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A FRAMEWORK FOR DEVELOPING VIABLE DESIGN METHODOLOGIES FOR INDUSTRY

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ABSTRACT

In this paper we describe the most serious shortcomings that restraint the use of academic design methodologies in industry. The focus is on the level of clarity on the design goals, formulated as: “How much do we know about the design goal in the beginning?” The data is captured by six Doctors of Science, three from academia and three from industry. We use a framework to illustrate the differences of the current, popular methodologies taught by academia.

When we compare the design processes and include also the industrial experiences we can see that a lot of knowledge and experience is needed to be able defining clear design goals and list requirements. This is not addressed sufficiently in the compared design process descriptions and it appears to be underlying assumption in the design processes. In most design processes it is feasible to start from requirements list, but it’s a mistake not to take account that very probably the requirement list will change during the conceptualisation because design teams knowledge level on that particular design task will increase and thus they are more capable to list the actual requirements than they were at the start. It is also common to state the solution as a requirement rather than describing the actual need.

There is clear need to develop approach that facilitates capturing the design goals and design rationale of the particular design process. The design intent, design object, amount of preset technical sub-solutions, level of knowledge on the technical system and the surrounding culture with belief systems, norms and constraints needs to be available in order to apply the design process successfully in industrial context.

Keywords: Design Methodologies, Design Rationale, Design in Industry

1 MOTIVATION

In Design Science, the German School in particular, new product design has a greater importance than first meets the eye. The design process that is generally accepted in the field and taught at universities is the process of designing a new product. This is due to the intention of Design Science to improve the world with product-oriented approach. A design process that includes an unprejudiced idea phase and the evaluation of ideas, and does not base design on the solutions of a previous design will yield a better product when considering technical aspects. It supports the introduction of novelties also. This can be perceived as an optimal solution but this is not the case as described by Suistoranta [1].

The fact that companies do not operate in this way in reality is because the actual business situation is not product-oriented. The success requires more than having an optimal product. In addition, the manufacturer must be able to manufacture the product using the available limited resources. In practise there are many constraints for the number of resources and competences available in the development process. The manufacturer has limited opportunities for communicating with the clients, and every contact cost money – thus a new revolutionary solution may not necessarily attain the approval of the market, even if it seems to be superior in an objective comparison.

This explanation is comfortable for Design Science researchers. It suggests that our methods are perfect, but the situation in the real product development does not allow for seeking the optimal solutions. Unfortunately this is not the case. The methods are not good enough. Instead there are serious shortcomings if these methods are used in the real product development environments. And that's why they seldom are used in such situations. Our hypothesis is that the most serious shortcomings in academic design processes[1] are:

1. Assumption on the clarity of design goals and strong belief that valid "requirement list" describing the solution can be made in the beginning of the process
2. Poor understanding of the sequence of the emergence of new knowledge (applies only to some of the methodologies)
3. Discarding the role of existing knowledge, ability and skill level of the actual design team.

2. FRAMEWORK FOR ANALYSIS AND COMPARISON

If we wish to compare Design methodologies and their processes with industrial practice, we must somehow put them in line according some criteria. There are many possibilities for selecting these criteria and approach. Previously Geis et al. [2] has proposed that design methodologies should be analysed by dividing them in elementary operations which are undividable atomic elements. According to Birkhofer we can then see, what methods share same meta-structure. Methods with the same meta-structure could then be supposed to use same principles. This is very interesting approach. It allows comparison of design methodologies with each other. In this paper this approach is too detail oriented and therefore the approach is not used in this research.

Christian Weber [3] has also made contribution on understanding the use of design processes in real design situations. According Weber the designer utilises so called solution patterns. Weber focuses very much on the third point we made "understanding of the sequence of the emergence of new knowledge". The proposed "PDD – Property driven development" is discussed more in the later part of this paper.

Although there is earlier research, we found it usable to use a different approach to study this topic. We collected list of typical challenges for industry in using the design processes. Then we studied the root causes behind the challenges. As a result of this process we are able to highlight the problematic factors for industry. The factors are 1) The extent of the design artefact, 2)The capability to state and share the design goals during the design process 3) The ability to "design the designing process" during the design process and 4) The capability of the design process to clarify the needed organising, roles, responsibilities and power.

The extent of the design artefact is sometimes easy and straightforward issue – the technical system has explicit boundaries. Some industrial cases displayed that the design process needs to deliver the technical system (e.g. mass produced product), the manufacturing plant, the demand-supply network and services offered with digital media. This issue contributes to the main factor, the clarity of design goals. The capability to state and share the design goals during the design process is the main evaluation dimension in this research.

