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A FRAMEWORK FOR EVALUATING APPLICABILITY OF DESIGN METHODOLOGIES

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1. Inroduction

The aim of this research was to find out what was the focus areas of the development process theory papers presented in Design 2010 conference. The results are presented in a framework which visualises cleary that there is a need for a development model/framework which represents how the whole development process should be defined in manner to combine the theory and the practice.
Our research questions in this article are:

1. Into which area of product development the methods presented in Design 2010 conference focus?
2. How the findings on the first question should be understood in design research?

There exist multiple different product development theories, methods, and tools like [Pahl and Beitz 1986], [Hubka and Eder 1996], [Stevens et al. 1998] and [Atkinson 1972]. These cover varying area of product development process. Some are aimed for the business case analysing; some are trying to capture the voice of customer aiming to help to find out new ideas for new products, while on the other end are specific CAD-tools for product modelling or focusing on one DFX area. At this moment there does not exist one theory covering all of these areas and aspects of the product development process.

Lehtonen [Lehtonen 2011] state that the existing design theories do not match the challenges and requirements which the industry have. One reasons is that the product development theories and industry's actual development processes do not correspond. Academically it can be suggested that our methods are perfect, but the situation in the real product development does not allow for seeking the optimal solutions. Unfortunately the situation is not like that. Instead there are serious shortcomings when these methods are used in the real product development environments, thus they are used seldomly.

Commonly design methods and processes begin with the requirement lists, but they do not consider the fact that the requirements evolve during the whole development process as designers gain more information about the product and its properties. Also in many cases the design intent is not presented, yet it is the essential part on design process. Another assumption or character of product development literature is that the process begins from empty table. Then the ideal process is to develop solutions which are evaluated and the best ones developed further on. This is effective method in developing mechanical designs and when the focus is purely on the product itself. [Lehtonen et al. 2011]

There is also significant difference in the design process when comparing the redesign of an existing product and a product that is new to the market and new to the company. E.g. the creationg and management of the requirement list is much more when defining new type of product.

The following chapter contains the review of other analysing about design methodology. The third chapter present the framework and the analyse results, and on the fourth chapter we conclude our findings.

2. Other analysis in literature

There exist multiple different studies e.g. [Gericke and Blessing 2011], [Geis and Birkhofer 2010] and [Jenssen and Adreasen 2010], which tell that the methods presented in literature are not suitable for industry and therefore they are not used. In some cases companies have defined their own product development method and in some cases it relies on a theoretical development method.

Gericke & Blessing [Gericke and Blessing 2011] conclude in their research that it is difficult to decide on what level the development process should be modelled. Too abstract model is not usable enough in actual product development process and too specific model cover so narrow area that it can be used by limited number of designers in limited scope of development challenges. Our view is that one needs several design models to cover the whole development process. Then the difficulty is to manage the development process in a way that the outcome is best possible solution for the current task.

Geis & Birkhofer [Geis and Birkhofer 2010] states in their classification of design theories that most of the known design theories are not practical and/or the industry do not see them usable. Thus the product development organisations are not using these at all. Geis & Birkhofer also state that most of design theories focus on certain area of development process and this is another factor limiting their usage.

Jenssen and Adreasen wrote a paper in Design 2010 conference about the systematic design method and industry practice. They present observations made by their students in Design Methods course. Firstly systematic method by Pahl and Beitz is not used as written in the case companies. Another fact was that if there was a written process in the company development team, it was seldom actually used, or when used, it was done in incorrect way. They conclude that even if the development process is very accurately described, it does not necessary result accurately described and good product. On the other hand very loosely formed method can produce very good product. [Jenssen and Adreasen 2010]

There exists different product development process analysing and categorisation in the research made earlier. These researches did not highlight the perspectives we aimed to look up in our research.

