TAMPERE UNIVERSITY OF TECHNOLOGY

PEKKA TYNKKYNEN

USE OF PRODUCT LIFECYCLE INFORMATION IN KNOWLEDGE BASED DESIGN PROCESS

Master of Science Thesis

Examiner: Professor Asko Riitahuhta

Examiner and topic have been approved at the Council meeting of Faculty of Automation, Mechanical and Materials Engineering on April 5th 2011

TIIVISTELMÄ

TAMPEREEN TEKNILLINEN YLIOPISTO
Konetekniikan koulutusohjelma
TYNKKYNEN, PEKKA: Tuotteen elinkaaren informaation hyödyntäminen tietopohjaisessa suunnittelussa
Diplomityö, 82 sivua,
Marraskuu 2011
Pääaine: Tuotantotekniikka, Tuotekehitys
Tarkastaja: Professori Asko Riitahuhta
Avainsanat: Tuotteen elinkaari, PLM, CAD, KBE, tietopohjainen tuotesuunnittelu, tuotetieto, informaatio

Tämän diplomityön yksi tavoitteista oli näyttää miten tietopohjaisen suunnittelu prosessin (KBE) käyttäminen tuotekehityksessä voi nopeuttaa huomattavasti siihen kuluvaa aikaa, ja tuoda samalla säästöjä suunnitteluprosessiin. Lisäksi tavoitteena oli löytää keinot miten KBE voidaan yhdistää tuotten elinkaaren hallintaan (PLM), ja siihen miten elinkaaren aikana kerätty tuotetieto saadaan hyödynnettyä. Tutkimus tehtiin tutustumalla ensin tavoitteista löytyvien konseptien ja teknologioiden teoriaan ja olemassa oleviin tutkimuksiin niiden alueella.

Työn alkuosassa todetaan tietopohjaisen suunnittelun edut kun se yhdistetään käytössä olevaan CAD ohjelmaan. Esim. mahdollisuus osittaiseen automatisaatioon suunnittelussa. Tässä yhteydessä esitellään MOKA metodi, jonka avulla olemassa oleva tieto voidaan muuttaa muodollisesti esitettyyn tietomalliin, josta edelleen CAD ohjelman tietopohjaisiin sovelluksiin. Tuotteen elinkaaren hallintaa käsitellessä osiossa selvisi, että elinkaaren aikana kertyy paljon tuotetietoa jota ei välttämättä hyödynnetä tarpeeksi suunnitteluprosessissa.

Ratkaisu KBE ja PLM järjestelmien yhdistämiseen löytyi eri kantilta käsitelleiden tutkimusten yhdistelmästä, johon on lisätty kirjoittajan omat ehdotukset prosessin parantamiseksi. Päätehtäviksi prosessissa muodostui: informaation hankinta tuotteen eri elinkaaren vaiheista, tiedon hallinta PLM järjestelmän kautta, ja informaation muuttaminen tietopohjaisiksi malleiksi. Metodit informaation hankintaan ja sen hallintaan riippuvat paljon teollisuuden alasta ja tuotteen tyypistä. Informaation muuttamiseksi tietomalleiksi tarvitaan tietotekninen alusta PLM järjestelmään, johon elinkaaresta kerätty informaatio tuodaan, ja muutetaan tietomalleiksi käyttämällä hyväksi erilaisia suunnittelutyökaluja (esim. laatutalo-matriiseja, tuoterakennetta ja vaatimuslistoja) ja lopuksi MOKA-metodia tietomallien luomiseen. Tällä prosessilla voidaan käytännössä kaikenlainen tuotteen käyttäjiltä ja muilta sidosryhmiltä tuleva informaatio muuttaa tietomalliksi. Mallin avulla tuotteeseen voidaan tehdä halutut muutokset joko manuaalisesti tai hyödyntäen osittain automatisoitua suunnittelua, minkä KBE mahdollistaa.

ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY
Master's Degree Programme in Mechanical Engineering
TYNKKYNEN, PEKKA: Use of product lifecycle information in knowledge based design process
Master of Science Thesis, 82 pages
November 2011
Major: Production Engineering, Product Development
Examiner: Professor Asko Riitahuhta
Keywords: Computer Aided Design, Knowledge Based Engineering, Knowledge based design process, Product lifecycle management, Product knowledge, Product information

One of the goals of this thesis was to show how the use of knowledge based engineering (KBE) in design process, can significantly reduce the time used for it, and simultaneously bring the design costs down. Another goal was to find out means, how KBE and Product Lifecycle Management (PLM) could be connected, and how all the product information gathered throughout the products life could be better utilized in product development. Research for the thesis was made by exploring theories and technologies behind the concepts included in the goals of the thesis.

In the first part of the thesis, several advantages were found when KBE technologies are connected to CAD, for example the possibility for partially automated design process. In this context, a MOKA methodology was introduced. With the methodology the knowledge can be structured into formal knowledge models, and further used in KBE enhanced CAD solutions. In the part focusing on PLM, it was found out that during the lifecycle lots of product information are been gathered, but not necessary taken enough advantage in the design process.

Solution to connect KBE and PLM was found by combining together results from various different researches around the topic, and by adding to this writers own suggestions to improve the process. Three main tasks were found for the process: acquiring the knowledge, product data management through PLM, and a system where product information will be converted to knowledge models. Methods for the first two tasks were found out to be highly dependent on the branch of the industry and the type of the product. Task of knowledge converting can be done through an IT-based knowledge system inside the PLM, to which information gathered during product lifecycle can be brought and changed then into to usable knowledge models with different design tools (for example: quality function deployment matrix, creation of product structure, specifications lists, etc.) and finally to a knowledge model through MOKA methodology. With this process basically all kinds of information from the users of the product, or other stakeholders can be changed to knowledge models and utilized. With the created model required changes can be made, either manually or using the partly automated design process enabled by the use of KBE.

FOREWORDS

I would like to thank Mr. Patrick Klein, Prof. Klaus Dieter Thoben and Mrs. Birgit Erdfelder form BIBA Bremen for giving me the possibility to write my master thesis in the faculty, and helping me with any problems I had during the process. Also thanks for Prof. Asko Riitahuhta for helping to establish connection with Prof. Thoben in the beginning.

Special thanks to Maryam, who was supporting me during the whole time, and giving me strength to finish the difficult writing process.

TABLE OF CONTENTS

TERMS AND ABBREVIATIONS

BOM	Bill of Materials is a list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, components, parts and the quantities of each needed to manufacture an end product.
CAD	Computer-aided design is a process where computer programs are been used in the design process of the product and for documentation of the designs.
DFMA	Design for Manufacturability and Assembly is a context where needs of manufacturability and assembly are been taken into consideration in the product development process.
DFX	Design for X is a wide collection of specific design guidelines are summarized. Each design guideline addresses a particular issue that is caused by, or affects the characteristics of a product.
DOE	Design of Experiments is systematic approach to investigate systems or processes.
DSM	Dependency Structure Method is a method where detailed list of dependencies between the parts and subassemblies are been gathered to a matrix.
ERP	Enterprise Resource Planning integrates internal and external management information across an entire organization, embracing finance/accounting, manufacturing, sales and service, customer relationship management, etc. ERP systems automate this activity with an integrated software application
FMEA	Failure Modes and Effects Analysis is a procedure in product development and operations management for analysis of potential failure modes within a system for classification by the severity and likelihood of the failures.

ICARE	Forms used in a MOKA informal model. Forms are Illustration, Constraints, Activities, Rules, and Entities.
KBE	Knowledge-based Engineering is an engineering process and a tool that captures and enables the possibility to reuse previous knowledge again in the design process.
KBS	Knowledge Based Systems. A system in which the previous knowledge can be used in the knowledge based design process.
MDO	Multi-disciplinary Design Optimization is a field of engineering that uses optimization methods to solve design problems incorporating a number of disciplines.
MOKA	Methodology and tools Oriented to Knowledge based engineering Applications.
PDM	Product Data Management is concept which includes product data creation and management.
PLM	Product Lifecycle Management is the process of managing the entire lifecycle of a product from its conception phase, through design and production to its usage and retirement.
UML	Universal Modeling Language is a standardized general-purpose modeling language in the field of object-oriented software engineering.
QFD	Quality function Deployment is a method to transform user demands into design quality, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process.

1 INTRODUCTION

Several efforts have been archived in recent years to make product development processes more effective, especially by reusing previous gained knowledge more and more in the design processes. However, these days' designers are still doing a lot of simple and repetitive tasks when making changes to the design of the product or setting up a new product line. Often these tasks do not require enhanced engineering skills or specific knowledge, and it hence should be possible to find a way to reduce the amount of such ineffective work by computer support. Being aided by Automated Design features the engineer doesn't need to waste his/hers time for repetitive or "stupid" work, and hence more time can be served for crucial product development tasks. To enable an effective automation of the design tasks the implicit knowledge in terms of product information, standardization documents etc, has to be made explicit. This process, where knowledge will be reused for product design, is also called Knowledge Based Engineering.(Stokes & MOKA Consortium. 2001)

One of the main goals for this thesis is to show, what kind of product information can be used for a transformation into KBE systems, and what kind of structure and format is needed in this context to ensure that it can be interpreted by respective KBE software (e.g. provided by modules of major CAD applications).

At the beginning of the thesis (chapter two) the concept of Knowledge Based Engineering is introduced as well as typical KBE systems. In this context the following questions are addressed: what can be defined as engineering knowledge and what benefits can be expected if it be included a lot more in design processes? Upon this the connection between Knowledge Based Engineering and CAD supported design processes will be introduced.

In the following as a typical example for contemporary knowledge based engineering applications the KBE-features of CATIA V5 are presented. The CAD application provides a bunch of KBE-modules, covered by the so called *Knowledgeware* workbench. This way typical feature will be introduced and in addition different ways how to use the *Knowlegeware* module for design automation. Also in chapter two, the appropriate structures for the knowledge will be discussed: how the knowledge should be structured? Upon these findings a methodology for transforming knowledge gained from available product related information to a formal representation of knowledge will be introduced. This methodology is based on a framework created in co-operation of different European Institutions (MOKA Consortium 2000). In this context the *Knowledgeware* module will serve as a concrete reference application to validate the "formality" of the formal representation.

The second main focus of the thesis is the Product Lifecycle Management (PLM). PLM offers the platform for bringing the available information to the knowledge based design process, where it can be than reused to improve current design of product lines.

Usually a huge amount of information is saved in PLM systems during the complete lifespan of a product. In the chapter three, the PLM concept will be introduced in detail. Since Product Data Management is one of the core functionalities of contemporary PLM systems at first the concept of Product Data Management will be introduced shortly.(Stark 2005) Further the following questions are addressed: What are the typical phases of a product lifecycle, what kind of information is actually covered these phases? And what branches of a company are included? Further an overview of established PLM software applications will be given. The structure of the PLM systems and the ways how the different kind of information can be saved within will be outlined afterwards. The structure of the saved information is a prerequisite in order to identify which kind of information which can be transferred into explicit knowledge.

In the chapter four begins the most central part for the subject of this thesis. The chapter concentrates on the idea to link the concept of Knowledge Based Engineering to Product Lifecycle Management. At first the typical lifecycle of a product will be analyzed. Therefore typical examples of different kind of information are collected which can be processed and saved to PLM systems during products life. Every phase of the lifecycle will be focused separately, and examples of possibly usable information will be identified.

Second part of the chapter four is concentrated on ways that the information is been brought from all over the lifecycle to be reused in the design process. A suggestion for creating a platform that enables the information flow between the systems is presented. Within this platform, the available information can be converted to usable design knowledge. The information flows between PLM, this knowledge platform and design phase will be discussed. Next, the tasks required for knowledge converting will be discussed. Different design tools and methodologies used inside the knowledge converting platform will be introduced. With them the available information can be converted to usable forms and features for design. Most of the information can be found useful in design process, but there is a matter of complexity. How complex will the information to knowledge converting process be, and are benefits that are gained from it worth the extra work. The complexity of information gives limitation to the use of automated design process. Also in the chapter four, a suggestion for workflow inside the knowledge converting platform will be made, and a suggestion of how and who should manage this kind of platform will be made.