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[1] A lot of methodologies and processes can be found in the literature. In this paper we refer to following "Konstruktionslehre" by Gerhard Pahl and Wolfgang Beitz, VDI 2221 "Methodik zum Entwickeln und Konstruiren technisher Systeme und Produkte", VDI 2206, "Entwicklungsmethodik für mechatronische Systeme / Design methodology for mechatronic systems", "Ship design diagram" by Evans, "Systems Engineering" (according Stevens., Brook., Jackson. And Arnold, "Theory U" by Otto Scharmer. "Axiomatic Design" by Suh is discussed as a separate topic.

In this paper the ideal design process consists of following elements: Design Intent, Design goals, design tasks, input and output of design task, milestone, milestone criteria, design roles, division of work, decision making authority. When adapting the process in particular purpose also meta-information is needed such as dependencies between design goals and design tasks, technical solutions and design tasks, product lifecycle and milestone criteria, design intent and company strategy. These elements are related with Design Coordination work described by Andreasen, M.M., Bowen, J., MacCallum, K.J., Duffy, A.H.B., Storm, T., in "Design coordination framework", Paper for CIMMOD/CIMDEV Workshop at Torino, September 22-23, 1994.

When the design artefact had long history the requirement list was created in industry. In these cases the requirement list contained preset technical sub solutions that had to be used as part of the “new” product. Most of the design processes assume that the requirements relate to the need of customer, not to existing, readymade partial solutions. In these cases the design intent was easy to share but the design process did not match to the assumed sequence of the emergence of new knowledge.

When the design artefacts had no history the capability to state and share the design goals during the design process was a major issue in industry. The requirement list is detail-oriented, suitable for engineering but does not serve as viable tool to state the design intent. Especially when the technical system is of great extent and requires lot of design effort multitude of stakeholders and viewpoints are required to have successful optimisation and design decisions. The bigger the developer network is the more crucial role the rich encapsulation of design goals is needed. In large networks many companies are contributing and they have need to understand the financial aspects also to be able to calculate business cases thus providing motivation and resources for the design process.

The ability to “design the designing process” during the design process was highlighted as one main root cause for poor success with the design project. This is the case especially in large, multi-organisation projects with several technologies and disciplines in design process. Different companies and organisations are using different design processes and to align and avoid operative conflicts due to different designing philosophies is very challenging. In such situations the design process needs to offer capabilities to deal with several different design processes and practices even if carrying out tasks concurrently.

We will illustrate the differences of the methodologies by putting them on line according to how much knowledge on the design artefact is assumed to possess in the beginning. On the right side of the figure 1 the design goals are known and defined in detail, also the importance and priorities of the design goals are explicit. In the middle area the design knowledge enables to define the design goals but the impact on the product structure and functionality needs to be clarified in the design process. On the left side the starting point is even fuzzier; the design process needs to facilitate understanding and definition of the design goals, the extent of the design artefact (e.g. whether to create product, manufacturing line and supply network or just the product) and the actual design solutions.

