FUNCTIONAL PRODUCT INNOVATION - REAPING THE BENEFITS OF SIMULATION DRIVEN DESIGN

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ABSTRACT
Innovations are crucial to companies' competitive strength. Functional Product Development (FPD) is a base for a Functional Product Innovation vision, aiming for a new way to design, develop and sell physical products. The purpose in this paper is to discuss relations between the development process for these products, called FPD, and a simulation-driven approach to design these products, called SDD.

FPD consider a holistic approach in early design phases. A life-cycle perspective, cross-company collaboration and a focus on stakeholder needs are examples of issues which are part of the wider view on product development. The SDD approach puts forward an integration of simulations to provide support for designers in FPD. The goal is to take the knowledge domains of engineering, business and production into account in the design to provide for the ability to sell 'functions per unit'. The combination of FPD and SDD is paramount. The influence of needs plays a leading part in FPD and the use of simulations could create a virtual structure to combine and recombine resources and thus, nurture innovations.

KEY WORDS
Collaborative strategies, innovations, simulations, virtual product development, product development

1. Introduction

On a business level, a new scenario is occurring in industry entailing a shift in view from transaction of physical artefacts to providing services. Besides engaging customers as co-producers in product development, service provision conveys that the ownership of the physical artefact is not transferred to the customer. The change into service providing companies involve the intentions to provide customers with an encompassing offer and to take extended long-term responsibilities regarding the agreed upon functions. Thereby, this new scenario is referred to as functional products [1]. The service provision or the total offer is realised through, e.g., leasing and/or contracts based on the customers use of 'functions per unit'. This new scenario is emerging as an additional business model, hence the companies has to manage multiple models since the traditional mode of selling artefacts is still present. In relation to this, the best model to meet customer needs, as well as provide for the best revenue for the companies' businesses has to be decided upon at an early concept stage of the development process.

The business strategies and visions, or commercial development process [2] are feeding input to the product development process. A new complementary way to define the business brings consequences for the development of physical artefacts. For example, the integration of service aspects lead to a focus on user needs and the life-cycle perspective entails down-stream knowledge to be understood in early phases of product development. Furthermore, the extended and long-term responsibility for the agreed upon functions provided by the physical artefact calls for the design team to have a thorough understanding of the physical artefact's performance as well as how the customers use it.

Thomke and von Hippel [3] argue that "…*traditional product development is a drawn-out process of trial and error, often ping-ponging between manufacturer and customer. First, the manufacturer develops a prototype based on information from customers that is incomplete and only partially correct. The customer then tries out the product, finds flaws, and requests corrections. The cycle repeats until a satisfactory solution is reached, often requiring many costly and time-consuming iterations*" (p.76). To change the ping-ponging development approach into a better one, Thomke and von Hippel suggest, that customers can be provided with a computer supported tool-kit including e.g., simulation capacity. By doing so, a virtual structure, i.e., an extended enterprise, for close collaboration between manufacturers and customers emerge. Applied in a business-to-business setting, this virtual structure is part of the view for functional product development (FPD), as well as the emphasis on user needs to be present and guide the process.

Contemporary product development is extensively computer aided and the use of Computer Aided Engineering (CAE) tools is established in the industrial context. For example, finite element analysis techniques, as well as knowledge-based systems [4] are used in design activities, however viewed as internal and supporting engineering specific knowledge. Although commonly used by engineers in product development tasks, CAE tools are seen more or less as tools used for verification and validation to ensure performance measures [5], and not as support for design space exploration to nurture new products or innovations.

A business model for functional products based on a FPD approach, feed input for the vision of *Functional Product Innovation (FPI),* where the capability to use *Simulation Driven Design* (SDD) to guide collaborative engineering product development in a global extended enterprise is at the heart. A vision is a best-case scenario; there are of course obstacles to overcome to realise it.

1.1 Functional Product Innovation

The innovation part in the vision named FPI insists on further explication. We will present some qualities here, to clarify the vision; not to define the word innovation as such.

Innovations can be seen as new physical artefacts or commodities, i.e., *new things*, which satisfy some sort of needs. The input for innovations in this case is the FPD process; this is, in turn, thought of as capturing an integration of physical artefacts and services to be sold as 'functions per unit' in total offers. Besides adding *new services* as a quality in the word innovation, the integration of services transforms customers from being a client to be co-producers in product development. Involvement of customers in design activities entails, in a best case scenario, also knowledge sharing to take place and added-value to evolve. Such a collaborative product development brings in the qualities *new knowledge* and *new ideas* into the word innovation, and this shows the way to *new processes*. The word *new* can here be interpreted as in beforehand 'poorly understood' or 'unknown', and as a fact, exceeding what was intended from the beginning.