In conclusion, the goal of this thesis is to introduce concepts that will reduce the need for a design engineer to do simple and repetitive design tasks by finding a way to make knowledge based engineering more involved in the design process. This thesis is more theory orientated, and it offers description of a basic framework and processes how KBE and PLM can be brought together, and can be adapted into needs of various branches of industries. The main goals of the thesis can be described as following:

- Show how reusing the previous knowledge can be helpful for the design process resulting reduced overall time of product development process and thus cost savings through faster time-to-market for the products.
- Introducing Knowledge Based Engineering and it's usability in product development.
- Introducing Product Lifecycle Management and how the information from all over the products life can have an effect on the product development process.
- Finding methods for creating connection between Knowledge Based Engineering and Product Lifecycle Management systems.

2 KNOWLEDGE BASED ENGINEERING

2.1 What is engineering knowledge?

During the life of a product, huge amount of product information is being gathered. This knowledge about the product can be represented in different forms and models. Some of these forms are seen in the figure 2-1. Generally knowledge can be defined as: (Simpson & Weiner 1989)

1) Expertise, and skills acquired by a person through experience or education; the theoretical or practical understanding of a subject.

2) Something that is known in a particular field or in total; facts and information.

3) Awareness or familiarity gained by experience of a fact or situation. For modern products this knowledge is often very detailed and is presented with certain structure.

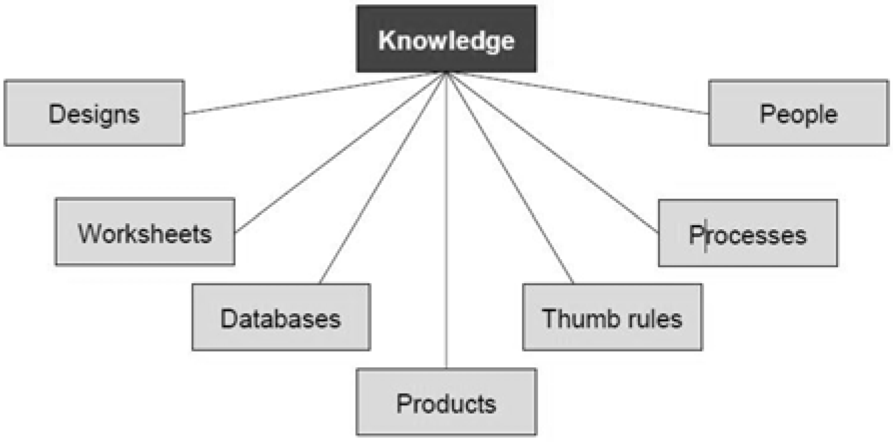


Figure 2-1 various forms of engineering knowledge. (Alcyon n.d.)

Design knowledge can be for example three dimensional CAD models, design drawings, sketches and every other form of the knowledge from previous designs. Knowledge can be stored by using worksheets and databases. Products have become more and more complex during the recent decades and the trend of increasing complexity is continuing to rise. As the complexity of a product increases, also the amount of data and information that is available of it will get higher.

Design problems are typically characterized by a huge amount of very different kinds of knowledge. This is not simply a matter of quantity, but more a matter of quality. Very different types of knowledge have to interact in design problem solving in a well defined manner. This diversity and complexity of knowledge and of its interactions provides also a challenge for human intelligence. Humans are dealing with this challenge in two ways: first, by using experience and heuristics, and second, by design and engineering methodologies. Also well defined procedures are used (like requirement engineering, quality gates, and design–to–X). Depending on the type of design problem to be solved (explorative conceptual design, routine and adaptive design, configuration etc.), these procedures can be quite different. (Klein 2000)

In order to successfully control this amount of knowledge different databases are in use. More of databases and the management of big amount of product data will be discussed in the chapter 3.2, where product data management will be introduced. As stated, knowledge means also expertise and skills acquired by a person through experience or education. A problem with the knowledge from people or engineering rules of thumbs is that they will be learned mostly only through years of experience. There will be disadvantages, if an experienced person with the needed knowledge isn't available for a specific task, or a previous version of design was made in another office of the company. In product development can the design process last severely longer time, than it would have with all the possible knowledge would have been available. There is a need for systems, where information of the design knowledge is saved, defined and accessible when needed.

Information about a product is been produced from the beginning of its life, when it is designed or manufactured to the knowledge of how the product has been used by the customer. At the end of products life there is information on how it is been disposed or recycled. This means huge amount of available information, which needs to be managed somehow in order to be used later to help when needed. Management of the product lifecycle will be presented in the chapter three, where is also discussed which kind of knowledge from the products lifecycle can be reused and how is actually done.

2.2 Introduction to Knowledge Based Engineering

Knowledge Based Engineering (from now on just KBE) can be described as a subset of Knowledge Based Systems (KBS). According to (Stokes & MOKA Consortium. 2001) KBS is a usage of suitable computer software for acquiring and reusing knowledge on a product and process in a possibly most integrated way. KBS and KBE systems are part of the technology field called Artificial Intelligence. Other members of this group are Expert Systems and Rule-based Systems. The intelligent behavior of a system is shown though symbolic inferences and use of heuristics. KBE has been markets already around 20 years, but has become more popular these days after being already adapted to use by PLM system vendors. (Fan & Bermell-Garciá 2008)

The term Knowledge Based System applies to any system, which performs a task, by applying rules of thumb to a symbolic representation of knowledge, instead of employing more algorithmic or statistical methods. A key characteristic of KBS is that they show a marked degree of separation between their knowledge and control portions. The major difference between KBE and KBS differs of the application area where Artificial Intelligence is put to use.

KBE can be defined as engineering on the basis of electronic knowledge models. Such knowledge models are the result of knowledge modeling that uses knowledge representation techniques to create the computer interpretable models. The knowledge models can be imported in and/or stored in specific engineering applications that enable engineers to specify requirements or create designs on the basis of the knowledge in such models. There are various methods available for the development of knowledge models; most of them are system dependent. (Wikipedia (a) 2010)

The engineering process is by definition an iterative process. The knowledge base must be kept in step with the pace of repetition of the engineering process. In addition engineering requires and produces output that poses manipulation challenges. Any KBS targeting the engineering area will have to support the data produced by the geometry aspect of the process, which is linked to the end product.

KBE systems lifecycle has six different phases. (Stokes & MOKA Consortium. 2001)

- Identify
- Justify
- Capture
- Formalize
- Package
- Activate.

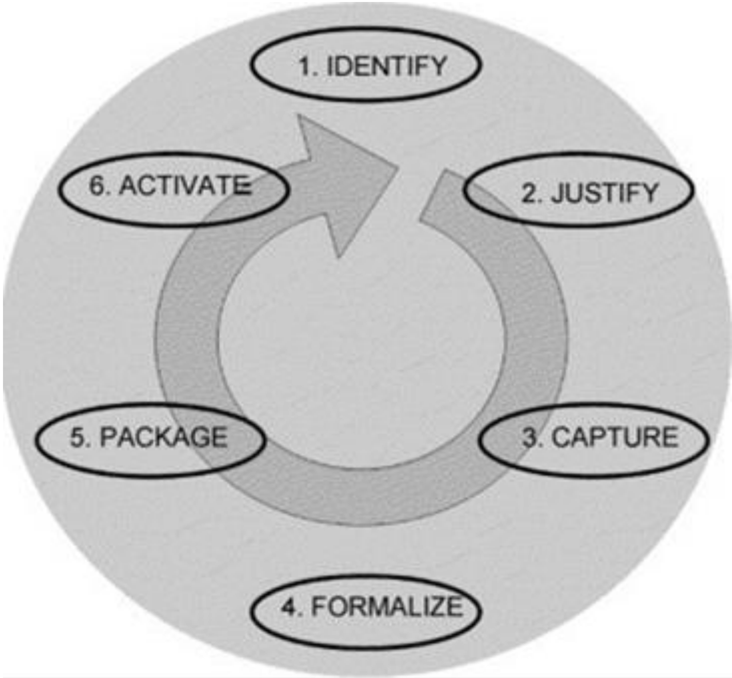


Figure 2-2 General KBE lifecycle. (Skarka 2007)

The first phase of the KBE systems lifecycle is **"Identify".** Before a new KBE system can be populated with knowledge or the knowledge in an existing system can be maintained, the knowledge required must be identified. According to (Klein 2000) this included identification of:

- Possible knowledge sources (product information)
- Appropriate tools and techniques for identification and analysis
- Representation methods.

Identify activity can form the basis for a project plan. After it is done, the resources can then be allocated and an estimate made of the time required. Next phase is in KBE lifecycle is **"Justify"**. It includes the gaining of management approval of the KBE process. Third phase **"Capture"** consists from the sub-steps Collect and Structure. Collect involves the elicitation of knowledge from the three categories of knowledge source - human, document and repository. Then the raw knowledge is structured of into a user-friendly representation. The result of the Structure phase is the Informal Model. This model (or sets of models) is then translated into a Formal Model in the **"Formalize"** stage. Typically, this is not a one way process, but iterates repeatedly between the collection/structuring tasks and formalization. Formalize analyses the informally structured knowledge from the Capture activity and represents it in a consistent, formal, neutral format (which is independent of any KBE application platform) to enable it to be assessed for correctness and suitability for reuse. **"Package"** phase retrieves the appropriate formalized knowledge in the knowledge repository and translates it, manually or automatically, into the form that suits the target KBE system before incorporating it into the system. In the last phase of KBE lifecycle **“Activate”** the KBE system will be activated and the knowledge used. (Klein 2000)

Due to the complexity of the engineering process in modern industrial companies and of the associated knowledge, the KBE life cycle tends to be quite complicated. A large quantity of diverse knowledge from different sources (people as well as documents) has to be taken into account. Parts of this knowledge are changing quite frequently whereas other parts remain static over long periods. (MOKA Consortium 2000)

The six phases result in formation of a KBE system and enable its supervision and controlling. According to (Skarka 2007) a detailed description of a KBE lifecycle constitutes methodology of its creation and development. Methodologies describe some of the phases and cover necessary steps or sub steps, and also goals and objectives. The information is been processed in order to find the inputs and outputs. Methods are needed that a strategy for analyzing and realization of the knowledge can be created. Methodologies offer frameworks and generic knowledge to help guide knowledge acquisition. With the help of the methodologies tasks, knowledge of experts is available and represented in way that it can be comprehended by others. There are different methodologies available for every phase of the lifecycle. The choice of the methodology is of course depending on the tasks that the KBE system is used for.

The whole concept of KBE is really broad, but basically it is a tool that captures and enables the possibility to reuse previous knowledge again. With a functional KBE system many advantages can be gained in the design process with the help of CAD programs. These advantages and also limitations of KBE will be introduced in the chapter 2.3. By integrating KBE to a CAD the available knowledge helps a design engineer to reuse the knowledge to speed up the product development process.