2.1 Other methods to present design situations

One well known theory about the evolving of the product is the domain theory. It propose that design goes through four stages during which the abstract becomes concrete and non detailed becomes detailed. The domain theory is based on the Transformation model of the Theory of Technical Systems and thus the most abstract and non-detailed level is the domain of transformations. The next domain is effect-systems, which describes the functionalities of the technical system. Moving towards more concrete and more detailed, the next domain is the organ domain on in which the functions are described as solution principles. The fourth domain is the part domain, where there are actual (or at least generic) parts of the technical system.

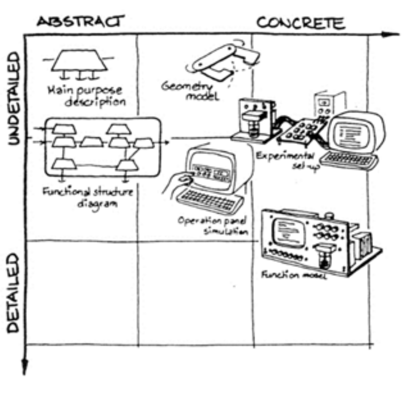

Figure 1. Levels of abstract to concrete and detailed-undetailed [Andreasen 1994]

Zier et al. [Zier et al. 2010] presented an approach to investigate elementary design methods. They evaluated the methods by Abstraction level, variation and decomposition. They focus on the concretisation level from function structure to function carriers. The work is useful on the means of elementary methods. Thus these methods are needed in detailed design processes. Yet we need a broader view of design process to exemplify the actual industrial development process.

3. Our analysing framework

For the product development process analysis the methods have to be put in some king of an order in same coordinates. We analysed the presented methods by two different perspectives. One is the abstraction level of the design and the other is the amount and finality of the design object knowledge [Hubka and Eder 1996]. The finality means how sure it is that the selected solution will be in the product under development.

These perspectives can be used to compare different development methods. The perspectives we chose, do not enable the analysing of tools and methods aimed for improving the process of designing itself, such as Concurrent Engineering, Information management, or PDM.

The abstraction levels we used in our framework are:

- SoS = Systems of Systems by Stevens et al. (see Figure 2). All products are systems related to other systems. It is important to understand what are the other systems which effect to the design at hand and to which systems it effects.

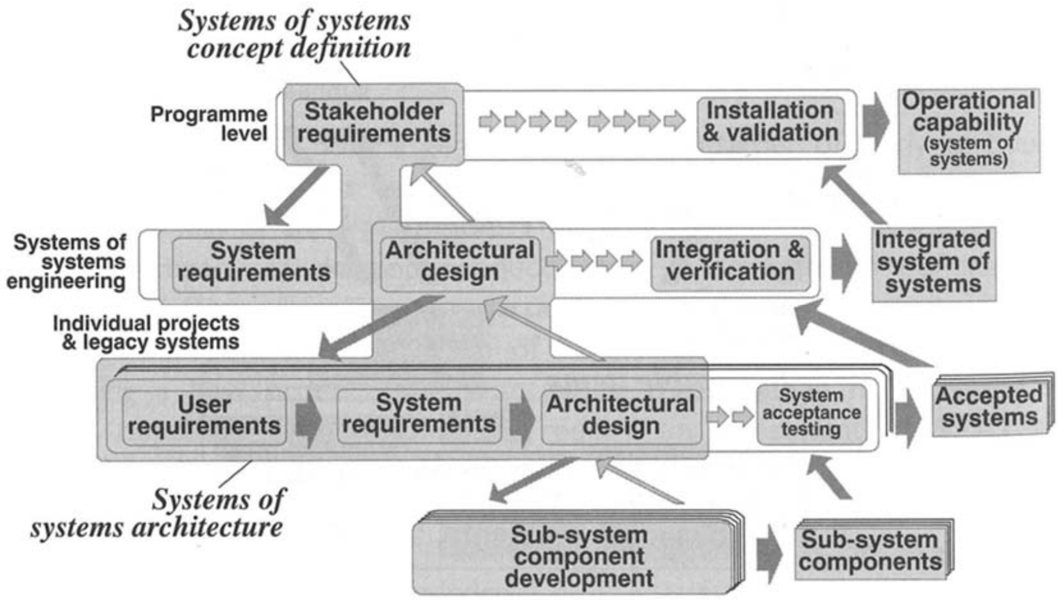

Figure 2. Framework for systems of systems [Stevens et al. 1998]