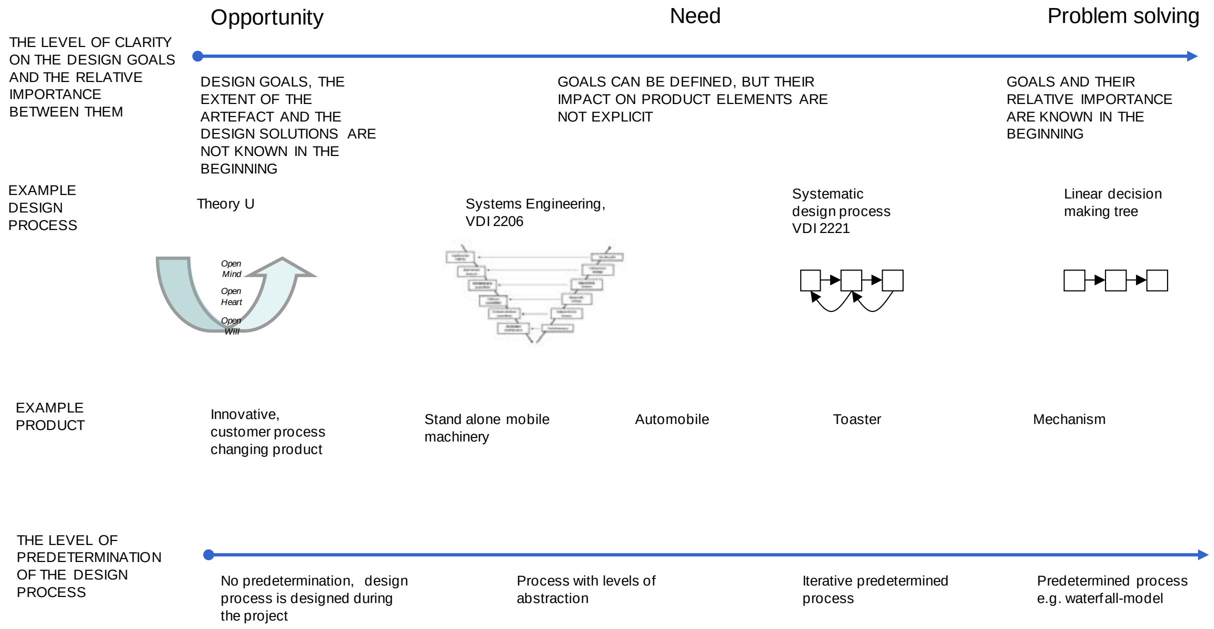

Figure 1. The framework for analysis and comparison of different design processes.

2.1 THE SYSTEMATIC DESIGN PROCESS

In the teaching of machine design, the emphasis was - and still mostly is - on existing mechanical engineering, that is, existing machine parts and the related measuring and drawing. It is much more difficult to teach the designing of modern multi-disciplinary machines. In the 1960s, the problem was the lack of constructors threatening the industry. As a result, the research of the methodology of machine design was born in Germany, funded by the State. The aim was to make machine design a learnable and teachable subject [4].

Creating a systematic design process was chosen as the way to develop the methodology of machine design. The design work was divided into phases, and specific methods and tools were created for each phase. A number of textbooks were written on this subject, of which the most widely used is probably ”Konstruktionslehre” by Gerhard Pahl and Wolfgang Beitz [5]. Another important part of the introduction of the systematic design method was the instructions (richtlinie) of the Verein der Deutschen Ingenieurs. The most important of these is VDI 2221 ”Methodik zum Entwickeln und Konstruiren technisher Systeme und Produkte” which defined the course of the systematic design process [6].

The creation of a design process is based on the experiences of its developers in practical design work. The starting point of the presented systematic design process is the abstraction of the task formulation. The goal is to break free from existing solutions, to be able to openly search for the optimal solution for the situation at hand on the basis of defining general functions. The starting point is that the design process is not modelled on any existing model. Previous knowledge appears in the form of outlining the principles of solution. The process does not always proceed in a linear manner, but steps may have to be taken to return to the previous phase. This, however, does not affect the principal order of accomplishing the tasks.

When we place systematic process on the framework we use the following argumentation:

- Clarity of design goals: First step of the process is to clarify the requirements. Because the requirements could be clarified, this method will be in on the right side of the chart.
- The level of predetermination: The sequence in the process is fixed. There are different opinions how much iteration is acceptable, but iteration does not change the sequence. However, the iteration is seldom value adding activity and thus according LEAN-approach[7] these would be eliminated in the ideal case.
- Knowledge and competence needed: This process does not address the design team skill level. This can be seen as consequence of the history of the methodology. The idea was that within this methodology even the unskilled new designers could reach good results.

2.2 THE SYSTEMS ENGINEERING PROCESS AND VDI2206

According to INCOSE community Systems Engineering is: ”an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: Operations, Cost & Schedule, Performance, Training & Support, Test, Disposal, and Manufacturing. Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.” [8]

Unfortunately, the V-model proposed in Systems Engineering does not have as mature and ready tools and methodology as systematic design. (See e.g.[9]) One of the challenges for the tools is to bring its verification methods on the same level of maturity as those used in systematic design.