2.3 Integration of KBE and CAD

CAD/CAE systems have been used mostly for classical design tasks such as definition of geometrical shape. New development focus for these programs has been to include a knowledge application to CAD that would improve the design process by allowing the better use of the knowledge available. In CAD design knowledge can be used for example parameterization, creating design rules, geometric features and functions. (Dassault Systemes - c 2010)

Nowadays there are already several CAD programs that have an integrated knowledge module or a separated program that enables easy use and control of the design knowledge. In this thesis, CAD program CATIA V5 will be used for example purposes. It has its own knowledge module called *Knowledgeware*. This module will be introduced in the chapter 2.4. Other CAD programs with integrated knowledge module or support for KBE programs are:

- Adaptive Modeling Language (Technosoft 2011)
- DriveWorks A SolidWorks Certified Gold Partner (Solidworks 2011)
- GDL (Genworks 2011)
- Kadviser (Nimtoth 2011)
- KBEWorks (VISIONKBE 2011)
- Knowledge Fusion (Siemens 2011)
- Knowledgeware from Dassault Systemes
- Pro/ENGINEER Expert Framework (PTC 2011)
- SmartAssembly for Pro/ENGINEER (SIXMAXIM 2011)
- TactonWorks Interactive design automation inside SolidWorks (Solidworks 2011)
- YVE - Your Variant Engineer (Tecneos 2011)
- KBMax Configurator. (Citius 2011).

The importance to have system that uses knowledge in the design and modeling process has made different CAD program companies to invest into the development of KBE modules. The main advantages that are achieved with the integration of the KBE and CAD are for example: (Stokes & MOKA Consortium. 2001) (Skarka 2007)

- Reusing the knowledge
- Reducing need for routine tasks
- Time savings
- Cost reducing
- Shorter product development cycle
- Increased automation.

The main reason for integration of KBE and CAD is the possibility to reduce the need to work on routine tasks. According to (Stokes & MOKA Consortium. 2001) percentage of routine tasks in design process is about 80% (fig 2.3). When a design engineer doesn’t need to use all the available time to routine tasks, he has more time for creative design. This results for more innovations and better possibilities to improve the product. With a minimized time used for routines the total time used for the design will be shorter, which results in time saving and with a reduced time-to-market also cost savings.

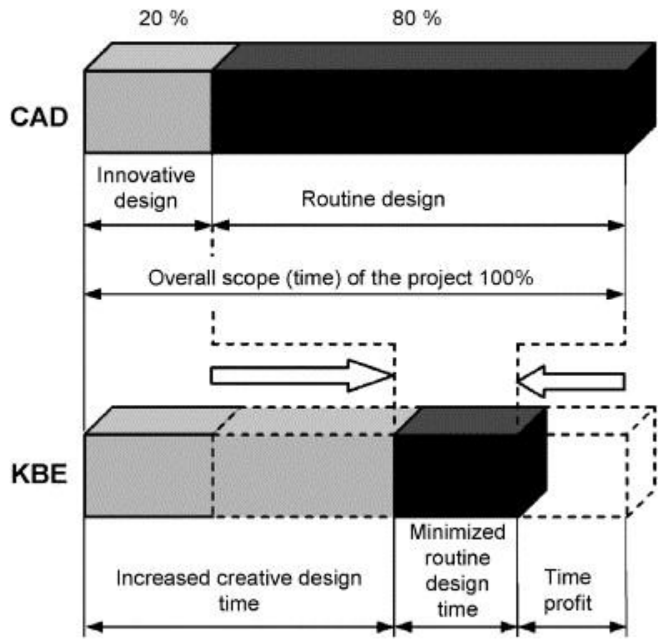


Figure 2-3 Time saved by using KBE in CAD (Skarka 2007)

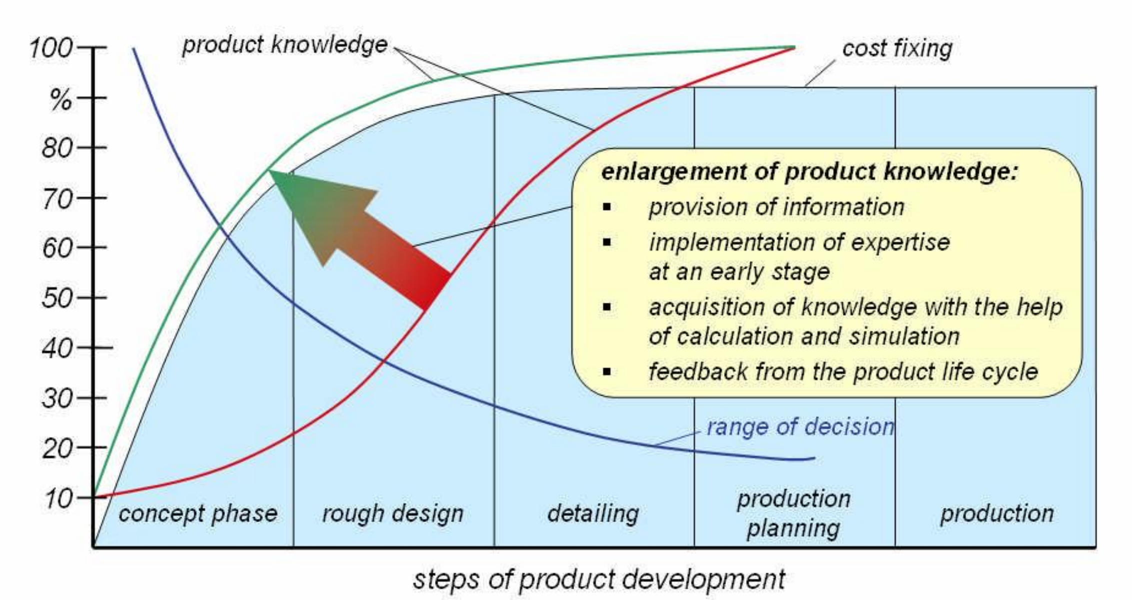


Figure 2-4 Provision of product knowledge in the development process (according to BOEING COMPANY) (Danjou et al. 2008)

Figure 2-4 shows connection between use of the product knowledge in product development, range of decisions and costs and time of the product development process. The blue line shows that in the beginning of development process the number of decisions is highest. Also the costs are rising quickly in the beginning. The red line shows the percent of knowledge used in the normal product development process and the green line shows the product knowledge usage when KBE techniques are been used. With the KBE system knowledge is more available already in the beginning of the development process. The more knowledge there is available in the beginning when most of the design decisions are made, more quickly will the beginning steps of the development process be done. This results in to savings in time-to-market and cost.

When all the possible information is available for early design decisions, there will be less need to make costly changes to the design later. If a design change takes place later in the design process, it will also produce more costs.

In cases where the product is highly modular and the different modular configurations are geometrically close to each other the KBE techniques can bring great advantages (Danjou et al. 2008). With the modular products also the interfaces between modules need to be reconsidered. If one part of the assembly uses KBE techniques, for the other parts should there also be KBE solutions that the modularity of the product won't be affected.

2.3.1 Limitations of KBE

Knowledge based engineering (KBE) is today an established technology. Commercially available tools or special purpose systems are used in routine design support as well as in other engineering areas. Typically KBE applications currently operate as isolated systems, and to build an application requires, in many cases, a significant effort from KBE and domain experts. It is often quite complicated to maintain or to reuse the knowledge contained in such KBE application systems. There are mainly two reasons for these shortcomings. (MOKA Consortium 2000)

- Limitations of KBE techniques
- Issues with knowledge modeling.

Engineering knowledge tends to be complex and diverse. Many different aspects of knowledge, from basic physical, geometrical and technical laws to highly sophisticated expert heuristics, have to be taken into account. Similarly complex is the engineering problem solving. It can be considered as an iterative interplay between analysis and synthesis steps. Requirements analysis, principle decisions in conceptual design, conflict resolution, optimization considerations, etc. are interacting in this process. Engineering problem solving typically involves large groups of people from different engineering areas. The complexity of the knowledge as well as of the engineering process results in a large diversity of special purpose engineering tools: CAD, numerical simulation tools, computer algebra systems, engineering product data management systems, etc. Each of them follows its own problem solving approach, own information structures and requirements and its own underlying assumptions. The kinds of knowledge used in these systems and the ways it is processed are very different. In the extreme, this is frequently beyond the capability of current KBE technology. (MOKA Consortium 2000)

Knowledge modeling has some issues to be considered. The complexity and diversity of engineering knowledge results in high demands for knowledge modeling in engineering: the many different aspects and their relationships have to be described in a complete, consistent, coherent, and concise way. Even if we assume that the corresponding advanced knowledge processing capabilities exist, adequate modeling of engineering knowledge provides a challenge. Neither general information modeling approaches, nor general purpose knowledge modeling techniques, have proved to be fully adequate. They do not provide sufficient expressiveness and platforms for knowledge modeling. (MOKA Consortium 2000)

For solving the described KBE issues a MOKA project was created around the year 2000. It offered solutions for the urgent industrial needs for advanced knowledge based engineering capabilities, and the need for a systematic and powerful approach to knowledge modeling in engineering. According to (Stokes & MOKA Consortium. 2001) the use of KBE techniques will never substitute totally human actions. In some cases the use of KBE isn't useful. For example when:

- Particular phases of design process aren't possible to be defined.
- Production technologies are constantly changing.
- For some reason required previous knowledge is not available.
- Problem is simple enough to be solved without KBE.

Before using KBE techniques, the company should know its own processes and product details good. This way the KBE wouldn't be used in cases where gained advantages won't be small in comparison to the efforts used for adaption and use of KBE techniques.

2.4 CATIA KnowledgeWare Module

In this chapter the CATIA's knowledge based module *Knowledgeware* will be shortly introduced. CATIA is combined from various different modules. For example the modules are: mechanical design module, surface module, assembly module and many others. One of these main modules is called *Knowledgeware* and it consist four different sub modules. These sub modules make it possible to automate some of the design tasks. Sub modules are:

- Knowledge advisor
- Knowledge expert
- Product knowledge template
- Business process knowledge template.

In CATIA, part features are been represented in a certain way and can be modified by using existing tools. These tools make the changing and defining the design and part features possible.(Dassault Systemes - c 2010)

CATIA design tools are:

- Parameters

- External parameters
- Published parameters
- Formulas
- Design tables
- Rules and checks
- Power copies
- User features
- Document templates
- Reactions
- Equations
- Scripts.

The part can be parameterized. External parameters offer reference of separate connecting parts and published parameters define relations between parameters in assembly level. Formulas, rules, checks are been used to reference the design features in a desired way. Power copy, user features, document template enable reuse of entities of product. Reactions modify the part behavior.

In the figure 2-5 can be seen the complexity of the knowledge modules, and how much cost saving potential they could have when used effectively. According to (Rennet 2002) Knowledge advisor and Knowledge Expert can provide advantages with moderate increase in the complexity. Best potential for the cost savings will be offered with the use of Product Knowledge Templates. However, the advantages come with a price of increased complexity.

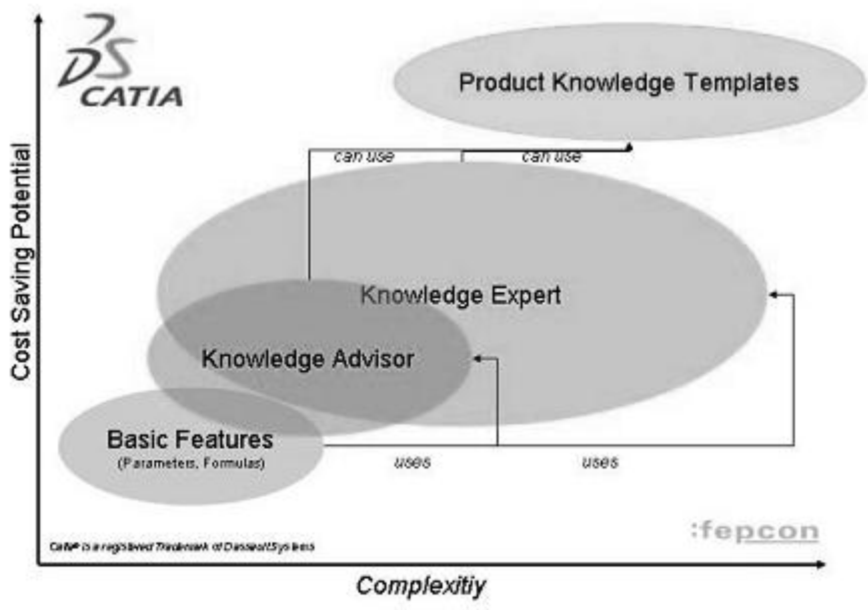


Figure 2-5 Complexity versus Cost Saving Potential with Knowledgeware Modules. (Fan & Bermell-Garciá 2008)

Knowledge advisor

In Knowledge advisor, users can embed knowledge in design such as formulas, rules and checks and leverage it when required at any time. Knowledge is then taken into account and acts according to its definition. It's easily accessible; for example check intent can highlight the parameters involved in verification. This enables the user to understand in what way a standard has been violated.

