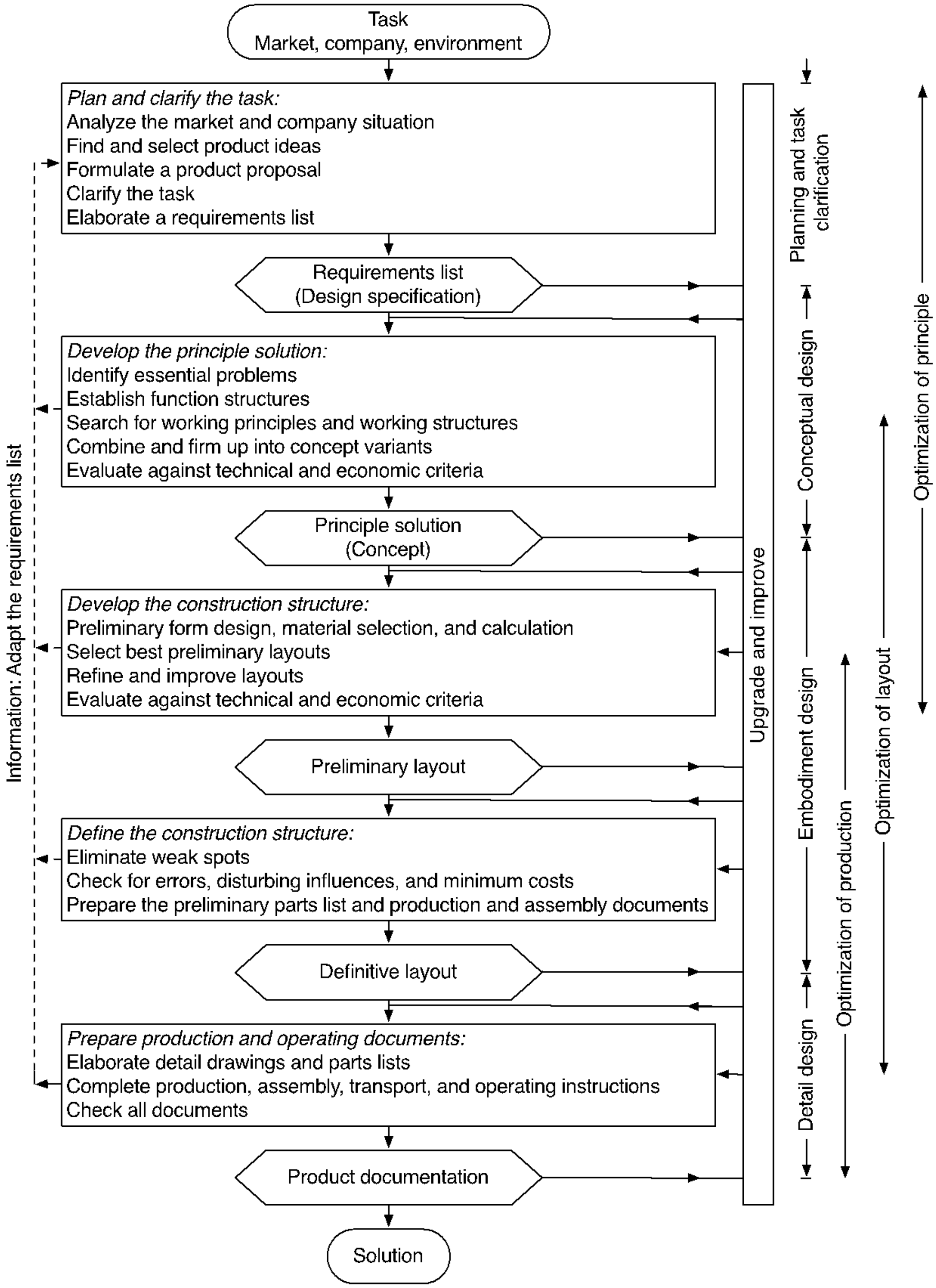

Figure 4 – Steps of the planning and design process (SPDP) [13]

