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DEFICIENCIES IN MANAGEMENT OF THE CONCEPT DEVELOPMENT PROCESS: THEORY AND PRACTICE

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ABSTRACT
Concept development is a key success factor in product development and in theory concept development means that a number of concept solutions are generated and evaluated in an objective way using a systematic evaluation method. This paper presents identified deficiencies in both theoretical models and industrial product development. The aim is to supplement previous research, by increasing the understanding of how concept decisions are managed in product development in practice, in order to suggest proposals for improvement of management procedures. Empirical studies have been performed in two large product developing companies that act on the global market. The results imply that actors in the concept development, instead of evaluating different alternatives (as recommended in theory), rather are struggling with developing *a* solution that will fulfill the specifications. Decisions concerning concepts are found to be embedded in a complex weave of actors and activities that characterizes concept development. It is concluded that changes are required in theory as well as in working procedures in practice in order to actually support the actors in product development.

Keywords: concept decision, decision making, product development process, management models

1 INTRODUCTION
Making wrong concept decisions, ending up in a bad design, can harm a product developing company in several ways. These mistakes can be revealed already during the product development project which results in rework costing extra engineering hours and tool investment [1]. There is also a risk that the design flaws reach customers on the market and may result in poor sales due to that competitors' solutions were better or that the company risks to face a lawsuits [2]. Decisions made in concept development will strongly influence all following phases of the design process and it should be emphasized that a weak concept can never be turned into an optimum detailed design [3]. Also, due to that main part of the product and lifecycle cost is committed in the concept phase [3], [4], [5], the importance of the concept decisions cannot be neglected.
The research presented in this paper is a part of a research project initiated in industry due to the fact that wrong decisions are made in spite of that formal management models are available in the companies and the research concerns the context of large companies where product development is a core activity. The focus of the research project is decision making in early project phases and the aim is to understand concept decision-making activities, explain faults made and suggest proposals for improvements regarding how to perform concept decisions in product development projects. The long term goal of the research project is to improve the conditions, such as working procedures, for leaders and teams in order to enhance their ability to perform concept decisions with higher quality. In line with the overall research goal the purpose of this paper is to presents results from empirical studies conducted in industry, as well as a thoroughly examination of what the prescriptive literature proposes, regarding concept decision-making activities. In this respect, concept development is both generation of concepts (enlarging the solution area) and evaluation of concepts (narrowing the solution area). The present paper focus on the latter: narrowing the solution area into a decision.

2 DECISION MAKING
"Decision making is like talking prose – people do it all the time, knowingly or unknowingly." [6]. Decision making is a vast theoretical area that can be considered from a multiple of different views such as psychology and cognition that deal with human cognitive processes, or rational, mathematical

areas where decision making always strives for maximized, optimized utility. The classical rational decision making, summarized by March [7], requires a complete information search and is based on the following prerequisites:

- Knowledge of alternatives: decision maker has a number of alternatives
- Knowledge of consequences: decision maker knows the consequences of alternative actions
- Consistent preference ordering: decision maker has consistent values used in the comparisons
- Decision rule: decision maker has decision rules that are used to select a single alternative

However, due to human's limited knowledge, ability and capacity of information processing it is stated that humans are rational only within certain limits and that decision makers stop the information search when they found an alternative that is good enough [8]**Error! Reference source not found.**. This contrasts to the rational decision making that strives for maximum utility, not considering the effort and cost of doing the information search.

2.1 Intuitive decision making in engineering design

In engineering design literature decisions made intuitively are somewhat treated. Ullman [1] comments that it is difficult to make decisions, due to that commitment are based on incomplete evaluations. Most design decisions are made with elements of intuition, otherwise the design process would have no progression and people *have* to simplify a situation to be able to reach a decision at all. Examples of heuristics that designers use when evaluating solution can be [3]:

- Seeking a 'satisfying' alternative: searching stops when the first alternative passes the criteria.
- Seeking an 'excellent' solution: each alternative is identified with its single best property (can be different property for each alternative) and the alternative with – comparatively – the most valuable 'best' property is chosen.
- Elimination by aspects: an alternative is rejected if it does not pass the criteria (tested in order of importance of criteria) and searching stops when all alternatives except one have been rejected.