In short, Knowledge Advisor enables users to (Dassault Systemes - a 2007):

- Capture corporate engineering knowledge as embedded specifications allowing complete consistency.
- Easily define and share know-how among all users.
- Automate product definition.
- Ensure compliance with corporate standard.
- Increase productivity.
- Increase Knowledge management for sharing and understanding intents.
- Build Knowledge components management for customization and reuse.
- Allow early attention to final design specifications preventing costly redesigns.
- Guide and assist users through their design tasks.

Knowledge Expert module uses as a base the basic features of CATIA. It can also use the features of Knowledge Advisor. Knowledge Expert allows a designer to build-up and share corporate knowledge in rule bases and ensures that design is created according the established standards in the company.

Knowledge Expert's key features are that it: (Dassault Systemes - b 2010)

- Captures and standardizes the corporate engineering knowledge.
- Capitalizes and organizes the corporate knowledge.
- Shares corporate standards throughout the enterprise.
- Allows easy management of corporate knowledge.
- Is integrated with other CATIA V5 applications.

Knowledge Expert

Knowledge Expert allows definition of as many generic rules and check specifications as needed for all classes of CATIA V5 objects. These expert rules are not only usable in one unique design. They can rather be used to automatically monitor the actions of any designer throughout the company. The rules work for example when geometry is changed, by checking the compliance with the corporate standards. If a diameter of hole is changed, it can be checked that the new diameter doesn't go over the company's manufacturing limitations and capacities. When a rule or check is violated, corrective actions can be recommended or automated using scripts, macros, texts or links to URL files. For example, a designer adds a hole to a part, and the knowledge expert rules identify that according to engineering skill, the hole is too close to the edge. A pop-up menu can suggest either that the hole be moved or that reinforcing material be added. By simply selecting the desired solution the designer can allow the system to instantly solve the problem.

By sharing the corporate standards throughout the enterprise a better quality can be achieved. Once know-how is captured and stored, CATIA - Knowledge Expert allows the standard to be spread across the enterprise. Designers have access to data, and are more consistent with their designs. Therefore, the risk of errors is reduced, improving productivity as the user converges toward an optimized design while focusing on the best approach for the company as they work.

Expert rules and checks are stored in CATIA documents. Users can define and manage rule sets to structure the corporate knowledge base. Rules are then classified in rule sets that are part of a rule base. This structure allows different sets of rules and checks to be set up for different design or manufacturing processes, according to the user's needs. Creating rules in Knowledge Expert is been done for example by using the Knowledge Expert Language (KWE). The tools that KWE offers for rule creation are (CadFamily 2010):

- Declaring variables.
    - In the For All field.
    - In the check body.
- Using types.
- Using types attributes.
- Using Functions.
- Using statements.
    - If Construct.
    - If...Else Construct.
    - If...Then...Else Construct.
    - While Construct.
    - For Construct.
- Using Operators.

In conclusion, the key benefits of CATIAs Knowledgeware module are: (Dassault Systemes - c 2010)

1. Increased ability to innovate by automating repetitive and tedious design tasks.
2. Reduced time for bidding and increases responsiveness to inevitable customer engineering changes during design and manufacturing.
3. Faster production ensures high quality development.
4. Reduced product complexity and lower overall product development costs.
5. Quickly investigates and finds options of the most robust designs for product lifecycle quality.

6. Lowers costs by using extensive virtual prototype testing.
7. Eliminates inaccurate designs by automating compliance with defined standards.
8. Eliminates costly and time consuming corrections downstream.
9. By helping to adhere to company standards, data exchange is easier and inter-process collaboration is facilitated.

2.5 Bringing knowledge to CATIA Knowledgeware

Bringing the available information to the KBE system and a knowledge based CAD module (in this case CATIA *Knowledgeware*) requires certain tasks. In this chapter a methodology for capturing and formalizing of the knowledge will be introduced. Earlier the KBE system's lifecycle was introduced. KBE system has six different phases in its lifecycle. This chapter shows examples what kinds of actions in certain phase is taking place.

Phases of KBE lifecycle:

- Identify
- Justify
- Capture
- Formalize
- Package
- Activate.

For capturing the knowledge for CATIA (Skarka 2007) recommends methodology based on MOKA that was first introduced by (Stokes & MOKA Consortium. 2001). MOKA is tools oriented knowledge based engineering application. I was created to fill an increasing need for industrial companies to reduce lead times and costs for industrial products. Advanced information technologies will result in an ongoing increase of computer support in engineering and the whole industrial business process. Due to the complexity of engineering tasks, the integration of knowledge plays a prominent role in this process:

- In order to integrate knowledge from various process steps.
- Enable concurrent engineering.
- Support engineers in routine design and decision making.

The main advantages of MOKA methodology are: (Stokes & MOKA Consortium. 2001)

- Specialization of methodology in designing tasks different from general usage of KBS systems.
- The range of usage including commonly used computer aided engineering systems.

- Clear distinction between formal and informal model separating knowledge acquisition process from knowledge integration in KBE application.

(Skarka 2007) introduces a generative model concept that adapts the cooperation between available knowledge and lifecycle of KBE system. Model is focusing on the three main phases of the lifecycle and KBE system information: capture, formalize and package. (Figure 2-6)

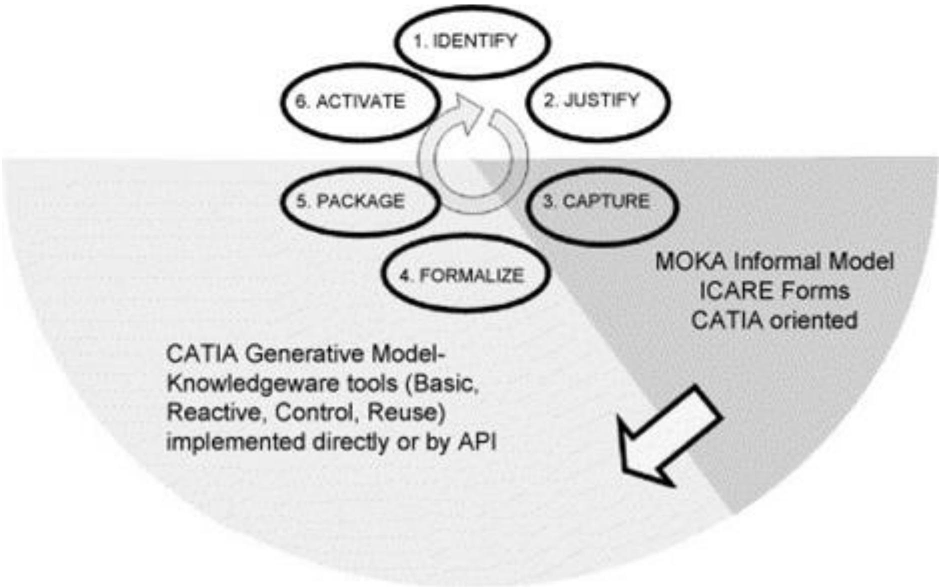


Figure 2-6 CATIA generative model for KBE lifecycle (Skarka 2007)

In capture phase CATIA acquires knowledge by using different models and forms. Forms are based on meta-models of the informal model that is being created from MOKA. Also the knowledge of modeling inside the CATIA is been captured and included. In formalize and package phase a generative model is been created from the knowledge and is been described in a formal manner. To create the generative model four different CATIA tools are been used:

- Basic:
  - Parameters, formulas, laws and knowledge inspector.
- Reactive:
  - Rules, checks and reactions. These can apply against known geometry or cause geometry modification.
- Control:
  - List and loop handlers.
- Reuse:
  - Power copy, user feature and catalog.

Tools from basic, reactive and control groups are been used to create a formal model of the knowledge and the tools from the reuse group are used later in the package phase. The whole MOKA methodology is not completely suitable for creating the generative model for CATIA. MOKA model consists of two main parts:

- Informal model
- Formal model

2.5.1 Creation of Informal and Formal knowledge models

Informal model is focused on identification of the knowledge, and acquisition or management tasks. In this part of the model the knowledge can't be described automatically by a computer process and should be rather processed by a human. The first part is completed with the definition of basis of knowledge resources.

Informal model offers a reasonable step on the long path from human understandable knowledge to its formal representation in a formal model. The informal model supports the somewhat complex knowledge collection and structuring process. It provides a usable communication framework between knowledge engineers and domain experts. All elements of an informal model can be linked back to the original raw knowledge - corresponding paragraphs in text documents of any kind: textbooks, interview protocols, etc. An informal model is a set of together related ICARE forms: Illustration, Constraints, Activities, Rules, and Entities. Informal model allows the user to structure knowledge in a way that is especially adapted to engineering knowledge.

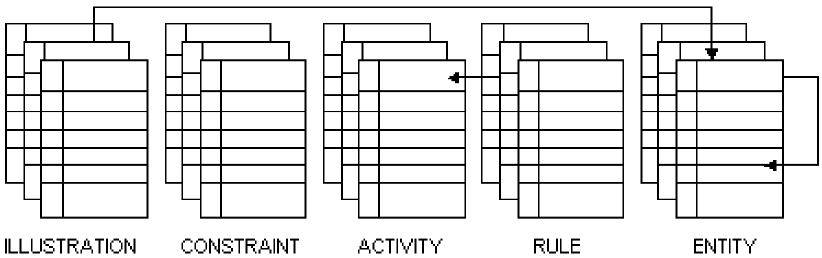


Figure 2-7 ICARE forms used in the MOKA informal model creation (MOKA Consortium 2000)

Different ICARE forms in the informal model can be used for following tasks:

- Illustration forms can be used to represent all kinds of more general knowledge, overview descriptions, or comments.
- Constraints are used to model interdependencies between entities.
- Activity forms are suitable to describe the various problem-solving steps in the design process.
- Rule forms allow the modeling of control knowledge.
- Entities are used to describe the product object classes (not only the physical ones but also functions, behaviors', etc.).