3.2 Separation of search area definition and identification of needs

The strategy formulation stage of the DCMPIP starts by clarifying the company's strategic situation followed by an internal and external analysis identifying search areas for new business opportunities. Results are evaluated, and the most promising area is selected for further examination. The design brief formulation stage involves finding new product ideas within the selected search area. Analysis concerns internal bottlenecks, such as production deficiencies, and external needs, which can be retrieved from customers or other stakeholders. Ideas are then generated and evaluated. The most-likely-to-succeed concept is specified in a design brief. Although difficult to measure in terms of time or percentage, the strategy formulation stage and design brief formulation stage make up a considerable larger part of the DCMPIP, than the planning and clarification of task does in the SPDP. Considering Figure 4 by itself leaves an impression that finding the right product idea is a mere formality, but 'Engineering design – A systematic approach' does offer a thorough explanation of how to conduct a systematically executed product planning process, although this investigation appears to be focused on technical developments and an overall view of markets. Gaining deep insight in customer value does not seem a priority. A distinction must be made between efforts aimed at satisfying wants versus those aimed at satisfying needs. According to Huthwaite, a *real Want* is a "spoken, or unspoken, value that is desirable" [16]. It is worth noting that most things we want are not needs. Using the SPDP without further support on the product planning stage, may work well when trying to satisfy clearly defined needs. The problem is however, that a majority of products, particularly those intended for consumer markets, are not aimed at satisfying needs. Staying competitive within such markets calls for the ability to create innovations that are superior in terms of fulfilling customer wants. The DCMPIP acknowledges this fact as it clearly illustrates the importance of analyzing needs or wants within the marketplace. (The DCMPIP uses the term 'need' as a description of both needs and wants.)

3.3 Emphasis on technical development

While the SPDP provides an extensive description of how to organize the product development activity, the DCMPIP summarizes the same activity in two words; 'product development'. The DCMPIP clearly falls short when it comes to describing technical development, which *is* an important success factor in bringing new products to market. The application of systems theory and following a function-oriented approach are two attributes clearly separating the SPDP from the DCMPIP. In spite of risks of sub-optimization, utilizing a systems approach is essential when dealing with complex products. Failure to do so makes it virtually impossible to divide development activities between people and combine results into a complete product.

3.4 Concurrent development of product, market, and manufacturing

The Product development stage of the DCMPIP suggests equal importance between manufacturing, product, and market development. Conducting development activities in parallel is an example of concurrent engineering, as described by Ficalora & Cohen [17] among others. Although 'Engineering design, A systematic approach' involves guidelines for making assembly-friendly products, the SPDP does not seem to encourage dialog between product development and manufacturing development. Manufacturing specifications are merely an output of the planning and design process, and people working on process development do not appear to have a significant impact on the final product design. Furthermore, the SPDP considers market situation an input to product development rather than something that can be primed to increase the successfulness of a product, and the model does not appear to account for changes in the market place. Failure to appreciate changes in fast-moving industries such as the consumer electronics businesses involves a risk of investing large resources in developing obsolete products.

3.5 Linearity vs. circularity

Buijs suggests teaching about linear logical models and circular chaos models as two sides of a coin. "This innovation coin is without proper value with one side left blank" [4]. Buijs as well as Pahl and Beitz make the link between product development and creative problem solving explicit. Still, while Pahl and Beitz merely mention the TOTE-model (Figure 3) as a way of organizing thinking processes, the design community has developed complete innovation models based on the notion that logical order oftentimes deviates from chronological order, since the results from one activity tend to affect other tasks running in parallel. Circular models emerged as design researchers experienced difficulties trying to capture the chaotic innovation reality in linear logical models. While the design community accepts that the reality is chaotic, engineers appear to hang on to the idea that human work patterns can be presented in an orderly and predictable fashion. If the innovation activity is accepted as a type of problem solving, which must be addressed using logically driven behavior and reflection over past experience, the need for circular chaos models is by all means present.

3.6 Attention to detail versus overall applicability

While the DCMPIP and the SPDP are both aimed at supporting the innovation activity, the ways in which this challenge is taken on appear very different. Pahl and Beitz offer a structured framework for tackling the assignment bottom-up. Activities are broken down into manageable pieces, and results are then combined, making up a complete solution. Tools for conducting each phase of the design process are described in detail using visual models and examples. There is no apparent questioning in the logic behind the system. Attention is rather directed towards making the system as comprehensive as possible. Buijs on the other hand, appears to put a great deal of thought into the applicability of the overall framework at the expense of developing detailed descriptions of each phase. The systematic approach is by large prescriptive – it tells people how to act. The DCMPIP shares this property, while placing more emphasis on offering a good description of the innovation activity. Developed using feedback from practitioners describing their own work patterns, circular chaos models are primarily descriptive. Product quality, timeliness, and management issues are among Pahl and Beitz' arguments behind the need to follow a systematic approach. Considering these arguments, the systematic approach may be more applicable in supporting management in gaining control, and improving effectiveness. Paying more attention towards observing actual practice, and imposing a less stringent view, the DCMPIP seems more appropriate for supporting developers making better products more effectively.