Applying the systematic design method as an inner loop of the V model does not pose problems. This idea occurs in the VDI standard 2206 ”Entwicklungsmethodik für mechatronische Systeme” from

2004. In this work, the V-model is called the main cycle ”Makrozyklus” and the processes of systematic design (Problemlösungszyklus) within it are called micro cycles ”Mikrozyklus” [10]. Earlier, it has been suggested as a special case of mechatronic products, and the universality and the importance of the observations has not been proved. As shown in [11], the conclusions and the justifications for the solutions are taken on a whole different theoretical level; it is also proved that this is not a special design process applied only to mechatronic products. While comparing the design processes and specifically the mentioned special case of mechatronic product, we should question what makes the process different. As defined, the mechatronic product consists of integrated mechanical, electrical and computer technologies. However, as these different technologies have to be considered concurrently during the development to establish product functions and behavior, it is nothing different to products including various technologies developed by specialists from different disciplines. As such, the difference with more traditional systematic approach is the conceptual and architectural design as the realization of functions and behavior do not follow the physical part structure as with mechanical products.

Argumentation for placing the process on the framework:

- Clarity of design goals: Some of the requirements are known, but more detailed information is needed from different viewpoints to define the requirements and design goals. This process is placed on the middle of the chart
- The level of predetermination: The sequence in the process is somewhat known yet the order of tasks depend on which methods are used in which viewpoint.
- Knowledge and competence needed: This process addresses visualizes how the knowledge increases during the design process. It does not address the design team skill level, but it includes idea that the specialist skill is brought in cumulatively along the process progress.

2.3 THEORY U BY OTTO SCHARMER

Theory U is used for creating systemic, holistic transformations and innovations [12]. It is used not only for technical systems but also on larger social systems. As a theoretical perspective, Theory U suggests that the way in which we attend to a situation determines how a situation unfolds: I attend this way, therefore it emerges that way. As a practical social technology, Theory U offers a set of principles and practices for collectively creating the future that wants to emerge (following the movements of co-initiating, co-sensing, co-inspiring, co-creating, and co-evolving). It is based on the "Presencing," a blend of the words "presence" and "sensing," refers to the ability to sense and bring into the present one's highest future potential—as an individual and as a group.

The U consists of one main process and five movements (phases). When leaders develop the capacity to come near to that source, they experience the future as if it were "wanting to be born" — an experience called "presencing." That experience often carries with it ideas for meeting challenges and for bringing into being an otherwise impossible future. Theory U shows how that capacity for presencing can be developed. Presencing is a journey with five movements: As the diagram illustrates, we move down one side of the U (connecting us to the world that is outside of our institutional bubble) to the bottom of the U (connecting us to the world that emerges from within) and up the other side of the U (bringing forth the new into the world). On that journey, at the bottom of the U, lies an inner gate that requires us to drop everything that isn't essential. This process of letting-go (of our old ego and self) and letting-come (our highest future possibility: our Self) establishes a subtle connection to a deeper source of knowing. The essence of presencing is that these two selves — our current self and our best future Self — meet at the bottom of the U and begin to listen and resonate with each other. Once a group crosses this threshold, nothing remains the same. Individual members and the group as a whole begin to operate with a heightened level of energy and sense of future possibility. Often they then begin to function as an intentional vehicle for an emerging future.

Argumentation for placing the process on the framework:

- Clarity of design goals: The process is design to work on situations where we want to learn from the future as it emerges, the first step of the process is letting go of existing constraints and preset solutions. Therefore this process is placed on the left side of the chart.

- The level of predetermination: The process has main sequence but the emergent nature of working does not enable one to predict what really needs to be done next.
- Knowledge and competence needed: This process does not address competence levels needed by designers.

3 THE DESIGN PROCESSES IN THE INDUSTRY

When dealing with development processes in the industry, one can not ignore the product development project practices; even they are not “theories”. The stage-gate–model [13] proposes that design process should proceed thru checking gates, where the achieving certain goals is checked. Normally the checked topics at the gates are related to maturity of the design, completeness of the design (or more likely the completeness of the design documentation) and verification of the design against pre-determined criteria. Very important idea in the gate-model is “freezing” the decisions. After design is checked at the gate, it will not be changed. The type of design process, which supports best this kind working, is linear decision tree. Thus gate-model as such cannot be seen as an advanced contribution to the design methodologies of which some include similar mechanisms.

It can be even claimed that using state-gate –model in addition or instead of a proper methodical development process, is harmful. Typical real life situation where new experts join in the running development project is an example of this. If we look figure 1 model, we see that entering of the new experts takes us to the right side of the picture; competency based goal setting. However, it is more than probable that development project running has passed this stage and if we are using gate-model, it dictates that it is a mistake to go back and open “freeze” decisions. If the keeping the development schedule is more important than optimizing the quality of the project outcome, the gate-model guides to the right direction. If the time is not the prime importance, using gate-model is dubious in challenging new product development.