1.2 Simulation Driven Design

Simulation is a word which includes a plethora of actual computational techniques; each of them can be used for specific purposes and/or within a variety of application areas. Nevertheless, applied to engineering design specific tasks the diversity persists. In general, simulations could be viewed as a method to, based on a computer model, describe a course of event which is happening in reality.

A SDD approach [6] in product development is based on an integration of; **(1)** *discrete event simulation* (integration of development and business processes), **(2)** *rule-based simulation*s (knowledge automation and reuse), **(3)** *simulations of mechanical processes and properties* (manufacturing processes and in-service). SDD strive to facilitate the use of simulations early on in the design phase and to support a broader range of design tasks. Hence, provide support to drive design activities according to a number of perspectives, e.g., business, engineering and production. Besides being used to support design activities in a network of companies, SDD should be supportive to internal design activities, by the same token, taking several perspectives into account, providing design performance forecasting and design space exploration regarding business and engineering.

1.3 Purpose and disposition

In this paper, relations between FPD and a SDD approach are discussed, to contribute to insights into the potential to use simulations in early phases of product development to nurture innovations. An extended enterprise business model is outlined as a departure for the discussion. The frame of reference for this paper is found within an engineering design perspective.

The paper is arranged as follows, firstly, the data generation for this study is presented. A workshop approach has been used for identifying problem areas for two academia/industry pilot projects. The result from the workshops, i.e., the identified areas, is outlined to highlight changes on the use of simulations identified in industry, as well as intentions for FPD. Examples of business models are presented. Hierarchical and partnership business models are typically used in industry, while an extended enterprise business model has evolved in parallel with FPD.

2. Data generation

Data for the study presented in this paper has been generated during a number of years of interaction with companies affiliated to a research centre. The authors of this paper have interacted with people from the affiliated companies in formal as well as in informal meetings. Two workshops have been conducted in addition to this. There were 15 participants (10 from industry and 5 from academia) in one of the workshops. 5 companies were represented in that workshop. There were 13 participants (9 from industry and 4 from academia) from 4 different companies in the other workshop. People from both academia and industry have contributed in the workshops. Hence, the method for data generation can be described as participative and interactive. During the two workshops, the problem areas were to be discussed in relation to the ideas for a future business environment and FPD. This made it possible to generate rich data for the purpose of this paper. The generated data is based on interpretations, understandings and/or experiences [7]. Interpretation, analysis and reflection on data take place continuously during the data generation activities. Notes have been taken during the workshops and the formal meetings.

3. A workshop approach

The approach in the workshops is referred to as the Tiger Team approach [8]. The objective by using the approach is to jointly, academia and industry, solve a specific research problem in a rapid response environment, e.g., running industry pilots. The approach encourages diversity in competences of the team to be utilised to contribute to the activities. Creative methods are used to support the work and to enable the workshop participants to, e.g., build on fragment of other's ideas, gestures and drawings. The introduction of the Tiger Team approach is done to radically improve the workshop format to allow for creative and productive academia/industry collaboration, and to open up for research on methods and technologies to support collaboration. The Tiger Team approach in this setting will be further elaborated on in forthcoming papers.

In the initial workshops, the activities were dedicated to find and understand a problem area relevant to run in mutual pilot projects. Besides finding industrial problems which have research potential, any possible conflicting interest among industry participants has to be handled in real time. The workshops were run in parallel, one with a perspective on FPD and the other with a focus on SDD.

3.1 The identified problem areas

The identified problem for FPD emerged from the difficulties to understand how the extended responsibilities regarding the physical artefact would affect the design activities. In short, how to translate 'agreed upon functions' into a product that would meet those functions in a long-term perspective. It became interesting to find those components which builds up the total offer and are likely to have an impact on the development of physical artefacts sold as 'functions per unit'. The interest was specified to support decisions in early design phases. The problem area was captured within the question: *How can components from within an extended enterprise form a total offer that can be evaluated regarding the life-cycle commitment?*

During the workshops, the industry participants expressed an interest to speed up the processes and to provide added value for all stakeholders within the total offer by being able to deliver the contracted function. In FPD the product to develop has to be understood in a life-cycle perspective and the 'agreed upon functions' has to be translated into a product specification. These issues increase the intangibility in decisions in the design process. One industry participant expressed his view on the extended responsibilities in a total offer as *"this is complicating the development area"*. Another participant from industry pointed out that, in relation to total offers and the life-cycles perspective *"we have something to take into account which we can not really do today"*.