The forms in an Informal MOKA Model can be related to each other in different, well defined ways, thus providing a rich representational network for structured knowledge. (MOKA Consortium 2000) The complete metamodel given in MOKA informal model, although it does not seem too complex, allows to build knowledge base with very complex relations that management of these relations without using additional tools becomes impossible for a designer. The example of the degree of complexity of relations between structure entities is shown in figure 2-9. (Skarka 2007)

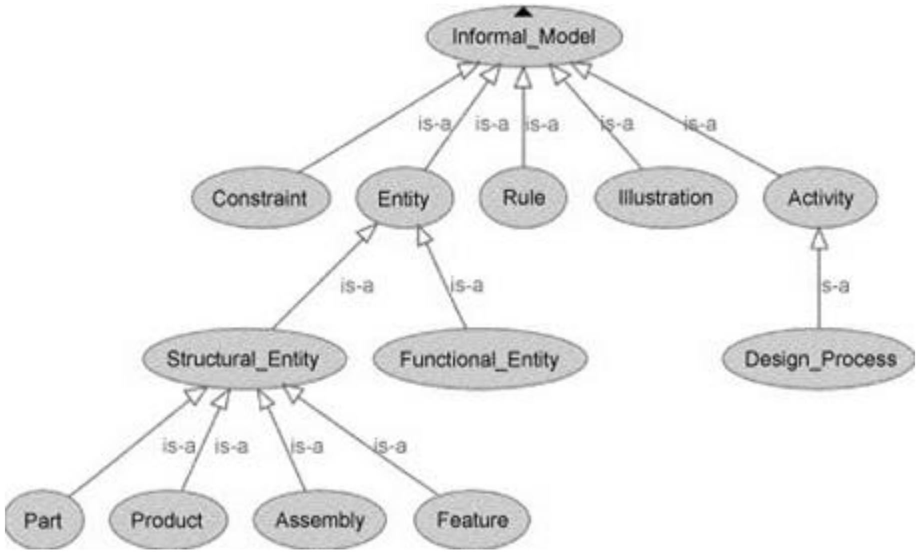


Figure 2-8 MOKA informal model structure (Skarka 2007)

After the informal model has been created, the second part, a formal model, can be started. For creation of the formal model is possible to use the help of computers. Formal knowledge representation is an established area today. The missing link seems to be the practical means for representation under current industrial conditions. For the field of engineering knowledge, the high demands identified in MOKA had to be translated into adequate formal knowledge representations. For this reason, an approach in MOKA was founded that was a trade-off between practicality and formality. The main aspects of formal knowledge modeling in MOKA can be summarized as follows: (Stokes & MOKA Consortium. 2001)

- A Product Model is used to describe the object level knowledge in the domain: the structures, functions, behaviors, geometry, etc. - including the various attributes, relations, and constraints. Closely related to the Product Model is the Design Process Model - a description of problem solving activities, control knowledge, and the links to the Product Model.
- In order to structure the Product Model, different meta-classes and views can be defined. In MOKA, a set of standard meta-classes was developed in pre-defined views that can be used as a starting point for engineering knowledge modeling. It provides meta-views, such as Structure, Function, and Behavior, as well as the relations between them).

- UML (Universal Modeling Language) is used as representational basis for the Formal MOKA Model. This gives a flexible representation that is familiar to many software experts and can be used for communication with domain experts.

The informal model allows the user to structure knowledge in a way that supports the transformation into the formal model. Entities are translated into UML classes, Constraints into UML associations, Activities in the informal model appear as UML activities related by various sequencing links, and Rules result in control information in the Design Process Model. The links that can be established between elements in the formal and the informal model allow the user to follow the various decisions in the modeling process and the relations between both models. This transition phase facilitates MOKA knowledge maintenance due to the knowledge traceability functions (links to the raw knowledge held within the different forms; those between informal Model and formal model, held within formal model displayed as a table of links.

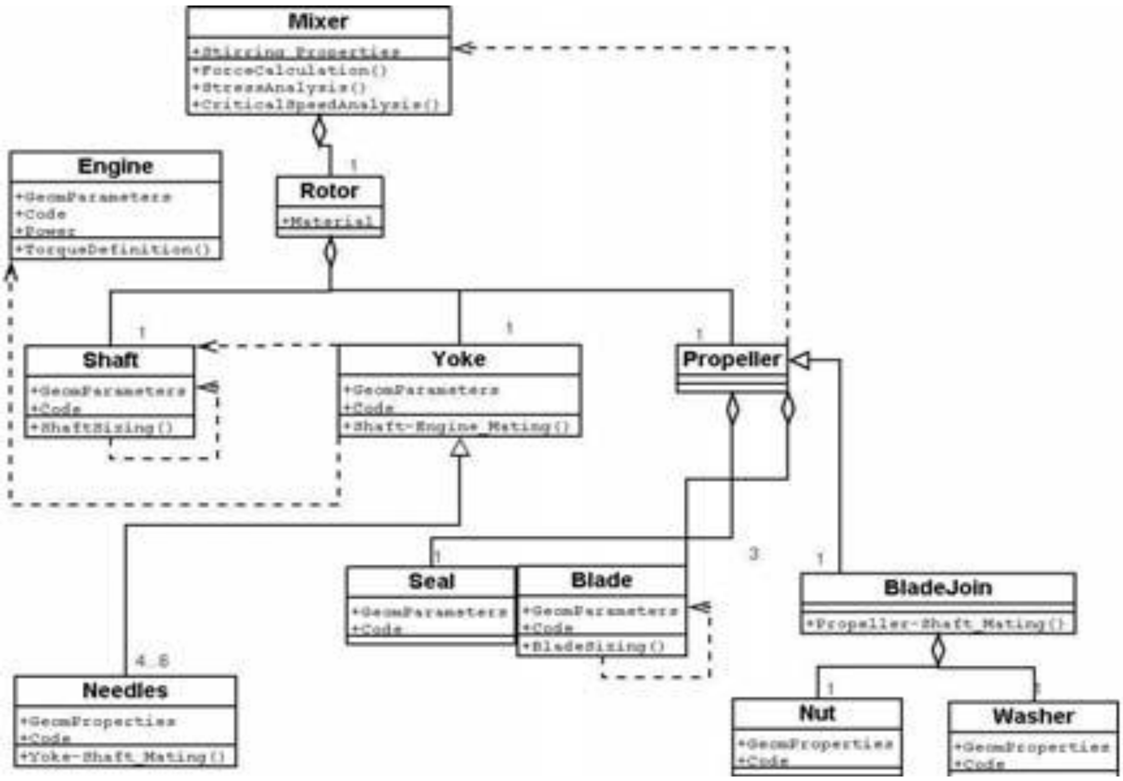


Figure 2-9 Structure of a mixer modeled with UML

Knowledge modeling in engineering is such a complex undertaking that only for quite small cases this can be done manually. Already medium-sized applications are too complex to model without support from a knowledge modeling tool. The MOKA tool was specified and implemented according to the conceptual model of engineering knowledge developed in MOKA. It supports the creation of an Informal Model as a set of interrelated forms, and the transformation of this model into a Formal Model by the generation of UML diagrams according to the rules defining formal knowledge modeling in MOKA.

2.5.2 Creating a generative knowledge model

After creation of formal model, the knowledge can be captured to a KBE application. MOKA informal model is not directly meant for any CAD tool (including CATIA) and that the connection can be established, must first a generative model be created. According to (Skarka 2007) for CATIA generative model can be created either by:

- Direct use of CATIA *Knowledgeware* tools or
- Creating a programming interface that uses functions of *Knowledgeware.*

According to (Skarka 2007) there are three different critical tasks that are challenging for the generative model creation and don't yet be fully supported by any programs and need manual aid. These tasks are:

- Knowledge acquisition and record for generative model creation in CATIA system.
- Transfer of obtained knowledge to the form of generative model representation.
- Justification and explanation of generative model operation.

The framework for the idea of generative model creation for CATIA is seen on the figure 2-10.

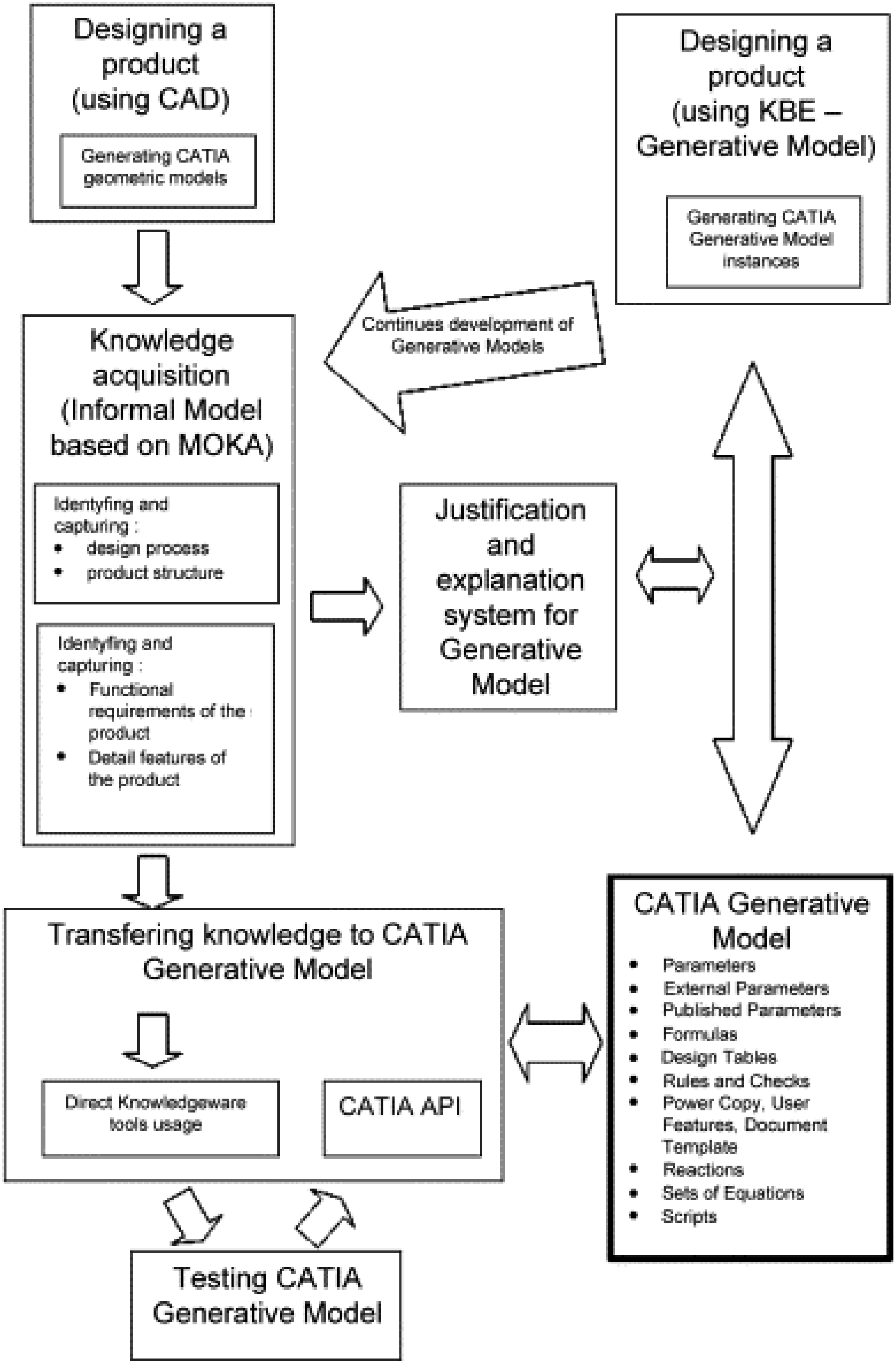


Figure 2-10 The framework of methodology for generative model creation in CATIA system (Skarka 2007)

Creation of the generative model can be described with the following tasks (Skarka 2007). First the general structure of product will be captured by means of entity forms. For each entity its features are determined, which can be time consuming due to a big number of these features. All features determined for a particular structure entity can be assumed as features. For each element in modeling process particular geometrical and material features are determined. They should be transferred to entities form. In entity forms, apart from describing all features, parts and assemblies, relations of belonging in a hierarchical form are recorded that is consecutive assemblies have consecutive parts and further features assigned. Entities will get their children, parents and forms a coherent structure equivalent to product structure.

Next stage identifies relations between features in form of constraints. They can be very different but most commonly they are in a form of formulas and are not too complicated. For example: upper limits for certain geometrical values. Defining designing steps constitutes the next stage. Activity forms are used for that purpose since they have the advantageous ability to define some atomic designing steps irrelevantly to other steps. These steps are joined together in nets and are showing previous, following steps and related steps. By means of such relations, it is possible to model and order even very complex designing processes. In the consecutive steps previously defined features are determined. It should be assumed that going through the whole net of designing activities is equal to determination of all designing features.