Project development is typically carried out as simultaneous or consecutive projects. For instance, [14] Loch et al. and [15] Pich et al. comprehend projects as systems that evolve from one state to another. In this context a technical system, the result of product development project, is only a sub-system of the system of project. Knowledge about the relations between the system input and output is the main characteristic of the state of the project. Hence, the knowledge about the subsystem, such as product definition, is an evolving model of a product.

The generic development methods have a high ambition level to cover the product development cycle in one staged process with pre-determined inputs and outputs for each stage. The methods present also iterative or feedback loops towards earlier stages to evaluate if the original target is not satisfied with the current results. However, the process flow from top (requirements) down (details) is tightly bundled between the consequent stages and practical iteration can only take place between those (as by definition when the output of previous stage acts as the input for the successor stage).

Within the industrial development projects the development cycle seldom is initiated in full scale, e.g. the development process is not applied to cover the whole design of a new product (from idea to product) or even to alter the main function (new concept). More typically the development activities are directed towards partial re-design of functions by implementing alternative concepts or new technology.

The development drivers in industry emphasize that the current status of the product along its life cycle (concept maturity) and the level of concretization determine the applicable development methods for that particular development activity [Figure 2].

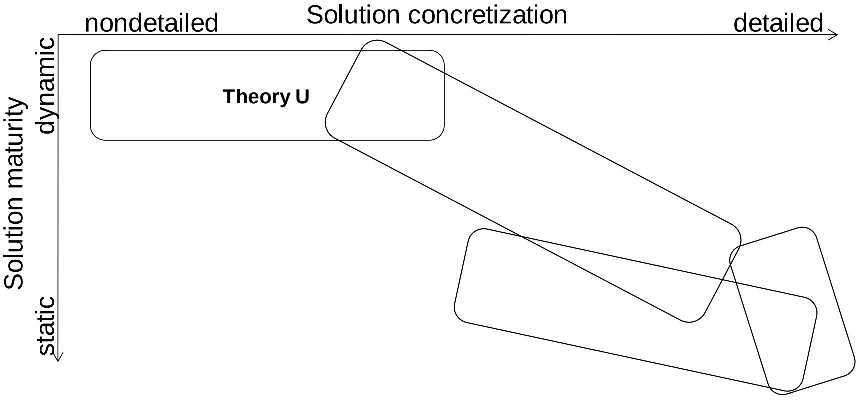

Figure 2. The development methods placed on the two dimensions.

The solution concretization dimension describes the level of details in the concept; from needs to detailed manufacturing documentation. Generic product development processes, like VDI 2221 or VDI2206 guides through the stages from abstract to concrete. The approach to the developed product is from top down and the requirements for consecutive product layers follow the output of the previous stage. However, the application of this process occurs only in case of a novel product development. In industry, the initiation or the driver of the development may appear at any level along the concretization dimension, or even in multiple levels as the product sub systems develop in different sequences.

The solution maturity dimension describes the concept status along the life cycle from dynamic to static as define by Utterback [16]. In the early stages during the life cycle of a new product various competing concepts exist on the market, while the number of alternatives diminishes longer the life cycle proceeds. A single product concept involves subsystems, which evolve during the product life cycle in different sequences, e.g. as long as the main purpose of the product remains the same, the modifications take place at sub systems. Therefore during the development, the activities face different challenges depending on the maturity level of each sub system.

We also identified cases where there is not just one design process in use, on the contrary. A large product development project uses four different main development processes and multiple adaptations of each main process for the sub-system development. Taken into account that every process is designed against particular drivers and objectives it is obvious that the several process variants do not aim for the same objectives as the product development project. The challenge is to introduce new design process making some of the existing processes obsolete and adapting the new process with the remaining ones. The viable process needs to have a systematic manner when adapting the process to the particular development project intent.

Acknowledging the various forms of development initiation and drivers, it is noticed that the development process in industry applies all (or most) methodological levels, however not sequentially from beginning to end, but iteratively starting according to correspondent sub system considering the position along the two dimensions presented in Figure 2.

4 ANALYSIS

The focus of this paper is on the level of clarity on the design goals, formulated as: “How much do we know about the design goal in the beginning?” When we compare the design processes and include also the industrial experiences we can see that a lot of knowledge and experience is needed to be able defining clear design goals and list requirements. This is not addressed sufficiently in the compared design process descriptions and it appears to be underlying assumption in the design processes. When this is the case there is need to also focus on creating the knowledge and experiences during the design process. Currently the design processes do not address the “on the job” learning aspects at all; the main focus is on the design tasks.