Most design problems are solved in teams and according to literature, concepts are often best generated by individuals, and concept selection and enhancement is often best performed in groups [9]. Due to group level activities additional challenges may appear:

- Reaching a decision in a team requires consensus, which is often difficult to obtain [1].
- Groups with members with long experience of design in industry tend to be impatient 'to get on with it' and may consider that a procedure holds them back from arriving at a solution [9] .
- Differences of opinions in the design-team and problem of passing the decision through local and higher management [10].

3 CONCEPT DEVELOPMENT IN ENGINEERING DESIGN

The research presented in this paper aims to contribute to improving the concept decision-making process. Therefore it is of great interest to review what existing literature within engineering design contains regarding this matter. The review of prescriptive engineering design literature was focused on textbooks for practitioners and students. The product development process is in general presented as a sequence of phases (e.g. [1],[3],[11],[12],[13]) where it starts with an initial need (a design problem) and the product is developed and verified to satisfy this need.

In the engineering design community the word *concept* is usually described as an idea that is sufficiently developed to evaluate the physical principles that governs its behavior [1] or an approximate description of technology, working principles, and form of the product [11]. A concept should be developed far enough to be able to ensure that the proposed product will operate as expected and, with reasonable further development, will meet targets set [1].

Concept development is a phase in early stages of the product development process with the purpose to generate concepts and evaluate them against customer identified criteria, and finally select one or more concepts for further investigation or development [11]. Despite not using exactly the same wordings the authors agreed on that concept development is initially a diverging process including generation of a number of alternative concepts, based on a search and exploration of a wide range of different sources (both internal and external) [3],[14]. The diverging concept generation is followed by a converging process where different alternative are evaluated regarding customer needs and other criteria, relative strengths and weaknesses of the concepts are compared, and finally one (or more) concept is selected for further development [11]. Concept development is mainly described with the

steps: generation of concepts, evaluation of concepts and selection of concept(s) [1],[3],[9],[11], [12],[14]. Development of product design specification is closely linked together with concept development [9] and an example of an illustration of concept development is the front-end activities according to Ulrich and Eppinger [11] (Figure 1).

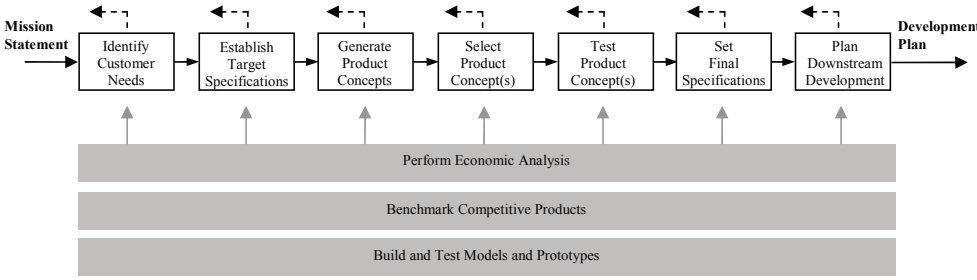

Figure 1 The many front-end activities comprising the concept development [11]

In the engineering design literature, expressions like concept development, generation, evaluation, selection, screening, scoring, comparing, eliminating and decision making are used sometimes as synonyms, sometimes as sequential steps in an overall sequence, and sometimes as subsets of an overall concept development activity. The present paper focuses on the later, converging part of concept development, ending up in the *concept decision*, selecting the preferred concept solution to pursue into detailed development. In the present paper *concept development* will be used to describe the total process that ends up in a selected and decided concept solution.

Methods to use in the converging part of concept development

In the concept development process, distinguished by uncertainty and ambiguity, a structured concept selection process encourages decision making based on objective criteria, decreases personal biases and guides the product development team through a critical, difficult, and sometimes emotional process [11]. A structured selection method can be used to reach, according to Pugh [9], a controlled convergence. General benefits of using structured processes and methods are that they remind team members of important issues, support documentation, clarify decision basis and reduce unconfirmed decisions [11]. Many design methods and support tools encourage integration and communication in the organization [11],[15],[16],[17],[18].