- **Transformation:** By the theory of technical system [Hubka and Eder 1988] (product) performs a transformation process what changes the operand from existing stage to desired stage (see Figure 3).
- Function structure = Function and their relations at the product
- Organ structure = *An abstract model of technical system that includes the organs that realise a certain class of modes of action, and relationships between those means.* [Hubka and Eder 1988]
- Function carriers = organ carrying a specific function
- Geometric shapes
- Measures
- Tolerances
- Manufacturing = the knowledge needed in actual manufacturing

Design object knowledge is derived form and based on the entire natural sciences (e.g. physics) as the designer must calculate, model, simulate etc. aspects of the design object. The designer has to understand these tools and skills to be able to find the best possible solution for the problem at hand. The design process operations (dimensioning, giving the form, material selection etc.) are repeated several times during the process, and different methods, but also different elements of knowledge are utilized in each situation. This means that different elements of the design object knowledge must be available to the designer, according to state of the relevant design situation. In this manner the first assumptions about form, dimensions or materials are made on different basis and knowledge, than in the later phases of the development. [Hubka and Eder 1996]

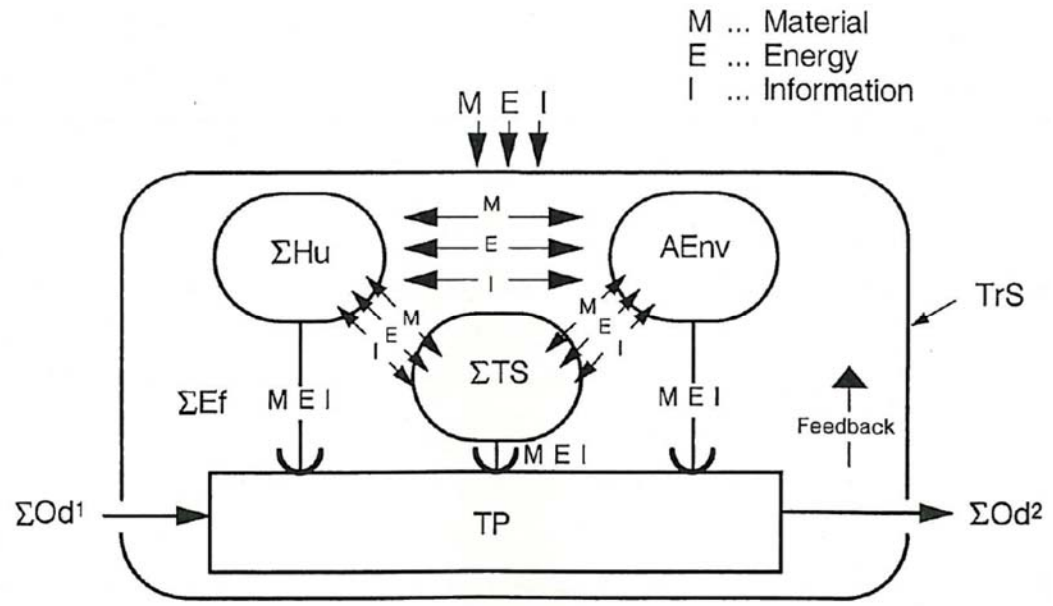

Figure 3. Technical system and its trasfomation [Hubka and Eder 1988]

3.1 Placing some of the known methods to the framework

In order to present to the readers the logic behind our framework, some of the known design methods from the literature are placed to the framework. These methods are: systematic design (such as presented by e.g. Pahl & Beitz, and Ulrich & Eppinger, Theory-U, Systems Engineering, and Atkinson Ship design spiral model.