The design goals partly narrow down the extent of actual solution needed, the technical system. There is strong dependency between particular technical systems and appropriate design processes as proved by Juuti [17]. Based on this thinking now we ask: “How much do we know about the actual design process/path in the beginning and what is the right order of design tasks?” If the technical system is rather simple the design process can be straightforward and with minimal iterations. As the technical system consists of many sub-systems, variety of technologies the design process becomes more complex due the interdependencies between technical elements. In these cases it is also very demanding to come up with a design process describing all the iterations needed beforehand.

When the technical system is rather large, such as 350-meter long cruise ship the knowledge and sub-solutions needed increases rapidly. It implies that hundreds, even thousands of people are needed during the design process in order to have all the knowledge needed available and used for design decisions. The design processes analyzed in this research also fail to describe how to involve people in the design process. This shortcoming is fatal in designing large systems but the design processes for simple products or just mechanisms don´t suffer from this.

A major finding is that in industry some of the design sub-solutions are set beforehand, preset as part of requirements. The design processes assume that the development is started from scratch rather than doing “incremental innovation”. Yet most of the product development is incremental-based rather than totally new, from clean table. There is clear need to describe how the “clean table” design processes should be adapted for “incremental innovation” use.

The systematic design process is too focused on the details and it works best in student exercises where a product with clear main functionality is designed without interference of actual customers. If we compare the progress of the design work according the systematic design process and compare it the “industrial opinion” in figure 2, we see interesting conflicts. The starting point is clarifying the tasks, which expects very clear understanding of the end result. The next step – “conceptualisation” – takes a long step backwards maybe up to the competency based innovating. Those who have read their Pahl&Beitz carefully [5], have noticed that in the proposed requirements list template in the book, there are column for chances. This point is not however expressed in the method itself. It is feasible proposition to start from requirements list, but it’s a mistake not to take account that very probably the requirement list will change during the conceptualisation because design teams knowledge level on that particular design task will increase and thus they are more capable to list the requirements than they were at the start.

In the academic world, most of these methods could be claimed sufficient tools for new product development. But none of them is sufficient alone. Systems Engineering is strong at the systems and product architecture level, but lacks methods for detailed design. Because the actual design process on the grass root level is not clarified, the verification process cannot be described either on pragmatic enough level and thus the right side of the V-curve is more or less undefined in this method.

In the spiral type estimation based design processes, there is inherent lack of guidance for design work. Everything is estimated “ad hoc” just for this situation. This leads to at least to situation where “design by re-use” is not utilized. It could have even more serious consequences, if best practices are not utilized and all design solution is used “for first time”. In such situation the problems with design work efficiency and the quality of the design will become evident. There are lot of experiences of this kind of problem in Shipbuilding Industry [18].

A combination of two methods is VDI 2206, which can be claimed most industry-oriented and thus maybe best state-of-art practice within discussed methodologies. From industrial and practical point of view this is step towards the needs of the actual design work. Not single methods, which work on the classroom, but are strong on some point and weak or unusable on the other, but instead processes which acknowledge different stages in the new product development and have applicable processes for different stages.

A general remark on the above mentioned processes is that the main focus is on the design object. This is natural as the researchers are not exposed to the operative aspects by nature. In industry there are many factors having impact on the design process in one way or another. In one case company there was clear make/buy strategy impacting to the work split in development project. The work split resulted in use of different design process by the main contractor. This again created need to adapt both supplier and main contractor design process by adding some new design tasks and administrative tasks. There was also need to re-align the underlying business motivations embedded in the supplier milestone checklists. Due to the make/buy also the product architecture was changed during the project having impact on which design tasks to carry out and using which methods. This was due to the negotiation power of the supplier; the decision making power is not within the development process by default.