Selection of concepts can be made in several ways, and even if only one concept is generated a method is used: choosing the first concept thought of [11]. Examples of other concept selection methods are: the decision handed over to the customer (external decision) [11], an influential team member makes the decision (product champion) [11] or by intuition (‘gut feeling’) [1],[11]. However, these authors are quite unified in recommending a decision matrix for evaluation performed in a team [1],[3],[9],[11],[12],[15]. Decision matrixes methods includes the steps: identify criteria for comparison, maybe weighting the criteria, select alternatives to be compared, generate and compute total score. Decision matrixes can be used in many different forms and a well known example is Pugh's evaluation matrix, which evaluate against a datum [9]. Evaluation methods can include a decision rule or not, meaning if the method establishes the 'best' alternative or just support the assessment of the overall value of the alternatives (not supporting the decision maker in the last step of the process) [3].

In order to reach an effective evaluation, alternatives and criteria for evaluation, must be in the same language, have the same level of abstraction [1], be deduced from the product specifications and be agreed [9]. Team members’ knowledge and understanding of different concept alternatives may also affect the evaluations [19]. Empirical tests have shown that respondents could say that they understood a concept when in fact they really did not [19]. If there was low knowledge of the concepts their evaluations could be based on other information than presented in the concept description [19].

More analytical approaches in decision support, such as the Analytical Hierarchy Process are recommended by Saaty [20] and Gandy et al. [21]. In a comparison between different types of concept selection methods, Weiss and Hari [10] concluded that the selection method has to be adapted to the

circumstances. They also state that when two or more concepts are found to be close, the project manager's intuition will be the best selection tool. For unbiased and honest concept selection, they recommend Pugh's evaluation method, but when any kind of biases are present in the team, a semi-quantitative, sophisticated selection procedure should be chosen, as it will increase the odds that the team's proposal will actually be accepted by external approving channels [10].

Iterations in the process

When studying the overview models of product development in general and concept development in particular in literature it is discovered that there is often noted in the textbooks that the processes are iterative. Roozenburg and Eekels [3] do have a feedback loop from the decision step to both analysis and synthesis in the basic design cycle. A cyclical iteration between generation and evaluation is shown in several models [1],[9],[11] and additional concept generation and refinement may be initiated [11]. Refinements, by iteration on a higher information level, should be made whenever is necessary [12] and in VDI 2221 [13] an assumption is made that design steps have been worked through in an iterative manner before a decision about an optimum overall solution.

A challenge for the development team is to decide when to narrow down to a single concept. Ideally, a designer would know enough about each concept at the decision point to choose one and put all possible resources into developing the chosen concept [1]. The authors mostly speak about *one concept* [13] to be detailed developed, but sometimes they use a saving clause stating that maybe concept selection should end up in "one (or more)" selected concept(s). It is notable that there has been a change during the years in Ulrich and Eppinger's [11] overview of the front-end activities (Figure 1) where the figure has been updated: "Select a product Concept" (up to 2nd ed.) is now replaced with "Select Product Concept(s)" (from 3rd ed.).

3.2 Alternative to classical point-based concept selection

There is literature that asserts that it might be advantages with refining a number of concepts before committing to one of them, referring to Toyota [1]. Toyota's designer thinks about sets of design alternatives, that are found within the solution space [22], rather than pursuing one alternative iteratively. This aims to avoid iterations and eliminate work on solutions that later must be changed [22]. Toyotas engineering and managers try to delay decisions and provide their suppliers with difficult specifications very late in the project [22]. "The manager's job is to prevent decisions from being made too quickly… but once a decision is made, we change it only if absolutely necessary." quoted from Toyota's General Manager of Body Engineering by Morgan and Liker [23].

3.3 Gap between prescriptive literature and previous empirical findings

Stage-phase models found in prescribing literature may be considered as rigid step-sequenced models and have received criticism for their non-dynamic characteristics [24]. This criticism asserts that the product development models are not designed to handle a changing environment and do not support learning during the projects [24]. However, Cooper [25] reminds the readers that the stage-gate is not a linear process or a rigid system but should be considered more as a "playbook" that should be adapted to the present situation.