4 WHY DEVIATIONS EXIST

The previous discussion suggests that differences exist between models of the industrial design and engineering design communities. Some of these may be explained by differences in scope, whereas the presence of other differences is less obvious. Building on findings from research in design, cognitive theory, and innovation theory, the following section seeks to explain the discrepancies presented above.

4.1 Impressions of what the design activity involves

There is no common understanding of what the term 'design' involves [18]. While natural scientists agree on the proper way to investigate properties of natural objects or phenomena, such an agreement does not exist in the artificial sciences. Atwood [18] relies on Simon's [19] distinction between natural and artificial sciences in making this point. Design research is recognized as an artificial science, since it concerns learning about an artificial or man-made process that involves the development of artificial objects. Atwood's work concerns the field of human-computer interaction (HCI), but the general idea that 'design' has different implications for different people, is nevertheless valid. The definition of engineering design depends on context. Table 1 summarizes three alternative views, as put forward by Pahl and Beitz.

Table 1 – Engineering design in psychological, systematic, and organizational respects, based on framework by Pahl and Beitz [13]

Context	Description
Organizational	An essential part of the product life cycle.
Systematic	The optimization of given objectives within partly conflicting constraints.
Psychological	A creative activity that calls for sound technical knowledge and experience in the domain of interest.

The DCMPIP (Figure 1) provides a good representation of the organizational view, as it positions product development as a part of a larger innovation process. The SPDP (Figure 4) mainly concerns the actual development process, and reflects a systematic view. Circular chaos models originate from psychological studies, and even those that are adapted to describe group settings, such as Figure 2, appear to be well in line with the psychological view presented in Table 1. Considering that a myriad of opinions exist just inside the HCI-community [20], it is no surprise that there is no common understanding of what the term design involves, or more importantly, what the most important aspects of product development are. Following the trail of thought put forward by Pahl and Beitz, the answer would probably be to satisfy constraints within the available time frame. Engineering is often responsible for managing product development. Furthermore, few absolute measures exist for benchmarking usability, and even fewer means are available for evaluating aesthetics. With these observations in mind, the risk of having engineers overriding the design department and promoting their view of what is important in product development, is by all means present.

4.2 Design languages

Clive L. Dym [21] points out that representation is *the* key element of design, both in terms of describing the artifact being developed as well as in documenting the actual design process. Common engineering design languages include verbal or textual statements, graphical representations, mathematical models, and physical objects. The various stages of a design process require different working methods and associated design languages. Designers and engineers tend to focus on different parts of the process, and are thus likely to have different opinions when it comes to determining relevance and value of a particular language with respect to their work. People with different backgrounds will thus place different emphasis on each stage of a design process, even if the processes appear similar on paper. This is perhaps one reason why the DCMPIP shares a great deal of resemblance with the SPDP. Challenges caused by language barriers between groups become visible when:

- The value of contributions is not properly understood, since people have difficulties seeing the extensiveness of information presented in a foreign ‘language’. We may be able to extract the big picture, but we fail to understand the importance of all the details.
  “Your work is not important!”

- The amount of effort behind a particular contribution is not properly understood, since people do not comprehend the information flow of a development process conducted in a foreign ‘language’.
  “I could have done what you have done in half the time!”

4.3 Ways of addressing a problem

The systematic approach described by Pahl and Beitz [13] uses systems theory in breaking down a complex product into manageable pieces. The process relies on discursive thinking in setting up the overall structure and optimizing parameters. That is; problems are solved primarily through conscious thought. Work associated with breaking the overall structure down into manageable pieces, and combining sub-systems to a final product can be expected to follow a linear process. The actual development and optimization of working principles however, relies coming up with new ideas and gaining insight into the problem by trial and error. This is by large an intuitive process, which is best described using a circular model. Considering that even a systematic approach relies on intuitive thinking, the preference for working with overall functionality rather than technical detail is perhaps what separates a designer from an engineer. While engineers see something as a technical artifact, designers may see the same object as something designed to fulfill a purpose. Designers place more emphasis on qualities that can only be seen when placing the product in a larger context, and they will hence develop the product as an item designed to work with its surroundings. The Designer might ask: “Is the concept right; does it provide the right value?” while the engineer wonders: “is the technology right; does it work as intended?” Figure 5 illustrates the concept.