In the same way as constraints form certain relations for features, the rules are determined in the consecutive forms, which control designing activities. The last of the forms illustration is of optional character and it allows placement of information facilitating understanding of the previous forms or direct sources of knowledge included in them. They may include, for example extracts of books, drawings, etc. knowledge identified and structured in described way offers model parameterization (entities and constraints), sets the algorithm for generation of designing features and rules controlling the process (activities and rules).

After product structure is been modeled to an informal model structure, can knowledge be transferred to CATIA. The process of creating the generative model doesn’t affect the general structure of the knowledge, but complements the structure with additional attributes. Also the use of an informal model enables better cooperation between design engineers and the ones responsible for the knowledge base (bringing in the forms, etc). Additional advantage would be a form of representation, which is determined as early as the knowledge acquisition stage in CATIA model system for constraints and rules

2.6 Summary

When considering the possibilities to connect KBE and PLM, one has to understand theory and methods used in both of these concepts, in order to find the linking connection. In chapter two the basics of KBE were introduced. With the help of the chapter, one can firstly define what kind of knowledge is used in the design process of the company and secondly identify how diverse or complex this knowledge is. This is one of the six phases of KBE lifecycle. These phases were explained deeply within the chapter two. When knowledge has gone through the phases (Identify, Justify, Capture, Formalize, Package and Activate) it is represented in a form that can be brought to design process through PLM. KBE has been used already since the 1980's, but nowadays as a result of its possible integration with PLM and CAD, have the possible advantages of KBE greater. In summary these advantages are:

- Reusing the knowledge
- Reducing need for routine tasks
- Time savings
- Cost reducing
- Shorter product development cycle
- Increased automation.

These advantages can be achieved when the knowledge is transformed to a certain structure that the CAD can use. For this process a methodology MOKA has been developed by different branches of industries. MOKA is used in the Capture phase of the KBE lifecycle to produce informal and generative knowledge models. In summary, in order to create generative model and bring required knowledge to a knowledge based CAD program (for example CATIA Knowledgeware) following tasks need to be done:

1. Choose the base methodology (MOKA).
2. Make precise inventory of knowledge representation forms in CAD system.
3. Create informal model with the help of ICARE forms and UML language for the purposes of cooperation with CAD system.
4. Choose a form of representation of MOKA informal model.
5. Create generative model.
6. Manage both informal and generative model so that it enables its constant development and improvement.

By following the more detailed steps introduced in chapter two, can available knowledge be represented with informal and generative models, and be the PLM system. Next step in the connection between KBE and PLM is to find out what kind of product knowledge is available, and how can it be connected to the MOKA based process introduced in this chapter.

.

3 PRODUCT LIFECYCLE MANAGEMENT

3.1 Introduction to PLM-systems

Product Lifecycle Management (from now on PLM) is a process where products entire life, its lifecycle, is been managed with a certain system. Product can mean actual physical product, but also services and other non-intangible products that are not services (For example: software). Products lifecycle can be described differently in specific areas. One general view of the lifecycle starts with a product idea and conception phase, then follows design and production phase. After that comes service/after sales and finally the lifecycle ends with the disposal of the product. Different views of the product lifecycle will be also introduced later in this chapter. Definition of PLM also varies depending on from which area of expertise it is been viewed. PLM is still a fairly new concept. The term has been used only since late 1990s and beginning of 21th century. But actually PLM has emerged together from different concepts that have been around for some time, for example: Product Data Management (PDM), CAD and Engineering Data Management (EDM). (Eigner & Stelzer 2009)

PLM is an information-driven approach to different aspects of a product's life. As already mentioned, a huge amount of information is being stored of product during its lifespan. Within this information are large amount of available knowledge that can be reused in different phases of the lifecycle. Also the amount of different areas of a company that connected to a products life, make PLM a very complex and broad system to define.

In figure 3-1 is been represented a general overview of the different concepts product lifecycle management actually does have in it. Of course these concepts vary in different branches of industry or products, but the main construction parts of a PLM can be divided into at least six different classes, which subparts combined and integrated together will be the base of a PLM- system. PLM is spanning over different aspects of a company. These aspects are for example:

1. People
2. Processes
3. Tools
4. Methods
5. Technology
6. Data
7. Platforms.

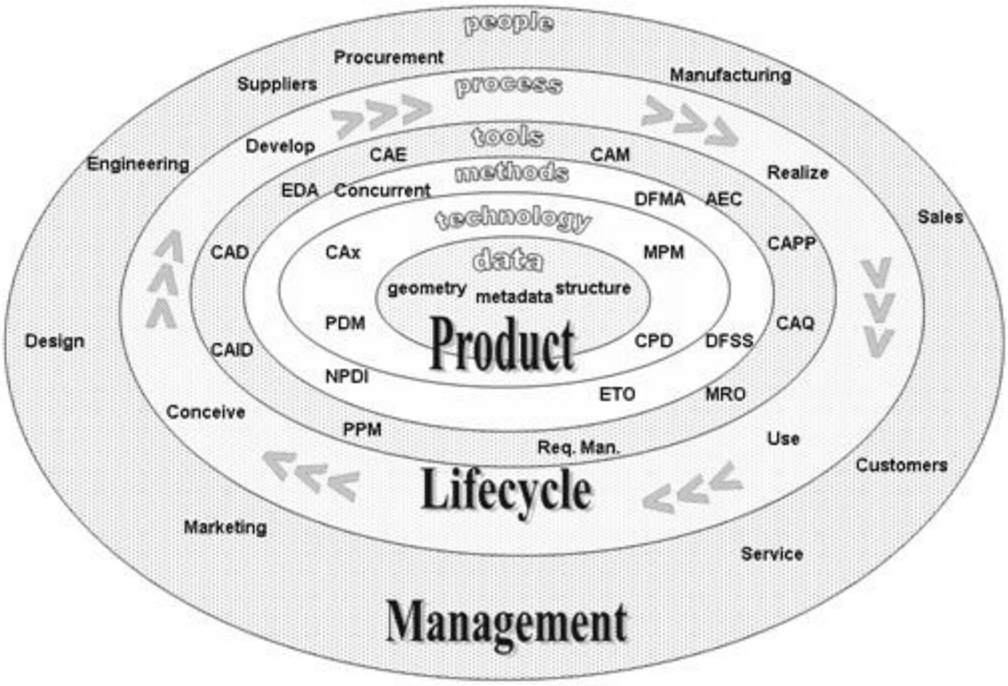


Figure 3-1 Overview of Product Lifecycle Management (Freeformer 2006)

PLM system is functioning in all branches of a company, thus also affecting a large amount of people working in different areas of work. Employers who are using PLM system are for example from following branches of work:

- Design
- Manufacturing
- Supply
- Procurement
- Sales
- Customer Service
- Marketing.

Product lifecycle can be divided to different phases. In the figure 3-1 it's being described with four process phases: Conceive, develop, realize and use. The number the different phases is of course depending on the fact that how detailed the whole lifecycle is been described and defined. Even though, for this thesis, the focus will be in reusing the information in the design phase; the goal is to find out what kind of information there are available in the other phase, and how it can be used. For this reason, all the different phases will be introduced. In order to get more detailed information of all the available product knowledge in this paper the lifecycle will be divided into a total number of six different phases and processes. Of course the phases integrated so that they sometimes overlap and task are made simultaneously between different stages of lifecycle.

These six phases are:

- Concept
- Design
- Manufacturing
- Use
- Retirement.

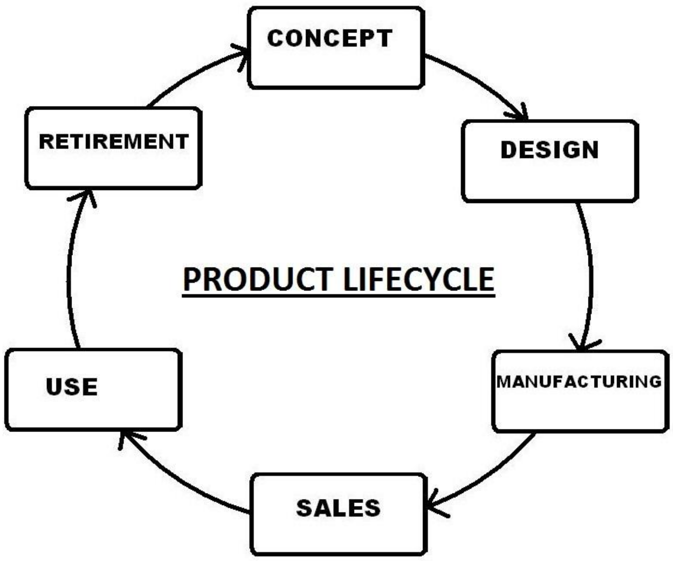


Figure 3-2 General product lifecycle

There are also several different views of the phases of a product lifecycle. The definition of the phases is depending on the area of work and what kind of products the PLM is used for. For people working on the sales department, it is more manageable to divide lifecycle to more phases when considering the life after the launch of a product. Then extra phases could be for example: distribution, service, maintenance, etc. Also the design phase could be divided into a more detailed phase. For example: concept design, detailed design, etc. Another example of a product lifecycle is been presented by (Engelman 2005) in the figure 3-3.

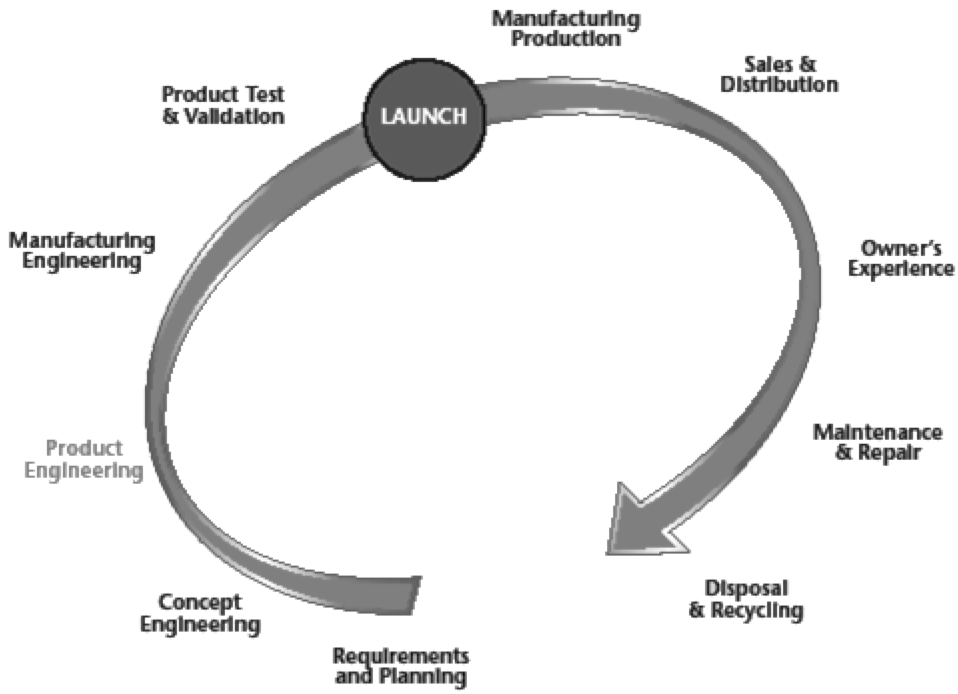


Figure 3-3 Different phases of a product's lifecycle (Engelman 2005)

Description of the different lifecycle phases is based on following sources: (Eigner & Stelzer 2009), (Saaksvuori & Immonen 2008) and (Stark 2005). Description of concept and design phase is based on (Pahl & Peitz 2007).