There are several empirical findings that show gaps between what literature prescribes and what is found in empirical studies. The findings state that step-oriented design methodologies are rarely followed by designers [26] and that some experienced designers are able to develop good solutions early in the design process without employing methodological strategies and conducting systematic analysis of important information [27]. Hansen and Andreasen [28] highlight that different stakeholders, both inside and outside the project, act as decision-makers, influencing the design process and its result. Other empirical findings state that there are both formal and informal factors, such as technical requirement levels and organizational climate, that influences decisions made in innovation and development environments [29],[30]. A critical comment to step-oriented engineering design methodologies is that they lack traceability and do not consider the minor design decisions made throughout the design process before leading to the design solution [31]. This can be complemented by the findings of Christiansen and Varnes [32] and of Bragd [33]. They reported that few rational decisions were made in official meetings in development projects. A conclusion was that the gate system was used, but in a different way than how it is presented in prescriptive literature: as an arena to justify decisions already made, and used as a signal and symbol for rational behavior [32].

Bragd asserted that instead of using the meetings for decision making they were used for screening status and keeping pace in the project [33].

4 RESEARCH APPROACH

The literature study focused on textbooks within engineering design (covering product development in general), due to that these books are more available to industry than the body of academic papers.
In parallel with the literature study empirical studies, at two different companies (Alfa and Beta) were conducted. Company Alfa is an automotive company, developing cars, and Beta is operating in transportation business, developing trains. Even if both companies develop products for a global market, the business environments for the two companies differ regarding how their development projects are initiated and their products sold. At company Alfa development projects are initiated according to an internally defined cycle plan and then the products are sold to customers on an open market. Company Beta operates in a business where products are sold to other businesses or organizations (e.g. cities, regions or governments) and the projects are initiated through a bidding-quotation process between the company and their customers.
At company Alfa a retrospective case study was performed, investigating a technical concept that had to undergo severe rework in later phases of the development project. The purpose of the case study was to gain more understanding of what went wrong in this specific case and to identify what had influenced the decisions made (for more details, see [30]). An additional interview study was performed at company Beta with the purpose of examining how they manage their concept decisions.
Both studies were using semi-structured interviews as main method for data collection. In the case study interviews were complemented by internal document research (e.g. gate reports and protocols from design reviews). The interview guides in the two studies were based on the same questions, with some additional questions for the case study. Open questions were used to obtain interviewees' opinions and experiences regarding the subject aiming to cover phenomenon and contextual conditions [34] and understanding dynamics present within a single setting [35]. In the case study at Alfa the respondents got the task to reproduce what happened in the specific case and in the study at Beta the respondents were asked to describe their experience of the company's concept decisions in general. Representatives from both project organization and functional organization were interviewed (Alfa: nine and Beta: six). The interviews were recorded and transcribed sentence by sentence as a base for the analysis. Coding and categorization [36] were used to analyze the material before comparing the empirical results to studied literature.

5 RESULTS FROM EMPIRICAL STUDIES

5.1 Results from the case study, company Alfa

The case study was investigating a concept in company Alfa that had to be reworked in later project phases. The need for rework in this particular case was discovered after that the concept phase was officially closed. Late occuring events changed the rating of the concept solution in a negative way, and based on the new rating rework had to be initiated. Examples of the most influencing events were: a new exterior design and new requirements published from an external institute. Besides the cost of extra tooling investment and engineering hours the rework also created a lot of frustration in the organization. The study was initiated from the company in order to gain more understanding on what did happen. A more detailed report can be found in [30].

How was the concept decision made in the investigated case?

The respondents reported that they worked on one main track in the concept development (hence, no alternative solutions were developed), based on a solution used in earlier projects. Some respondents reflected on that the solution got too detailed too early and that the team focused on getting *the* solution to work instead of having discussions on a more conceptual level. Computational analysis was used as main basic data. Additionally, some respondents reported how they used their personal experience to influence the concept development in certain directions. For example, one respondent reported that he was convinced that a certain solution should not be used, due to bad experience in a previous project, and the respondent reflected on that he tried to push the development away from that certain solution he wanted to avoid.