3.1.1 Systematic design process

The teaching of machine design has long relied on existing mechanical engineering. Thus the teaching has included the existing and know mechanical parts and elements. Teaching of this kind of systematic design process is easier than teaching of how to design multi-disciplinary machines. Research of the basic mechanical design originates from German industry and the aim was to make machine design a learnable subject. [Lehtonen et al. 2011] The systematic design process was developed for this need and it based on the work of Pahl & Beitz and on the instructions of the Verein der Deutschen Ingenieurs like VDI 2221 [VDI 2004].

To locate the systematic design process to our framework we need to define the starting and ending points. This process begins by defining the requirements which are abstact then followed by several clearly defined steps for defining the final function carriers. This situation requires plenty of knowledge about the design object. At the concretisation level the starting point is at the function structure level. The process ends to some guidelines for the different DFX areas. But by the definition of method, these guidelines do not belong to the actual method as there is not straight connection between the last step are not visible in the description.

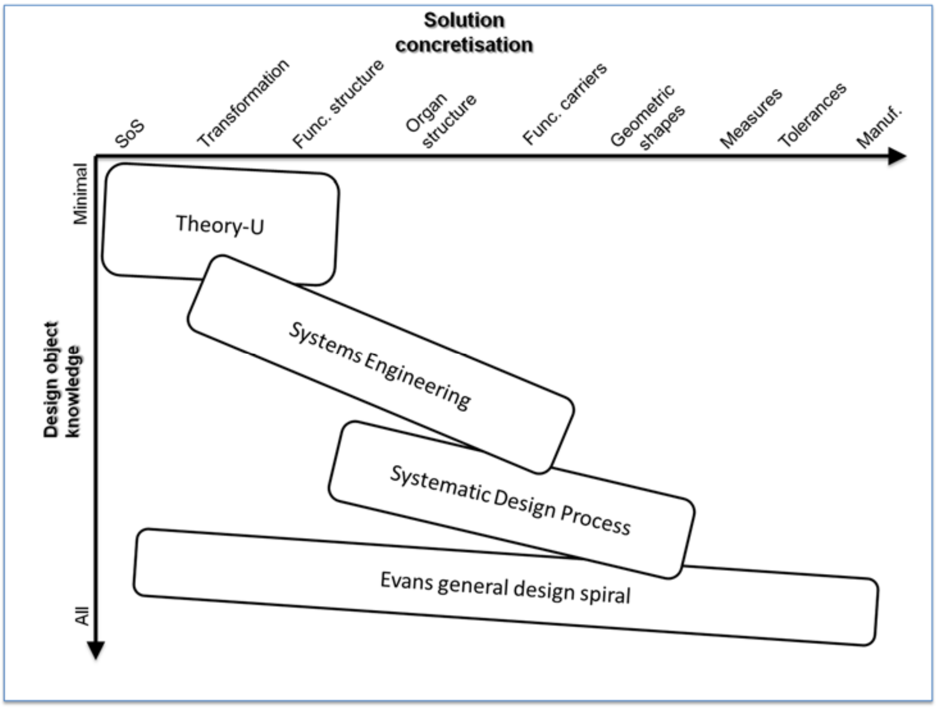

Figure 4. Placing some known design methods to the framework

3.1.2 Theory – U

Theory-U is used for creating systematic, holistic transformations and innovations (Presensing Institute – online). It is used not only for technical systems but also for larger social systems. As a practical social technology, Theory U offers a set of principles and practices for collectively creating the future that wants to emerge. It is based on "Presencing," a blend of the words "presence" and "sensing," referring to the ability to sense and bring into the present one's highest future potential—as an individual and as a group.