Concept phase

First phase of a product lifecycle is the concept phase. Idea for a new product can come from different sources or reasons. One important source is a current or a potential new customer. In this case an idea basically comes from a need and demand in the market. Reason for a new product idea or an improvement can be a result of a new innovation or breakthrough in technology. Ideas can be evaluated defined more detailed. In the concept phase requirements and specifications for the product are been created or updated from a previous version. The information from markets, other stakeholders and inside the company is first analyzed. Next, the needs of the product can be identified and determined. Then the structure of the functions, construction and system can be made. In the phase actually the whole product's life is been planned: why is it been made? What are the features that should be in the product? What needs to be improved and why? Also the life of the product after its design is been planned here. Business case for the product is been created, and the costs are been planned. The whole concept phase is heavily reliable from information coming for example from customers, focus groups, and other stakeholders. The concept and requirements phase is strongly bind with design phase and there is already an existing information flow between these two.

Design engineers are getting the information about the product required feature requirements and specifications, and creating the product design according to these frames. The last tasks of concept phase are already overlapping with the design phase. After creation of requirements list the product design phase can begin.

Design Phase

First part of design phase is conceptual design. Problems are been identified according the given requirements, and different variants for concepts and working principles are been found. Created concept design are been evaluated and as a result principle solution is been created. In embodiment design product is developed further. It includes preliminary form design, material selection and calculations. The best layouts for design will be selected, refined and improved further. Next the construction structure will be defined, and weak spots of the design will be eliminated. After the final defined layout for the product has been done, begins the detailed design phase. In the detailed design phase the acquired product specifications and requirements are been transformed into a final fully defined product. During the whole design phase the product will be optimized with various methods in order to get the best possible end design and product. As result of detailed design, different product documentations will be created. For example: CAD models, Bill of Materials, etc. Bill of Materials (BOM) is one concept that gives information to manufacturing phase. BOM is giving description of all the necessary parts for the product.

Manufacturing phase

The next phase consists on manufacturing, production and assembly. The designed products are been made according to the BOM and other product definitions. Manufacturing phase is also highly automated these days. Computer programs are been used to manage the production, and make it more effective. Most of production and assembly tasks are been done by the robots. Many companies are also nowadays complete global enterprises. This requires great deal of communication for example between f manufacturing plant in Asia and all other branches of business in Europe or America continent. For this problem PLM offers great solutions. Before the product can be launched to the markets and sold to customers, quality of it needs to be checked.

Sales and usage phase

After the product has been launched to the markets, it cannot be just forgotten by the company. After sales services has become more and more big part of companies' revenues in every branch of technology. The usage phase of a product lifecycle consists for example from: service, maintenance, repairing of the product, spare part sales. Most importantly the phase offers the way to communicate with the customer. Customer surveys, usage information and general feedback are been made, and offer very useful information that can be used support decision making in the design phase and also other lifecycle phases.

Retirement phase

When a product reaches certain age, breaks down, or doesn’t have any more use, it will be retired. Different tasks that are done to a product in the retirement phase are for example: disassembly, recycling, reuse of the parts and recycling. Some of the resources uses for the product can be used again, and they are starting the product lifecycle again as a part in a different product.

3.2 Introduction to PDM-systems

As mentioned before, PLM is constructed from many different concepts. One of these components of the PLM system is PDM (Product Data Management). PDM-systems are said to be one of the most important and primary system components of a functional PLM-solution (Stark 2005). PDM systems are used to manage the different activities of a products lifecycle. These come from all the different phases of it. Some examples of the activities where information is been stored to PDM system are been listed below.

- Product specifications
- Definition and analysis of the product
- Information about the manufacturing process
- Sales information
- Support (feedback)
- Etc..

More of the information of the different activities from the products lifecycle that is been brought or saved to the PDM/PLM system is represented in chapter 4.1. Number of different levels of the company, people from all over the different branches inside the company, and stakeholders are involved in the data/information flow during the life of a product. It is extremely important that the data flows is properly controlled and managed. In order to manage this data flow PDM system should have certain functions. Basic components of a PDM system are for example: (Stark 2005)

- Data storage
- Information management module
- User interface
- System interfaces for programs

- Information and workflow structure definition functions
- Information structure management
- Workflow management
- System administration functionality.

Data storage is pretty self-explanatory. It is a repository for the product data. The information management module is very important. It makes possible to access the data, to storage and recall it. It also makes sure that the information is secure and that the data can be used simultaneously from different users. The module also archives and recovers the data when needed. Its responsibility is to be able to trace all the actions that are made to the product data. The user interface enables the user actions for information stored, and also the input of the data to the system. As mentioned, PLM system is structured from different sub-systems, which need to bind together somehow with an interface. Also PDM systems need to have this interface in order to be able to communicate with different systems programs, such as CAD or Enterprise Resource Planning. The existing interface of the PDM/PLM system creates certain limitations when considering the integration of PLM and KBE.

Information and workflow structure definition functions define the structure and the workflows of the data. Workflow management means basically the management of the changes and revisions that the systems user is making to the data. Different information is meant for different people, meaning that not every piece of information from all over the products lifecycle needs or should be available for every user of the PDM system.

To control and modify the access rights system administration is needed. It also is used to set up, maintain configuration of the PDM system. The information structure management is responsible for maintaining the structure of the information from all over the lifecycle of the product. For this thesis, the structure of the information is an important and interesting area. Depending on the PLM/PDM system the information is been saved to different structures. The methodologies that are needed to capture the knowledge from the available information are depending on the PLM system used. In order to support the KBE technologies, the saved information structures need to be well defined, and convertible into useful design knowledge.

One important concept for PDM is metadata. Metadata can be described as information about information.(Saaksvuori & Immonen 2008) Basically it is used to describe the actual product data: what kind of information there is, where it is been stored, who has collected the information and how can it be accessed and used. Enables a better management of the saved product information, and has important task in data management when dealing with large amounts of data coming from different sources (product’s life). In general, PDM has a narrower focus and is mostly used to manage the product data within the product design. PLM on the other hand is gathering all the data of products and processes for the entire lifespan of a product.

3.3 Summary of PLM

Product lifecycle management (PLM) is a process where products entire life, its lifecycle, is been managed with a certain system. It is also an information-driven approach to different aspects of a product's life. PLM has emerged together from different concepts, for example: Product Data Management (PDM), CAD and Engineering Data Management. As PLM effects, manages and connects all the different areas and concepts around the company, it is also a perfect platform for KBE. Depending on the product or branch of industry, the product lifecycle can be defined with different phases and processes. There can be for example six phases: concept, design, manufacturing, sales, usage and retirement. This chapter introduces the basics of the PLM system and some general remarks of possible sources of product knowledge. One important aspect of PLM is also introduced. PDM is basically one of the core functions of PLM, because it manages different activities and information of products lifecycle. It offers way to get product information from different sources of the lifecycle to KBE system and from there on to CAD and other design processes.

4 THE CONNECTION BETWEEN KNOWLEDGE-BASED DESIGN AND PRODUCT LIFECYCLE INFORMATION

The information from the complete lifecycle has different forms. Information that is gathered from the manufacturing phase of products life differs significantly from the information that can be acquired from the users of the product or disposal. Nevertheless all this information can have its advantages when thinking about the product development. This thesis is concentrating on the possibilities to use such information in the product development phase, and more accurately for knowledge based automated design. Designers can use the relevant knowledge together with the expertise and experience they are using during product development.

Chapter 4.1 focuses on the different information that is coming to PLM systems from all over the lifecycle of a product. In chapter 4.2 the actual process of converting the available information to usable for knowledge based design is been presented. To be able to use the information, a method and process for controlling and converting the information to design knowledge will be suggested. A framework that enables the information to be transformed to design knowledge will be introduced.

4.1 Usable information for design from the complete product lifecycle

4.1.1 Information from the concept phase

Concept phase and design phase have always been very closely connected to each other. In the beginning of the products life, the idea or demand for an improvement is the driving factor. There is always information coming from outside the company that can also be the decisive factor that will make the improvement of the product and new innovations possible. This external information can be for example:

- Knowledge of latest innovations.
- New ideas.
- New available technologies.
- New available materials.
- New available resources.
- New markets opening.
- Knowledge of the markets.

- Legislation changes.
- New standards.

This information combined with the information gathered inside the company and managed by respective PLM-systems provides a necessary knowledge base that is been used for product development. Product development process, and its beginning, the creation and innovation phase, has always been the required information for creating the product specifications and plan. This information has come from the necessary departments of the company. From financial side: available budged, cost plans, market analysis and etc. The design engineers working with the product concept have of course had the information about the previous designs available: documentation, previous CAD data, configurations information and exact specifications from the previous designs. Nowadays PLM-systems information is centrally managed and can be thus used more effectively.

More examples of available information (mostly from inside the company):

- Knowledge about previous designs
- Product research
- Financial information
- Product specification list
- Model upgrades
- Documentation
- Current rules and legislation.

In the concept phase all the details of the product are planned and then the delivered to designers who create the needed features. The two phases, concept and design, are tightly linked to each other and are also overlapping to each other in most cases. This connection between the two phases has created a natural way for bringing the information to the design engineers. The existing information flow could be thus used also for bringing the other information (or usable design knowledge) from all over the products lifecycle through the PLM database to the design phase. This kind of way of information flow will be suggested in the chapter 4.2.

4.1.2 Information used in the design phase

As mentioned above, the design phase overlaps very much with the concept phase and planning of the product. Basically the information available here is the same as in previous phase plus the extra information that the design engineer needs in order to complete a given design. When the specifications of the changes for the product are made precisely, the information can be used directly by giving new design parameters to the CAD program. CATIA *Knowledgeware* uses also the product templates when creating more complex redesigns. Then of course the design engineer has the access to the previous CAD-models made in the company itself, or often these days by outsourced design engineering service companies. With all this existing information combined with the know-how and the expertise of the designer the product designing can be made.

Examples of the different information available in the design phase:

- Wanted specifications
- Knowledge from all over the lifecycle
- Knowledge about previous designs
- Product templates
- CAD – knowledge
- Knowledge of the subparts/assemblies from subcontractors
- Knowledge of outsourced designs
- BOM
- Know-How from the design engineer
- After design analysis:
    - Prototypes
    - Design reviews
    - Analysis
    - Simulations
- Design guideline and rules
- DFX:
    - Design for Manufacturing
    - Design for Assembly
    - Design for Quality
    - Design for Disassembly
    - Design for Recycling and Reuse
    - Etc…

After one version of the design is been made, and before it's been launch to production and manufacturing, are often simulations or actual tests with a built prototype been made. Results of the tests are analyzed and reviewed. If there needs to be some changes to be made the information will be sent back to the designer. After finishing design changes and adoptions have been made the tests are often re-taken and results are analyzed again.

If the problem requires bigger changes to be made, information can be send to concept phase, where the solutions will be found and new specifications of the problem related features can be send to the designers responsible for the detailed design. This iteration is typical inside the product design phase and can be seen as a life cycle inside the overall products lifecycle.

All information in this phase is basically needed for the detailed design, but not all of it can be used directly for an automated design. Mostly just geometrical values and design rules can be used. The effectiveness of the process of converting available PLM-information to directly usable codified knowledge for automated design is the key how much of the actual work in the design phase can be actually automated. The product development is going on regardless of the level of automation. The more the available information is been converted to directly usable values before the beginning of the detailed design phase, the faster the whole product development process will be through, thus shortening the time-to-market.

4.1.3 Information from the manufacturing phase

Manufacturing and production have also a tight connection with the design phase. One design management concept that is creating connection between manufacturing and design is Concurrent Engineering, which means the co-operation of the experts in production/manufacturing and the design. (Kusiak 1993). This way the design engineers have the most update knowledge of what should be considered in order to improve the manufacturability and assembly, when planning the product. Concurrent engineering is been used also to include other phases of the lifecycle to the design, However, the connection between manufacturing and design can be maybe the most widely adapted in industries. With the help of Concurrent Engineering, the elements of a product that affect its manufacturability and assembly are been considered from the early stages of the design. The Design for Manufacturability and Assembly (DFMA) is a broad concept, consisting for example following topics: (Yang 2009)

- DFMA:
  - Design, concept, function and sensitivity to manufacturing variation
  - Manufacturing and/or assembly process
  - Dimensional tolerances
  - Performance requirements
  - Number of components
  - Process adjustments
  - Materials handling
  - Ergonomics.