The use of computational activities in early phases was recognised by the members in the SDD workshop as important to support FPD, but also as causing extensive efforts to improve simulation software. Thus, the problem area was captured within the question: *Is it possible to use an object oriented Finite Element Analysis (FEA) code (already developed for certain applications) for simulation of manufacturing processes in a development project starting 2008, and can this code provide advantages that prove to support the need for computational support in early phases of functional product development?*

The object oriented FEA code to be investigated is a non-commercial finite element code with a potential for computational speeds in the order of magnitudes greater than most commercial FEA software of today. Other advantages are the possibility to tailor interfaces for the design analyst and the software development advantages of, for instance, interchangeability offered by an object oriented programming language environment.

When the industrial informants have described collaborative efforts they highlight the issue of being contacted and contracted in later stages of product development. They have expressed a wish to *"be present in early phases to be able to affect decisions made early in the process"*. They have also mentioned that *"decisions are made where the competence is"*. Issues regarding for instance manufacturability are addressed down-stream in the process. If knowledge regarding manufacturability is not made available in early design phases, decisions made at these stages can cause costly and time-consuming down-stream activities.

4. Multiple business models

Real life business models are complex. The models presented here are to a high extent simplified and should not be seen as representing the real world. They are intended to highlight differences in collaboration between companies. The models represent companies doing businesses with each other; in real life there are of course also 'ultimate customers' or 'end users' who benefit from the business-to-business scenario.

In Figure 1, a hierarchic business model is outlined. The supplier provides the customer with products that they are asking for. Inherent in this view is a transaction of physical artefacts, including services as add-ons. Discussions about what product to develop and sell, and on the other hand what to buy is occurring between marketing and purchase departments. Decisions regarding product development are made in the interface between the suppliers marketing department and the customers purchase department. Information needed for product development becomes separated from the designers and the information flow can be described as an over-the-fence approach. The user needs are interpreted and translated into product specifications by the marketing department and could not guide the process in a direct way. Needs are not used as a resource for new innovative products. The performance in the process influences CAE tools to be used for specific tasks and as separate from marketing and purchase activities.

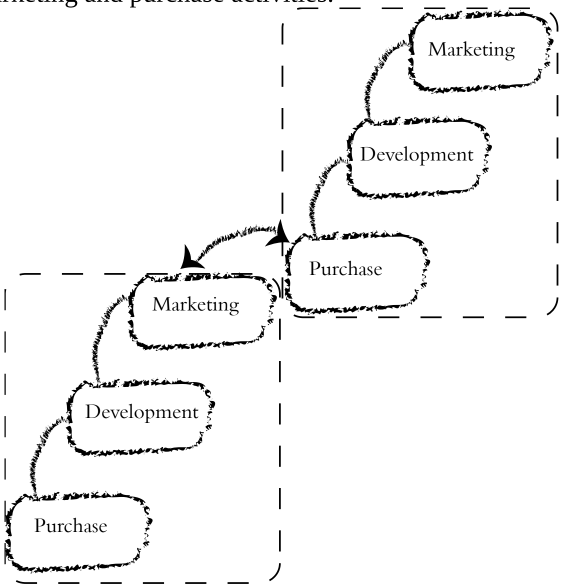

Figure 1: A hierarchic business model.

The importance to support hierarchical business models is related to the fact that customers climb a loyalty ladder [9]; they begin as stray customers and can end up being your best partner. A drawback with the model is that it can be seen as related to a ping-ponging product development process [3], where the stakeholders are engaged in time-consuming iterations to build up the incomplete information.

In Figure 2, the companies are partners, e.g., in terms of one company establishing connections to preferred suppliers on a contractual agreement. Within this business model, the partners have taken a step towards cooperation in product development by providing expertise in specific tasks, i.e., outsourced activities.

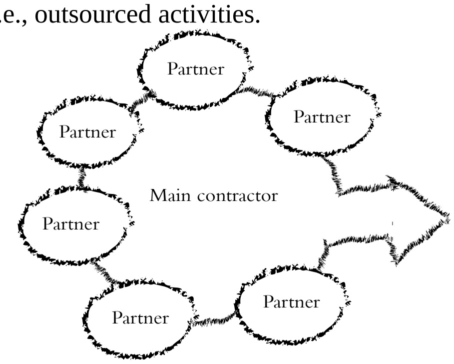

Figure 2: A business model based on partnership.