The theory-U does not take a position about where the starting point of the development process is. Thus and therefore the idea is to begin from outside the status quo and “forces” the designers to seach for totally new ideas. By acting this way can lead to conclusion that the existing knowledge is faulty and new developed design and findings are remarkably better.

For the reasons presented above, the theory-U can be classified as a method for purely innovative designing. The needed design object knowledge is minimal and it can leave the situation fully open after development loop. Thus it locates on the top part of our framework. On the horizontal level it locates between SoS and transformation.

3.1.3 Systems engineering

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.” (Incose – online)

At the beginning of Systems Engineering method the needed design object knowledge is minimal. During the development process designers’ knowledge increases so that at the end final decisions about the product are fairly confident. This leads to wide coverage on the vertical level.

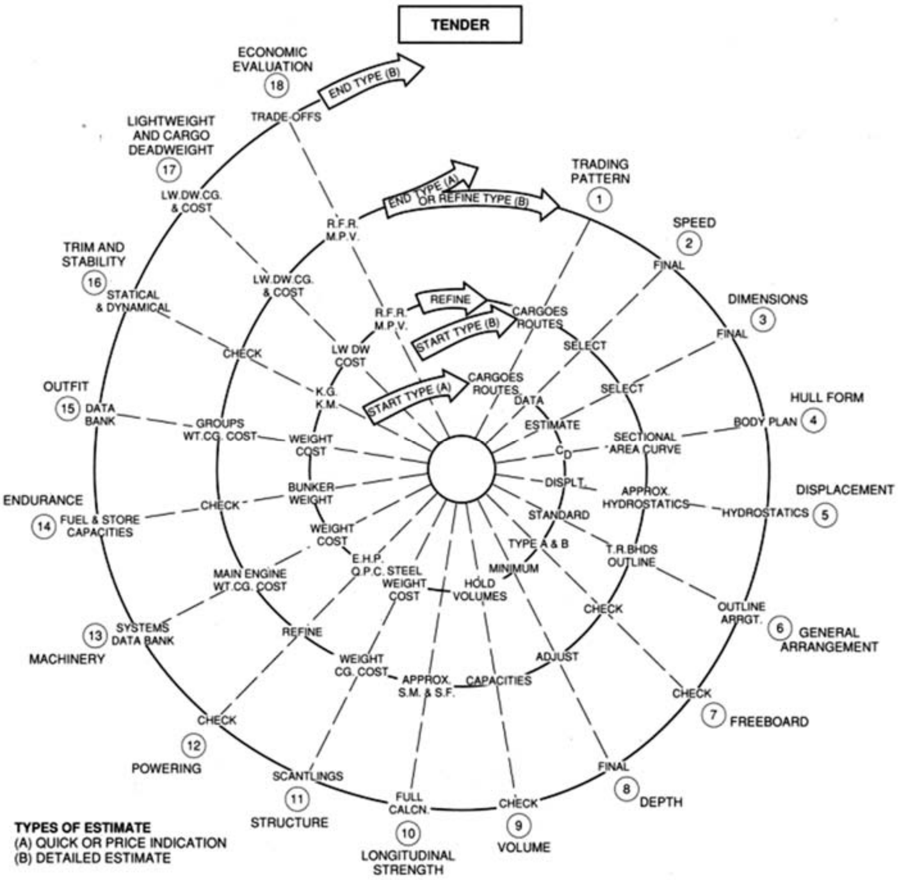

Figure 5. General design spiral [Atkinson 1972]

3.1.4 Design spiral

In the spiral-type (Figure 5) estimation-based design processes, there is an inherent lack of guidance for the design work. Everything is estimated “ad hoc” just for this situation alone. This leads to a situation where “design by re-use” is not utilized. This could have even more serious consequences, if best practices are not utilized and all of the design solution is used “for the first time”. In such situations 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 the Shipbuilding Industry.

The design spiral model covers mostly the horizontal axis of our framework, but it positions on vertical axis very low as the method requires significant amount on design object knowledge from the beginning.