The respondents could not give account for how the decision actually was made, instead they referred to several smaller decisions made during the process. Some of these decisions, that seemed proper at the time, were later found to have unforeseen consequences. Moreover, the concept phase was performed during a turbulent time in the company. Several actions, events and actors was found to influence, both formally and informally, the concept decision, some directly and other indirectly.

Available support for the development work

The company Alfa has a documented product development process with the phases concept development, detailed development and industrialization, including process maps, role descriptions and checklists for different occasions in the projects (available on intranet). Despite available support, the respondents reported that any supporting method regarding concept evaluation was not used.

Just before the projects concept phase, the company carried out an extensive re-organization, in the same time as starting up a new multi-brand platform. These two activities did require a lot of focus from all employees during the time of the concept phase and it resulted in a lack of attention to the technical development in the project. The re-organization and new functional structure, with more fragmented areas of responsibility, resulted in that some overall issues areas were not taken care of.

Furthermore, respondents stated that the status reporting (of the project status) was affected by a change in the leadership culture in the company. The working climate was considered as less open, resulting in that certain information (useful as basic data for decisions) did not reach top management decision makers.

5.2 Results from interview study, company Beta

The purpose of the interviews in company Beta was to examine how co-workers consider concept decisions to be made in the company. This section lifts up characteristic features of company Beta complementing the presentation in 5.1 including similarities and differences.

How are concept decisions made in company Beta?

The respondents referred to a *concept* as: a high level solution (no details) that is balanced on the total product level, and that fulfils both customer and internal requirements, and: "A concept defines the function, material choice and preliminary interface. There should be a solution for every aspect". The respondents were asked about who is making the concept decisions and most respondents clearly declared that: "the customer decides!", but still there were some nuances: "the customer get what they want except if their requirements are completely unreasonable", "the company often recommend a solution to the customer", and "we decide internally first to guide the customer in a specific direction". All along, they referred to developing one solution that they negotiated around.

They also reported that there was no common way in how they perform decisions and that decisions are made partly ad hoc. No official methods for concept evaluation with weighting of different criteria are used. Regarding relative importance of decision criteria, one respondent reported that he considered some attributes as more important and thought that his colleagues would agree, but they never had such a weighting discussion. Basic data used during the concept phase were computations, mock-ups and experience. The tighter time plans - the larger portion of experiences used.

However, a development project (including the concept phase) proceeds by a bid phase (before the contract between company and customer is signed). Any entrance into a competition for a contract is connected with a risk, since some technical decisions are made implicitly in this early phase. They stretch themselves quite long to meet the customers' wishes, in order to win the order, since there are not that many orders to compete for.

Due to the global market the company Beta meets customers with different cultures and they have experienced that they should work differently with different customers. One challenge is to understand how different customers interpret and relate to what is written in the contract. Some customer see the contract as a guideline and a starting point for negotiations while others see it as a law. "Clear expectations, good dialogue and good relation to the customer - giving and taking" but also cultural training of product development personnel were identified as success factors by the respondents.

The starting point in the concept phase is almost always earlier projects and products, and a reference project is identified. What can be reused from the reference project is investigated (a goal is to reuse 80%). The benefits of reusing are, not only to save money, but also to use proven solutions and

technologies. To ensure use of experience from the reference project the company has tried to use key competences from the reference project in the manning of the new project.
If problems occur during the concept development, the problems quite often ends up as an issue for the technical project leader, who often possess experiences from the reference project. Unfortunately, according to the respondents, too many issues end up consuming time for the technical project leader.
The concept phase is finished by a design review with the specific purpose of showing how the requirements are going to be met. This specific design review is considered as a major milestone in the project by the respondents. The design reviews during the projects are not considered as decision points, however, actions, investigations and responsible persons can be assigned during the reviews. The design reviews are, besides a chance to get an overview of the project and discover contradictions, an opportunity for experienced people to participate and share their experience: “It is a way of getting lessons learned from other projects”.