The partners' activities can be seen as input to the main contractor's product development, and applying for a high degree of interaction and coordination. The strategies and visions held by the main contractor are reflected towards the partners. The partners have to adjust to these strategies, e.g., use compatible computational support. Trust and commitment are characteristics which enable a partnership business model. Being a partner is seen as the final step in the loyalty ladder [9]; however in the discussions about a business model for functional products, further steps towards close collaboration in early phases, are considered. The business model for functional products is discussed as an inclusive model where all stakeholders become suppliers of 'agreed upon functions', as is presented in Figure 3. The companies collaborate in the product development having a mutual goal to meet the customer's need of functions.

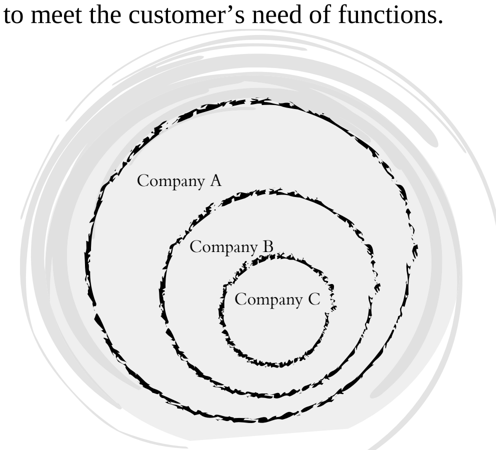

Figure 3: A business model for close collaboration in an extended enterprise.

A shared context for knowledge creation, sharing and integration could appear within the extended enterprise model. Within this interconnectivity, competences can be used to create added value to provide total offers. A virtual environment for achieving additional knowledge, as well as the combination and recombination of all resources within the extended enterprise could be enabled by computer support. In such case, the use of simulations could extend from verification and validation, to encompass an approach where simulations actually drive the design.

5. A changed view on the use of simulations

The advancement in the simulation software area has now reached a stage where, for example, FEA can be used by designers in regular design work. The potential of using FEA as a tool to build better products is underestimated [5]. Simulation software supports the design engineers' to achieve their goal, which is to develop a product. Hence, compared to an analysis specialist, the underlying principles for the analysis therefore gain less attention [10]. Adams and Askenazi [5] argue that there is a gap between the area of engineering design and traditional computational engineering. The advancements in simulation software make it possible to fill that gap with a new professional role, a design analyst; who is neither a designer nor an analysis specialist, but something in between [5].

The evolution of computational software for performance analysis (FEA, Computational Fluid Dynamics, Multibody Dynamics, etc.) has had great attention to the development of algorithms, mathematical formulations, and in general, functionality required to model different physical mechanisms. This evolution irrespectively of field of application (mechanical engineering, construction etc.), is still important, but there is also a need for a broader view on how simulations are used in a business perspective to support new product development, i.e., utilizing simulation to guide on what to develop rather than only focusing on if the developed product does not fail regarding performance.

Rule-based simulations, e.g., Knowledge Based Engineering (KBE) [4], have been used in industry to reduce time spent on design by automating routine tasks. KBE tools that have been developed within industry are used as internal company specific design support tools that almost never reach outside company walls. KBE tools are also closely coupled to the specific knowledge for solving engineering specific problems and, by tradition, bound to geometry modelling. By looking outside the computational side of design and bringing in engineering design methodologies and knowledge rich strategies, knowledge enabled engineering [6] can be reached. The aim is to capture both the formal design knowledge and the tacit, unspoken knowledge to aid the design process.

The ongoing evolution and advancement in simulation software, even though viewing simulations as support for internal cooperation and support for engineering problems, show the way for using simulations in new application areas focusing on collaborative engineering between companies, i.e., FPD.

6. Simulations in FPD

A process for integrated product development is iterative in nature and includes diverging as well as converging phases. The product to be developed is continuously progressing in a stepwise manner. Information from different internal and external stakeholders, e.g., marketing and sales staff, top management, customers and subcontractors, flows frequently back and forth in the activities. All in all, a vast array of knowledge and competences are needed to design competitive products. To be able to make sound and viable decisions in account for the design, these flows of information and knowledge has to be made available in early phases.

Simulations make it possible to utilize down stream information early on in the design process. By aiding information sharing and exchange it is possible to simulate a whole chain of processes, and thereby predict how a modification affects the characteristics of the product to be developed. A value of using simulations is found in the reduction of the knowledge gap, in turn this give potential to savings in the later stages of the product development cycle.