3.2 The methods presented in DESIGN 2010 conference

This section contains the evaluation of the design methods presented in the Design 2010 conference. The methods are place on our framework based on the same criteria as the known methods in Figure 4. We utilised the Rozerberg & Eekels conclusion of the Polyas description of a method, which defines it into following characteristics. Only sequences which fulfil these are considered as the utilisation area of method:

1. A method is a specific way to proceed
2. A method is a rational procedure
3. A method is general = applicable to more than one problem
4. The use of method is observable = one must be able to ascertain whether someone acts according to that method.

Table 1. Some of the presented methods included in our framework analysis

Paper nro Des. 2010	Authors	TITLE
122	Solaberrieta E., Arias A., Barrenetxea L., Etxaniz O., Minguez R., Muniozguren J.	A VIRTUAL DENTAL PROSTHESES DESIGN METHOD USING A VIRTUAL ARTICULATOR
157	Stockinger A., Wittmann S., Martinek M., Meerkamm H., Wartzack S.	VIRTUAL ASSEMBLY ANALYSIS: STANDARD TOLERANCE ANALYSIS COMPARED TO MANUFACTURING SIMULATION AND RELATIVE POSITIONING
142	E. Quanjel and W. Zeiler	COLLABORATIVE ACTIVE ROOF DESIGN
108	K. Osman, N. Bojčetić and D. Marjanović	MULTI CRITERIA DECISION MAKING IN PRODUCT PLATFORM DEVELOPMENT AND EVALUATION
286	P. Müller and R. Stark	A GENERIC PSS DEVELOPMENT PROCESS MODEL BASED ON THEORY AND AN EMPIRICAL STUDY
366	O. Kjeldal-Jensen and S. Ahmed-Kristensen	INFORMING EARLY-PHASE TECHNOLOGY DECISIONS IN PARADIGMATIC INNOVATION
123	M. Karakašić, Ž. Zadnik, M. Kljajin and J. Duhovnik	DESIGN SOLUTIONS WITH PRODUCT FUNCTION MATRIX AND ITS REQUESTS
335	A. Kain, R. Kirschner, C. Gorbea, T. Kain, J. Gunkel, R. Klendauer, and U. Lindemann	AN APPROACH TO DISCOVER INNOVATION POTENTIAL BY MEANS OF DELTA PPLICATIONS
241	P. E. Eriksson, Y. Eriksson, T. Swenberg and A. Sverrisson	NEW DESIGN PROCESS MODELS FOR THE AUDIO VISUAL INDUSTRY: A DESIGN SCIENCE APPROACH
255	T. Erbe, T. Stroehla, R. Theska and C. Weber	DECISION-AID FOR ACTUATOR SELECTION
349	N. Ahmad, D. C. Wynn and P. J. Clarkson	DEVELOPMENT AND EVALUATION OF A TOOL TO ESTIMATE THE IMPACT OF DESIGN CHANGE

All the papers listed in above table are by our interpretation product development methods or at least parts of it. The results of our analysing can be seen from the figure 6. The analysing was carried out by same criteria as when placing the known methods to our framework. First we analysed what is the situation at the beginning when utilising the method, what was the solution concretisation level and how much design object knowledge is needed to begin the process presented in the method. Analysing of the presented methods by the design object knowledge refers to the fact of how confirmed the design team is about the current design idea.If the knowledge is minimal, the situation needs more research about the design object. This is the case in innovative and totally new ideas to be implemented in the product. The development process evolves then in horizontal and also vertical direction. The level of knowledge increase during the design and at the same time the product under development concretises. The next step was to analyse what is the path to the ending of the method and what is the situation there.