Available support for the development work
Company Beta has a documented product development process and it includes the phases: bid design, concept design, preliminary design, detail design and industrialization. The company's general processes shall be available on the intranet but the respondents state: "The processes are not that well communicated. It is a known weakness″. "I know the process in general but not the details, but I know where to look". Another respondent refer to that the product development process ends up as "very limited to what kind of commitment to deliver we make in the projects."
The company is organized in a matrix organization (project and function), and a functional manager, commented that there were room for improvement regarding knowledge and common view of the product development process. However, there are meetings between key persons in the projects and the functional organization where they discuss those general issues. One key role in the organization is the technical project leader and there are about ten technical project leaders in the company and to share their experience to each other they try to have regular meetings. The most common comments and questions in those reviews are regarding recently made mistakes: "We have done like that before!", "Don't we now that?" and "Didn't we learn anything?"

6 DISCUSSION
Results from the empirical studies of concept decision making are discussed in relation to what was found regarding the subject in the studied engineering design literature. The concept decision-making processes revealed in the companies were found to have certain characteristics, which are discussed in the first section. In the second section, a specific discussion regarding the internal formal working procedures within companies is provided.

6.1 Characteristics of the concept decision-making process in the two companies

Good concept decision – a valuation that can change
The respondents in the two companies were using the expression *concept* in the same way, meaning a solution on a more abstract level, similar to definitions in literature [1],[11]. A definition of what a good concept decision is deserves to be discussed. In literature the ambition to make the best solution is treated and a concept should be developed far enough to ensure further, detailed development [1]. In the case study in company Alfa external events that occurred late degraded the valuation of the concept. Therefore, a decision that is considered as good when finalizing the concept phase can be degraded to a bad concept decision due to changes later in the development projects.

Developing only one solution
In the case study in company Alfa no alternative solutions were developed in the concept phase and in company Beta respondents reported that the only time alternative solutions were generated was when they asked a number of suppliers to show a solution each. The findings reveal that the studied companies did not develop solutions in parallel but instead they were struggling to develop *a* solution (as in *any*) that met the requirements. Therefore, concept decision making, as reported in the empirical studies, can be defined as more of accepting deviations (prioritize, compromise and trade-off) than choosing between alternatives. Reasons why developers do not consider alternative solutions might be explained by:

- the design problems are highly complex, and maybe no solution can comply to all requirements,
- limited human cognitive capacity [8] constrains the ability of dealing with several concepts,
- the two companies focused a lot more on reusing solutions than described in the theoretical models even though literature propose to use both internal and external sources [3],[11],
- alternative solutions is not requested by management or the internal development process.

Not a stepwise process

What the respondents reported, and what the authors observed in the studies, have a weak resemblance to what the objective, step-oriented theories prescribe [1],[3],[9],[11],[12]. The findings add to earlier research identifying gaps between prescribing theory and observed practice [26],[27],[28],[32]. Furthermore, decision matrixes for concept evaluation, that is recommended theory by several researchers [1],[3],[9],[11],[12],[15] were not used in either of the companies.

No explicit decision maker

In the study in company Alfa the respondents did not point out any specific decision maker, instead they reported several decisions made in several forums that later turned out to be governing what concept that was developed. In company Beta it was reported that concept decision were depending on individuals, and not as objective as theory recommends [11]. In both studies the respondents mentioned that different people, involved in the projects and in the organizations, influenced the decisions, such as customer (external concept selection [11]) and the technical project leader (product champion [11]). Having several decisions makers along the way have been observed before [28]. However, different business models (and different roles of customer) of the two companies affect their concept decision making: in company Alfa's project the customer is not present, and in company Beta the customer is present during the projects and can therefore make decisions.

Culture and structure

In the studied case in company Alfa previous findings state that more factors, than the ones considered in the theoretical development processes, influence concept decisions, such as leadership culture and climate in the organization [30]. When developing concept solutions, defined requirements and specifications, and technical data of the concepts play a dominant role. In company Alfa, the developers have to interpret the requirements, such as understand legal regulation or predict what future customers want. In company Beta an additional challenge is present: *the development team has to understand how the customer interprets a written contract*. Respondents from company Beta returned to the cultural issue time after time: regarding how customers negotiate and relate themselves to written specifications. The influence by cultural issues in company Beta's decision making is confirming earlier results reporting that both formal and informal factors (culture and structure) influence concept decisions [30].