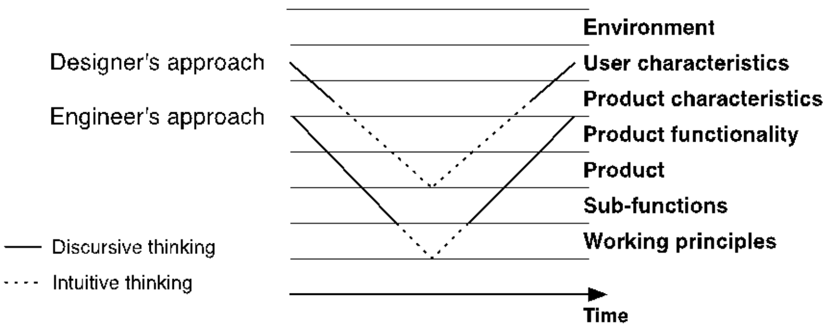

Figure 5 - Focus areas and thinking processes for designers and engineers

4.4 Reasons for modeling innovation processes

Referring to the introduction of this paper, the motivation behind modeling product innovation processes is twofold:

1. To structure and lighten the workflow of product development professionals, and
2. To support teaching about design practice.

While the original intentions may have been the same in both communities, later developments appear to have been guided by different interests. Pahl and Beitz [13] tend to concentrate on developing a detailed, prescriptive model, which is useful for dealing with complexity and satisfying time constraints within a project. Buijs [4] on the other hand seems more concerned with overall applicability. That is; the model's aptitude at describing what is really happening. Companies developing technical artifacts (e.g. cars, cell-phones, and household appliances) often use development engineering as an interface between R&D, production, design, and economics. Engineers are frequently assigned as project managers. This role implies responsibility for coming up with a functioning design within given limitations, and it does inherently involve dealing with complexity and time constraints. An innovation framework supporting engineering activities must subsequently be developed to tackle these issues. A model put forward by Dixon [22] and Penny [23] sees industrial design as a 'cousin' of architecture and art. It is reasonable to believe that most artists strive towards perfection, while both artists and architects have to be concerned with how their creations fit in as part of a greater context. Building on this view, models of the design community are likely to place more emphasis on the 'big picture' while sacrificing some attention to detail.

5 CONCLUSIONS

Employing product innovation models as a basis for comparing the worlds of industrial design and engineering design, this study points out six important differences between the mindsets reflected within the two communities. The study reveals a tendency in the design community towards seeing product development in a wider perspective, while engineers appear more concerned with technical detail. This trend becomes apparent by considering how designers have constantly questioned the validity of their models, seeking to develop theory that more accurately explains the nature of their work. Their attitude has resulted in a large variety of models, and the idea that describing the big picture calls for two types of innovation models – a linear logical version and a circular chaos version. Efforts in the engineering community appear to have been guided towards creating a complete framework that supports people in tackling the ever-increasing complexity of product development projects. While the general workflow has remained stable for quite some time, additional theory has been added, supporting the task of breaking down difficult projects into manageable pieces.

Examining the factors presented in Section 4, collaboration difficulties appear to be rooted in people's motivation for taking part in innovation activities as well as individual foundations used for judging the successfulness of the outcome. Consequentially today's problems may simply be the result of lack of insight. Resolving this problem is a complex issue however, since the 'mental frameworks' of each world tend to be self-reinforcing. That is; we prioritize different, and as we start learning about, and work on developing some attributes of some object, we enhance our impressions of what are the important attributes of that object. We recognize similar attributes in other objects, and after a while we have developed a framework of important attributes, which is highly subjective. This framework is created as we gain interest in something, usually during childhood, developed as we receive education on the relevant topic, and reinforced as we practice what we have learned. Try telling a 50-year old industrial designer or engineer that the qualities he is defending are unimportant. Based on our impressions, beliefs, and values, we create our own truth, our own world, and we prefer dealing with opinions supporting our own views.

Thoughts and practices within the entire communities of designers and engineers are here represented using only a handful of models. Consequentially, it would be natural to question the validity of this study. We are aware that a myriad of practices and philosophies exist within both groups, but a common framework, such as innovation models, is indeed necessary if some sort of analysis is to be conducted. Furthermore, pointing out what is the general nature of the factors behind problems in collaboration from a methodological point of view can serve as a starting point for future research using the same approach.

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