On the top left corner (Figure 6) is the very abstract and unlimited situation. At this point of the development none of the product properties, characteristics or components are settled. The situation resembles the assumption presented in most design literature that designing begins from empty table.
On the top right corner the decision about the final product are totally unsettled. But in most of the product development some components are purchaced instead of designing them. These components can already exist on the market, but at the beginning of development process it is not known if these will be in the product.
The bottom left corner would be situation where development process is in the abstract level when talking about the concreteness of the design. Still it could be that the designers already know what the components and most of the final solution principles will be in the product.
The bottom right corner is the ending of product development. Then all the components, parts, manufacturing methods etc. are fixed.

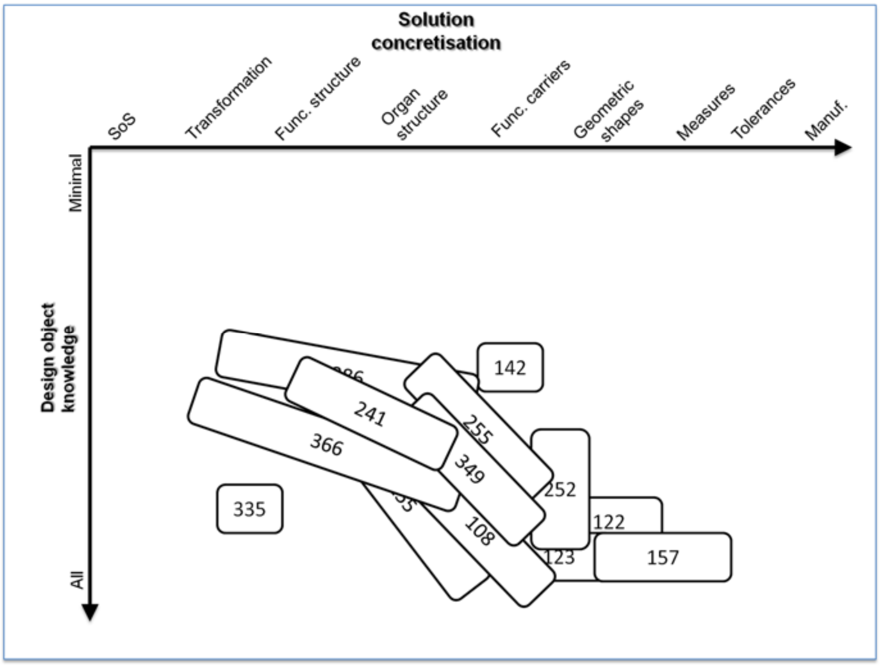

Figure 6. Part of product development methods from the conference Design 2010

We can see a clear cluster on the framework, but it can still be said that there was major differences between the presented methods. Some methods focus on one “segment” on the concretisation axis, like organ structure, while other methods are covering segments from function structures to geometric shapes. The alarming finding was that the cluster is fairly low in the framework. This means that the presented methods aim to tackle the situation in product development process where great share of design object knowledge is already known and the choices about the final product are somewhat already made. These methods are naturally needed to complete the product development work, but there is also need for the methods covering the rest of area.

3.3 The development process in industry

The industrial development project concerns typically one part of the product, not the whole product from idea to final solution. More typically the development activities are directed towards the partial re-design of functions by implementing alternative concepts or new technology. Thus development project requires variable development methods to fulfil the design task at hand.
The design task is rarely as straight forward as presented e.g. in systematic design process. It is also an assumption in systematic design process that the development will mature from abstract to concrete and top-down. In reality the design tasks begins from existing product and it is developed to another, improved version of it.

In some cases the product development project is so large that instead of one process there are multiple different main processes in use. And in addition, sub-systems are developed in own processes. 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 requires a systematic manner when adapting the processes to the particular development project intent.
Industrial development process have variable initiation and drivers. The development process also applies to most of the situations in our framework. Yet the process does not proceed sequentially from beginning to end, but iteratively depending on the subsystem and where it positions on the axis.