Decisions embedded in the concept development

A design review at the end of the concept phase in company Beta's projects was mentioned as one of the most important points in their development projects. The purpose of these reviews is more of a screening and updating event than an official decision meeting. However, it seems like these reviews are important occasions where everything is inspected and conflicts may appear clearer. Thus, the reviews can be identified as a 'power event' (even if it is not a decision event), summarizing previous activities and decisions, keeping the pace in the project which also have been found in previous empirical studies on meetings in product development [32],[33].

How the actual concept decisions happened was very difficult to capture in the interviews. In both studies, respondents were unable to report the exact course of events, neither in the specific case study in company Alfa, nor in answering general questions in company Beta. The inability to report the total decision-making process may have different causes. It may be impossible for a respondent to give account for the total decision-making process since it is such an extensive weave of interactions and actors involved [32]. Maybe the decision is made when the team does not have time to iterate anymore, and therefore it is more of a non-decision. Moreover, the respondents are apparently neither aware of the total decision-making process, nor their own individual processes. This indicates that the respondents do not have a language, or practice, to reflect about decision making. However, such reflections ought to be improved in design education, according to Stempfle and Badke-Schaub [26].

Findings from the two empirical studies show that it was difficult to separate concept decision making from concept development activities, since there were no explicit decisions reported. Therefore, the authors conclude that, in the two studied companies, *concept decisions are made embedded in the development of the concepts*.

6.2 The companies' internal formalized working procedures

The studied companies have internally defined product development processes, and many respondents referred to the companies' internal working procedures and therefore they are discussed here. Company Alfa's process resembles more, regarding basic phases, to the process presented in theory (e.g. [1],[3], [11],[12],[13]) than the process of company Beta (which begins with a bid-phase).
In both companies the internal process descriptions were available, e.g. on intranet or in printed versions, but were hardly ever studied by co-workers in the projects. However, the respondents assured that they knew where to find the instructions if they wanted to, but that they have not prioritized to search for that kind of information.

Gap between theory and practice

In the studies it was observed that the concept development and decision making were not conducted as it is suggested in prescriptive literature, and this may have several reasons. The methods may not fulfill the needs in product development practice and are therefore disregarded. Organizations may nurture habits that hamper utilization, such as a stressful climate where supporting methods are seen as a hindrance in practice; i.e. there is a major difference between having methods available in the company and being able to use those methods. The gap between theory and practice has been a subject for extensive discussions in previous research [24],[26],[27],[28],[32]. A difference between prescriptive literature and empirical findings presented here is that the context and conditions are changing continuously in practice, meaning that projects suffer from events that reach beyond the company's control. Nevertheless, changing conditions are opportunities for improvements of developed solutions since more knowledge is gained.

The role of internal formal working procedures

During the interviews, the respondents sometimes changed 'views': they altered between describing how they actually did work and how 'it should' be done according to the internal formalized procedures (they never referred directly to engineering design literature, with one exception).
Both companies have a body of formal documents and procedures that could roughly be labeled as 'company specific theory' meaning e.g. internal instructions and flow charts. Therefore, the authors would like to add the entity of companies' *formal procedures* when discussing the gap between *theory* and *practice* (found in Figure 2). *Theory* represents academic literature (with requirements of being on a general form), *formal procedures* represent internal formal working procedures defined within a company (designed to fit a specific company), and *practice* represents actual work performed by practitioners.

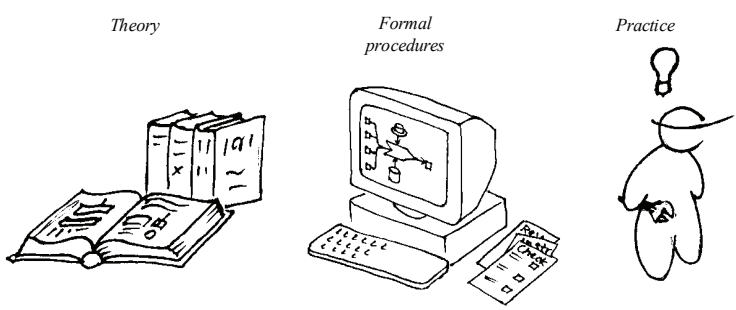

Figure 2. Theory, practice and formal procedures in between

The authors claim that the role of internal instructions has not been sufficiently discussed in previous engineering design research. Therefore challenges for companies trying to transform theoretical models into internal formal procedures have been neglected. The exact relationships between the three entities cannot be defined based on these empirical studies, and therefore the authors suggest that this could be an area for further investigations.