5 COMPARISON WITH OTHER CONTRIBUTIONS

Project uncertainty, ambiguity and complexity have been treated by Loch et al. [14] and Pich et al. [15]. They characterize different project management situations with the concepts of Complexity, Variation, Risk, Ambiguity and Chaos. The first, Complexity, is a situation where a large number of interacting activities exist. The static structure of activities can be predefined, modelled and managed with Gantt graph, Project Evaluation and Review Technique (PERT) and Critical Path Method (CPM). The second concept, Variation corresponds to the less stable situation, where progress of a large number of activities are influenced by a multitude of small uncertainties and managed with buffers, reservations, and provisions, which are typically assigned at the end of each task, as well as by calculating the distribution of possibilities to meet the planned schedule, simulation, and critical chain techniques. Third situation, Risk, is a state of affair when a distinct and identifiable project influence, i.e. one that is plausible to anticipate, may have a major impact on the project. This influence can be represented and managed with a decision tree, where branches represent different outcomes of tasks and encourage the planning of alternative action paths. Ambiguity, represents a situation where an unforeseen factor may have a major impact on the project similarly to risk, but cannot be anticipated (and therefore transformed into risk) without continuous scanning and tracking as well as re-planning by project management by the evolving decision tree. Chaos is a situation where interdependent ambiguities and the emerging influences on the project success are unknown and interrelated leading to situation where it is impossible to construct a decision tree, but to iterate.

Product development projects are typically complex, but hardly static. Therefore, the management situation varies typically from the cases of Variety to Chaos. In well known processes where relatively small and anticipated variety of characteristics in subsystem, such as product definition, emerges, the traditional project management methods are still applicable. Also, the model of product development process may be relatively straightforward. Therefore, traditional models, such as VDI2221 needed, may be applied in the situation of Variety, e.g. the design engineering in repetitive delivery projects. When the influence of anticipated changes become large enough, the situation evolves to Risk, product development models have to comply with decision trees. Thus, the model has to cover different structures in such a way that e.g. the model of systems engineering [9]. Often, the cases of product re-engineering projects as well as retrofits and upgrading projects belong into this category. Ambiguity in product development recalls such kind of models where agility and preparedness for changes have to be involved. Typically, incremental innovation [19] represents the case of ambiguity in product development. Instead, the radical innovations relate to the potential of Chaos. There the product development models have to enable high level of iteration, which actually is denied in the models and methods of pure complex situations. Potential models favouring iteration are the spiral processes presented by Hubka et al.[20].

In addition to proposed development processes, there exist more descriptive approaches on product development processes. Christian Weber proposes PDD – property driven development [3] and also the “classic” theory of domains [20, 21] should not be forgotten. When comparing the abovementioned characteristics we can see in figure 1 that Complexity, Variation, Risk, Ambiguity and Chaos reduce close to zero when moving from “Opportunity”-side to the “Problem solving”-side. Loch and De Meyer [15] observe the same phenomena in industrial context.

The domain theory proposes that the design goes thru four stages during which the abstract becomes concrete and non-detailed becomes more detailed. The theory bases on the Transformation model of the Theory of Technical Systems and thus the most abstract and non-detailed level is domain of transformations. Next domain is effect-systems, which describes the functionalities of the technical system. When we are moving towards more concrete and detailed, next domain is organ domain on which the functions are described as solution principles. The fourth domain is part domain, where there are actual (or at least generic) parts of the technical system. If we interpret the domains as phases of proceeding in the design, we could find presentations, which are very near to our ideas as can be seen following figure 3. [22]. There is design process which is based on the domain theory. It is described in rich detail by Ernst Eder et al.[23]. However, it seems that this process (or at least its description as such) is not pragmatic enough that it could be taken in industrial use.

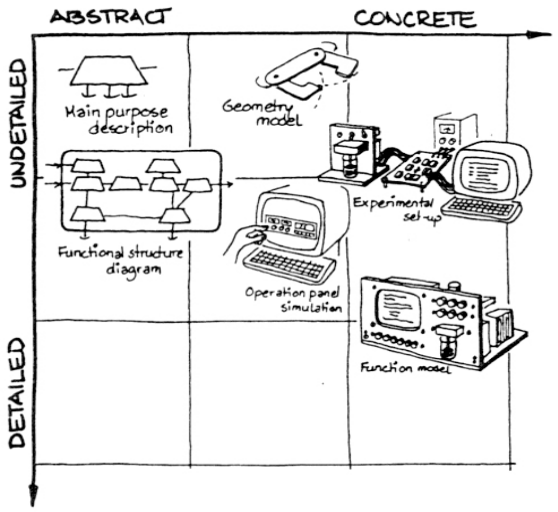

Figure 3. The different descriptions placed on the abstract-concrete and detailed-undetailed dimensions [22].