A process for FPD could be described as a more integrated product development process occurring in between companies, since it is thought of as being based on an extended enterprise business model. Besides increased competitiveness, incitement for companies to strive for FPD is to meet the higher demands from society on ecological, economical and social sustainability. These demands can be handled as separate issues in product development, however in FPD these aspects are thought of as having a holistic effect on the design of the product in early phases. In a business-to-business context, the sale of ‘functions per unit’ creates long term relationships and commitment to a mutual goal. The sale of functions also gain access to possibilities to upgrade and remanufacture the physical product, as well as provide for ‘embedded’ maintenance.

The domain of interest in engineering is most often represented by a physical structure and computational support is used to obtain approximate solutions of boundary value problems. This means that the nature of the problem has to be feasible to quantify, or at least be given an approximate value, to be captured into mathematical models. One underpinning thought in FPD is that the knowledge domains of business, engineering and production should contribute in early phases. This extended situation requires a more experience-based approach where pre-existing knowledge and know-how is needed to make the right decision at the right time. Tacit, unspoken knowledge needs to, if possible at all, be transformed into explicit knowledge. In spite of that, it may not be possible to express it in discrete values, rather within a span of possible outcomes. The input in form of approximate values could by rule-based simulations, which manages rules of thumbs, be transformed into a result showing the problem in a larger context. This makes it possible to make decisions guided by qualified guesses, instead of merely gut-feeling. By consider learning issues in the development of the user interface for simulation software, each interaction with such a tool gives insight into the design rationale for the product to be designed. The benefits for companies combining FPD and SDD, could be found within increased quality in the processes and decreased risk due to improved support for decisions in a life-cycle perspective.

Feedback from stakeholders is crucial to achieve FPD, an extended use of simulations, in this context, insist on compatibility with each others software. In addition to this, particular efforts is needed to adapt the graphical user interface, or rather interfaces, to suit differences in preferences between business people and engineers on how the result could be visualised. Essentially, simulations mean creating a meaningful computer interaction, where product developers are, through a complex translation phase - going from internal and external models to a virtual representation of the product being developed. This interaction must be work-oriented rather than tool-oriented [6], an issue of even greater importance when targeting a combination of FPD and SDD.

A work-oriented approach highlights the involvement of humans and the view on computational support to actually support humans to achieve their goals. Simulation activities are often performed exclusively by experienced simulation specialists downstream from the creative design phase. As a result, feedback into the design activities occurs too late to significantly affect the final product. The introduction of a design analysts [5] using simulation software could prevent this to occur. To provide simulation software for non-specialist people calls for extra attention on how the software is designed. Besides being easy to use and provide for substantial improvements in the design process, it should increase the confidence for those who is using it.

The possibility for simulations to provide foundation for decisions in FPD seems promising. Establishing long term relationships to provide 'functions per unit' and taking increased responsibilities for delivering the contracted functions continuously 'as-needed' by the customer, is a risky business. Bringing in simulations in early phases of design makes it possible to try out numerous of 'what-if' scenarios before prototyping, testing and production. Supported by the use of simulations, the ability to virtually combine and recombine cross-company resources, might increase the knowledge level so that new business opportunities and innovations could be an effect.

Separated analysis and design activities leads to simulation-verified design. An integration of computer support and analysis activities in the design process sustains SDD, while also calling for advancements in engineering methodologies and collaborative engineering, i.e., insights in FPD processes and design work. Essentially, but not trivial, we need to provide support for communication between engineering, business and production domains.

7. Conclusion and further work

In this paper, the relations between FPD and a SDD have been discussed. The discussion has been framed of an engineering design perspective to contribute to insights into the potential to use simulations in early phases of product development to nurture innovations. We have suggested that simulations could be used to drive, and not only verify, the design of a product. SDD and FPD are linked by a combined use of simulations, i.e., discrete event simulations, rule-based simulations and simulation of mechanical processes and properties. The changed view on the use of simulation and who is using it relates to FPD by aiding life-cycle decisions in early phases. Input from stakeholders, e.g., needs, plays a leading part in FPD, and simulations software could create a virtual structure to combine and recombine resources and thus, nurture innovations.

Underneath the FPI umbrella, Distributed Collaborative Engineering is a vital part. This part is not considered in this paper, but research within the area contributes to the vision for innovations by the view on extensive support of information- and communication technology to aid design teams in FPD. Inherent in the vision for FPI there is anticipation for spin-offs that in turn can render up in new companies. Research on entrepreneurship is recognised as interesting. In this paper, we have not considered business specific computational support. Yet, research within this area is of great interest.

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