Implications for product development theory and practice

Theoretical models in literature seem to show an idealistic picture of product development, which may be required to be able to capture the overview of the models at all. However, the authors question to what extent those idealistic models support the product development in practice. In the textbooks it is stated that reality is more complex than what the models show, but this information seems to be peeled of when designing a company's internal procedures, resulting in that the company's formal procedures do not reflect all comments related to the models, e.g. regarding looping between evaluate concept and generate concept, as described by Ullman [1]. Those iterations, not included in the company-models, are seldom planned for in industrial projects. Therefore, the authors have identified a risk that companies do not use the models presented in theory to their full extent when they design their internal working procedures. The authors assert that both literature and practice could improve in order to support the actors in the concept decision-making process:

- Engineering design literature should improve the way to visualize and communicate the complexity (the complexity is mentioned, but the models are not showing it clearly enough). Maybe the main task in developing the theory in engineering design should be to improve the visualization that consider the complexity in decision situations.
- The companies should be challenged in order to be more aware of the role and implications of their internal formal procedures.
- Models in literature have no actor perspective, and neither do formal models in the companies. Those models require a rather simple world. However, decisions are made by people and therefore managing decision making can consist of managing the process, but should also lead people and clarify decision structures.

In order to improve theory and practice regarding evaluation of alternative solutions (unlike struggling to find a solution) the authors suggest that a change of mindset is needed. Is the search for convergence an attempt to be rational but instead creates, if anything, irrationality? The alternative approach with set-based engineering has been reported to be successful [22]. The search for convergence, results in that decision are made in a gradual manner (reported in both empirical studies presented, confirmed previous research that states that decisions grow out of a situation [28]). Without constant striving for convergence one might hold the solution space opened longer. The mindset needed is to have an acceptance of working with a solution space, to consider parallel alternatives, not get stuck in details, and be willing to expose conceptual solutions for evaluation. The mindset has to be present in both the development team as well as in management, and the authors suggest that this is subject for further research.

7 CONCLUDING REMARKS

The intention of the work presented here was to provide nuanced insight in concept decision-making in practice based on studies in two industrial companies (i.e. no general conclusion can be made).

It can be stated that the studied companies were not following the proposed step-wise 'generate, evaluate and select' process: generating a number of alternatives that are evaluated using a structured concept evaluation method. Instead, the companies were struggling to develop *a* solution good enough to meet defined specifications. Concept decisions as reported in the empirical studies are more of accepting deviations (prioritize, and trade-off) than choosing between alternative solutions.

The respondents could not separate concept decisions from the concept development performed and they were not able to define explicitly who actually made the concept decisions. Therefore the authors conclude that *concept decisions are embedded in the concept development*, including many activities and actors, at the two studied companies. The studies also clearly showed that it is not only formal factors that influence the concept decisions, which confirmed earlier research.

The authors also conclude that changes are required in theory as well as in the companies' internal working procedures in order to actually support the actors in concept decision making. In discussions regarding the gap between *theory* and *practice* the authors want to emphasize the role and implications

of internal *formal procedures* (defined within companies). The findings show that the transition from theory into company specific procedures includes a risk that theoretical models are not used to their full extent. Furthermore, the authors claim that the engineering design literature should be challenged to improve the ways to visualize and communicate the complexity of their product development models. Further research could be to investigate the relationships between *theory*, *formal procedures* and *practice* in order to understand more of how they are interconnected and how improvements should be implemented. It should also be interesting to widen the empirical base in order compare the results presented here to other companies and industries.
Additionally, the authors assert that the mindset in the product development organization has to be dealt with in order to create a change regarding handling of alternative solutions; e.g. accepting fuzziness, without seeing any detailed models during the concept phase, ability to deal with parallel solutions, and not pushing decisions too early.

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