Christian Weber [3] has also made contribution on understanding the use of design processes in real design situations. The requirements are starting point for the design work, but according Weber the designer utilises so called “solution patterns”. The designer chooses an earlier design pattern, which he/she tries to adapt the design on hand. The solution pattern has properties, which more or less can fulfil the original requirements. The gap between the properties of the chosen design patterns and the requirements is the driving force of the design work. So Weber focuses very much on the third point we made “understanding of the sequence of the emergence of new knowledge“. Weber’s model acknowledges very well the “competence level” dimension. Also the model describes very well the working of a designer. However there is one important difference in our and Weber’s works. According Weber, the original requirement list stays the same, but we do not think that this is the case. As the designer knowledge increases the ability to formulate and detail the requirements increases and the design team has better perspective to evaluate which requirements are truly valid and relevant.

Another approach which prefers linear decision tree is Axiomatic Design by Nam P. Suh.[24] One of the cornerstones in Suh's theory is the theory of good design properties. He presents an independence axiom which in simplified terms means that the matrix that links the functional and the physical domain becomes a bottom triangle matrix. In addition, the more dependencies on the diagonal line only, the better. Anyone initiated in managing product development projects sees immediately that this means a ”cascade model”, that is, a decision order that does not require iteration in the design process can be found. In a pure cascade model, dependencies only exist on the diagonal line, in which case the one-on-one dependency between the function and the function carrier is implemented. The idea of a good design is the universal prerequisite in Suh's theory. Suh states:”Products that violate the Independence Axiom are not good products in terms of quality, reliability and functional robustness.”

This is true when we examine things from the viewpoint of design data management and the management of the requirements, which is, looking at the issue with the eyes of designers and design managers. The most important feature of the product is, however, not always the design easiness and the easy maintenance of the design data. Suh's axiom leads to the identical form of the function structure tree and the element structure tree, which has been observed to lead to increased weight and costs and reduced performance in connection with modularity. Certainly, it is easy to understand the structure of such a product, it seems logical (is this quality?), it is easy to maintain (reliability), it is easy to configure, and a defect in one function does not necessarily affect the others (functional robustness). The importance of these depends considerably on the area of application, but the independency axiom cannot be generalized to be used as a universal prerequisite.

Herbert Birkhofer [25] has made observations on the use of systematic design methods. The observations focus mainly on the designer addressing also time pressure and the complexity of technical system and design process. The use of designers “self-acquired toolbox developed in the past” is proposed as main factor reducing the use of systematic design methods. The lack of knowledge how to use or adapt method in an industrial context is also described as one factor. These findings are fully aligned with our results. There is need to document not only the process but also the main assumptions such as what is the assumed design object of the design process, what are the guiding principles that must not be violated to execute the design process properly and which issues to consider when adapting the process in particular industrial context.

6. CONCLUSIONS

This research has gone through various design processes, more or less used in the industry. We have identified several factors having impact on the applicability and usability of any design process. The first conclusion is that in industry there are wide variety of opportunities and needs to be solved with technical systems. The technical systems differ from each other in many ways thus requiring applicable design process or at least customization for that particular case. Our main conclusion is that there is clear need for different design processes. The debate on which process is most relevant or superior is not adding value for the industry purposes.

The basic nature of each design processes can be understood by placing them on the axis based on the amount of knowledge needed in the beginning of the project (see figure 1). Detail-oriented, single discipline based design methods on the right are very valuable under certain conditions but fails to address systemic, holistic view and understanding on the left that is required under different conditions. At the same time the systemic, holistic design processes can be very valuable but the level of abstraction requires more pragmatic methods and tools to be applied and used in industrial setting.

This paper focuses on the gradual transition from unclear situation (“Opportunity”-end) to more precise understanding (“Problem solving”-end) using design processes. The proposal is valid based on the feedback from the industry. The first comments were that this is what they have intuitively done in practice and now they want to gain more insight and knowledge how to move from left to right. This knowledge would enable them to create high quality technical systems, design projects and capable design organizations. The similar needs were addressed in many research results by scientists in the Design Science domain.

There is clear need to develop approach that facilitates capturing the design goals and design rationale of the particular design process. The design intent, design object, amount of preset technical sub-solutions, level of knowledge on the technical system and the surrounding culture with belief systems, norms and constraints needs to be available. The designer and design manager uses the knowledge to choose which process to use and how the adaptation could be done without jeopardizing the inbuilt knowledge creation mechanisms of each design process. The knowledge enables industry to use the design processes more and more thus enhancing the interaction and co-creation with design science and industry resulting in technical solutions that improve the quality of life.

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