4. Conclusion

As seen from the Figure 6 we can say that the development methods presented in Design 2010 conference mainly focus on the situation where great amount of the design object knowledge is known already at the beginning. Another aspect is the lack of methods which begin from the System of systems – concretisation level. This emphasise that innovativeness is not on high level as it belongs to the area in which most of the design object knowledge is covered vaguely.
These findings points out the situation where plenty of research is made on a fairly narrow area of development process and/or focusing on a very specific area of design tasks. Some methods aim to improve the innovativeness yet they do not begin the process in the top left corner of the presented framework in this paper.

5. Discussion

The Figure 7 presents a simplified model of real product development process. There exist two different lines which illustrate the path of design evolvement. Firstly some components of the product are designed from the beginning (line A). The designing proceeds from abstract starting point to the completely defined solution. The "clouds" at the Figure 7 presents smaller development/designing tasks which are implemented by different development methods. Some of these clouds could be the methods like presented in Design 2010 conference. The line B illustrates the path of components already existing. Those are already manufactured and existing on the market, yet in the beginning of the whole product development it is not confirmed that exactly those are chosen in the end. Thus the design object knowledge increases also in the line B.

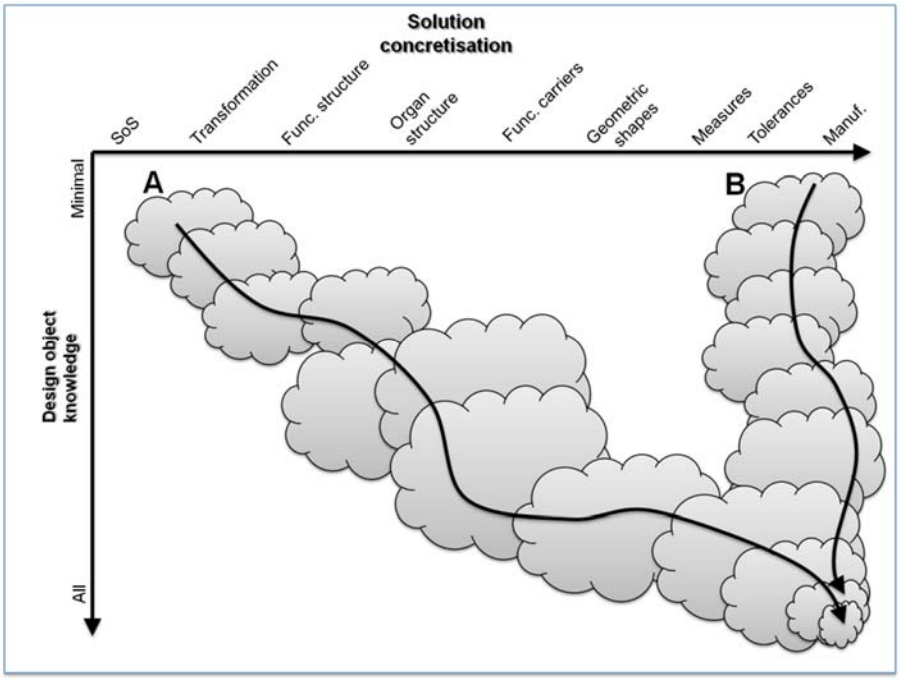

Figure 7. Product development process in practice

We can say that the path of development presented by us (Figure 7) is fairly idealistic and in reality the industrial development processes can follow some development methods, but some of the knowledge comes outside of any tasks described in forehand. Thus there is plenty of different lines which parts of the product follows, but in addition there are clouds which cannot be presented in forehand but they appear during the development process. This is not good thing from research point of view as we do not know the phenomena of knowledge creation or know how to capture it.
Lehtonen et al. [Lehtonen et al. 2011] state in their analysing that most of the known methods in literature could be said to be sufficient for new product development in academic sense. But in industrial cases there are many additional aspects to consider in product development than the product itself. Next step or a giant leap is to develop a framework which would be accepted by the industry into their development processes (or as the model of it), and which would cover the remarkable part of product development process from the innovative start to finalised and detailed product and its manufacturing description.

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