In concurrent engineering the communication between design and other phases, such as manufacturing, is mostly happening within design meetings where experts from different branches are exchanging thoughts about the improvements needed for the product. These meetings are very effective, because of the different views that are merged. However, the whole communication process and the knowledge transferring process can be made more effectively through the PLM system. Most of the concepts of the DFMA are already actually values that can be either directly used to change the design (tolerances, dimension changes, material changes, number of used bolts, thickness of the etc.), or they can be easily converted product specifications that to can be used in CAD. For example:

- Performance requirements
  - More tensile strength, but lighter product → material changes/thickness changes.
  - Quicker assembly → less components → two screws instead of three, but the same shear stress.
  - Etc…

Different information from manufacturing phase is mostly from sources that are working or being used during the phase: production workers, production control, machine/robot information, quality control, supplier information, etc. It can be opinions acquired trough experience. This human feedback can often very valuable and highly usable, while the source of the information probably knows the limitations and possibilities of the available design/manufacturing, in comparison with the customer feedback, where people are more likely to want an impossible improvements.

Other information from the manufacturing phase is often highly statistical data gathered from the process, for example through quality control. Of course, the data muss be first interpreted and analyzed, and the finding the relationship between data and usable design specification, will require more work. Nonetheless this analysis can provide extremely valuable information about the possible areas of improvement that wouldn't have been noticed without a longer statistical tracking.

Available information from manufacturing phase:

- BOM
- Manufacturability:
  - Feedback from the manufacturing
  - Requirements for manufacturing
  - Process capabilities.
- Information about assembly
- Knowledge about resources:
  - Human resources
  - Manufacturing machines
  - Collaboration
  - Infrastructure
  - Process
  - Subcontracting
  - Materials
  - Suppliers.
- Test results.

4.1.4 Information from the use and support phase

In the use of supports phase the information flow is mostly between the customers and the parts of company that are responsible for customer support, maintenance or repairing. Information that is gathered from the customers is one the most important ones for the product development. By identifying the customer needs, also the design problems can be identified. Identifying customer needs requires also a certain process that the available information can be then later be changed to a usable knowledge. For the identification process can be used methodology suggested by (Ulrich & Eppinger 2004). It consists six phases:

1. Define the scope of the effort.
2. Gather raw data from customers.
3. Interpret the raw data in terms of customers' needs.
4. Organize the needs into a hierarchy of primary, secondary, and (if necessary) tertiary needs.
5. Establish the relative importance of the needs.
6. Reflect on the results and the process.

Most of the information that is coming from the use and support phase is highly statistical raw data from the customers either directly from them or through a survey made by some sections of the company. Information for example about what has happened to the product, for how many customers it has happened, which components have had most failures and so on. This kind of statistical data can't be of course directly used for design process. It needs to be interpret; is there something that needs to be done for the product regarding of the statistical results and also for what functions/features of the product need to be changed.

Possible sources of information can be for example following:

- Knowledge about failures (Failure Modes and Effect Analysis).
- Service feedback and statistics:
    - Repair knowledge
    - Spare part usage.
- Maintenance feedback.
- Customer surveys:
    - Usage
    - Target groups.
- Feedback from customers and other stakeholders:
    - Usability.
    - Features.

    - Geometric properties
    - Functions
    - Design.
- Data of the product usage history.
- Knowledge about the competition in the market.

As mentioned most of this information isn't directly usable for the design process, but with the help of different tools, the design problem can be defined and points of focus for product improvement be found. For example, many companies use FMEA (Failure Modes and Effects Analysis) to prioritize and report the possible failures. It is used for example to prioritize different failures, and to document how often and how severe the problems were (Wikipedia (c) 2010). FMEA is one of the tools that are included in the introduction (chapter 4.2) of the ways to convert product information into usable design parameters. Other discussed tool/methodology is Quality Function Deployment that is been used to convert the customer needs (and other information from the lifecycle) to usable design specifications. In the chapter 4.2, where methodology for knowledge converting is introduced, also a more detailed introduction of FMEA and QFD, and their use in knowledge capturing will be represented. Nonetheless, already now can be stated that FMEA databanks should be, if aren't already in some companies, more included into the whole PLM system. With this implementation information flow can be made more effective.

Of course, there has been always a way to get the information of the customer needs to a design engineer, but with the help of a PLM system (and tools like QFD included in it) this process could and should be done more effectively, making it possible to have more dynamic lifecycle, with shorter time for product improvement. There is lots of information from usage phase that can't be directly used, but give vital background information to be used to support the decisions in the design phase.

However, there is also information that can be used directly in knowledge based design: geometrical properties and visual design of the product. This won't of course come directly from the customers in usable form of knowledge representation, but certain feedback can be easily converted to a codified knowledge that a KBE enhanced CAD can use. For example: customers give feedback that a handle of the device is too big and it is hard to hold in the hand. Of course this would directly result the information that the diameter of the handle needs to be made smaller. This is then a basic geometrical value usable for CAD to create a new version automatically, without the need for an expert design engineering to do the completely routine task. But as already stated in the chapter two, the product knowledge is getting more and more complex and number of this kind of simple change requests has reduced.

In summary the information from the usage phase of the lifecycle can be used for design:

Indirectly by:

- Identifying the targets of improvement and customer needs.
- Prioritizing the design needs.
- Gathering raw data, and analyzing it, and using different tools convert it into design specifications.

Directly by:

- Need for change in geometrical values.
- Need for change in design forms.
- Giving minimum/maximum values for:
  - Design rules, scripts and equations.
  - Parameters.

4.1.5 Information from the product retirement phase

The last phase of the lifecycle, disposal and retirement, is pretty similar in comparison with the usage phase, when considering the usable information. There are many things that can be learned for example from the disassembly, recycling or part reusability. These are all details that give information about the possibilities to improve the product. As before, the data would be used indirectly by changing it to some usable values through expertise and know-how. For example every component of the product could receive an evaluation for reusability or recyclability. This would again help to find the features that can be reconsidered.

Also the opinions of the people working for example in the recycling process can provide valuable information that is based on the experience. For many companies the retirement phase isn't that important in comparison with the others lifecycle phases. Nonetheless, if the different parts or materials could be effectively reused in the remake of the same product or a new generation product, huge savings could be gained. A good informal flow between the retirement and design phase would ensure that product's properties would support the reusability and recyclability of the product. This would, firstly make the whole lifecycle more effective and would reduce costs, and secondly and more importantly would be better for the environment.

Possible sources of information from the end of products lifecycle can be for example following:

- Disposal information.
- Recyclability:
  - Materials.
  - Recycling costs.
- Design for recycling.
- Design for disassembly.
- Reusability of the parts.

4.2 Transforming the PLM-information into a usable form for knowledge based design process

4.2.1 Framework for converting available product information to be usable in design

One approach to the problem of bringing the product information from lifecycle to design process has been introduces by (Ramón-Raygoza et al. 2008). They suggest a method where knowledge is brought for the DFX process, but the same framework/methodology can be used of course also for knowledge based design process, with some small changes of course. The suggested framework with light changes is presented in figure 4.1. Within this framework certain tasks for the information converting will be done.

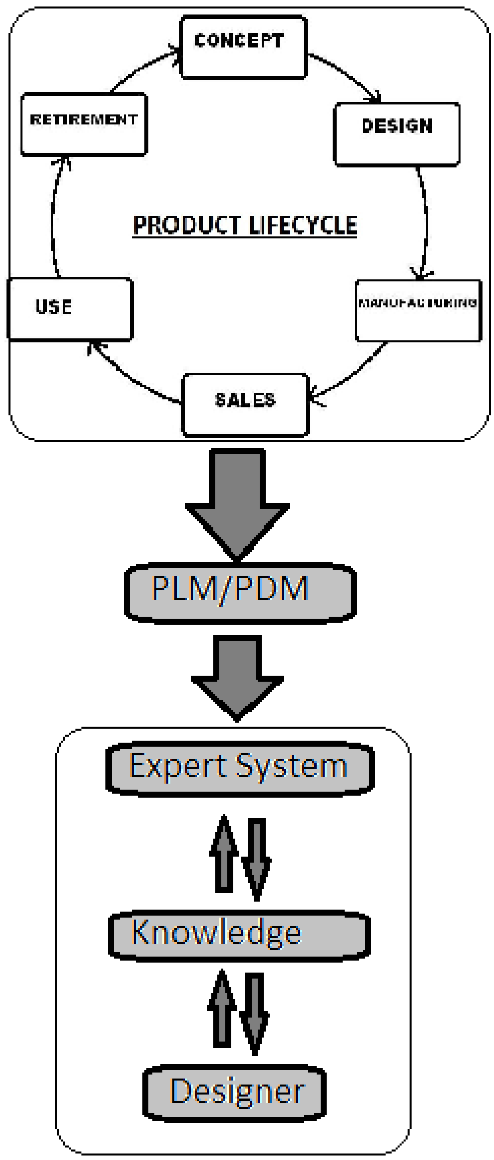


Figure 4-1 Framework for bringing the information to design process

Variability of different kinds of information needs a customized process for the companies needs. The framework (Ramón-Raygoza et al. 2008) suggests basic tasks before the acquired information (for example: results of a customer survey) can be divided for example in three different tasks:

1. **Acquiring the knowledge:**
   - Identifying, capturing, defining, and formalizing the information.
   - Different phases of the lifecycle, different methods for data acquisition.
   - Identification of needs.
2. **Product data management through PLM/PDM system:**
   - Structure of a data repository.
   - Organizing the information.
   - Data availability and change management.
   - Data availability for Expert system.
3. **Converting the knowledge in an Expert system:**
   - Collect the information from data repository.
   - Use different methodologies and tools to find out what information represented in the data is useful.
   - Define design problems and relevant design specifications and characteristics.
   - Convert information to usable design knowledge using different tools and methodologies.
   - Use acquired design knowledge to create codified design parameters that a KBE enhanced CAD can use.
   - Give acquired parameters as inputs to automated CAD process.

First is the task of capturing the product information that can come from the processes inside the company or from stakeholders outside it. As stated, the form of the information varies depending on the company. In chapter 4.1 the example information was described in general manner. Actual company needs first to define their own processes and the product lifecycle in order to identify the usable information for their own product. It’s the way also to identify the needs. The information capturing, defining and formalizing can be then done with different methodologies (for example MOKA which was introduced in the chapter 2) and also with different methods in different phases of the lifecycle (for example: statistical data, FMEA, etc.). The choice of the methodology is made so that its outputs support the structure of the company’s PLM/PDM system. The process depends on not just the form of the original information gathered, but also which the PLM system is been used or what kind of information is actually wanted to be saved to the system.

For the second tasks, structure of data repository and the way information is organized, are of course dependant of the PLM/PDM system used. In order to make sure that the saved data is easily available for the expert systems, the information flows of the suggested framework need to be considered. The chapter 4.2.2 is focusing on this matter.

The third task in the suggested framework is the actual process, where lifecycle information that is saved into the PLM/PDM data repository is been taken, and trough various tools and methodologies converted to a codified knowledge that can be used in a KBE enhanced CAD for product design. The process of knowledge converting, and the tools and methodologies used in it, will be more detailed described in the chapter 4.2.3.

4.2.2 Information flows in the knowledge converting process

PLM system is bringing the every aspect of the life of a product under a same system, where at least in theory, all kinds of information is available for different phases always when needed. Here we are assuming that the information is stored from all over the lifecycle to the central PLM data repository (Seen on the figure 4-2). In this chapter the main focus is the information flows between different phases of the product lifecycle.

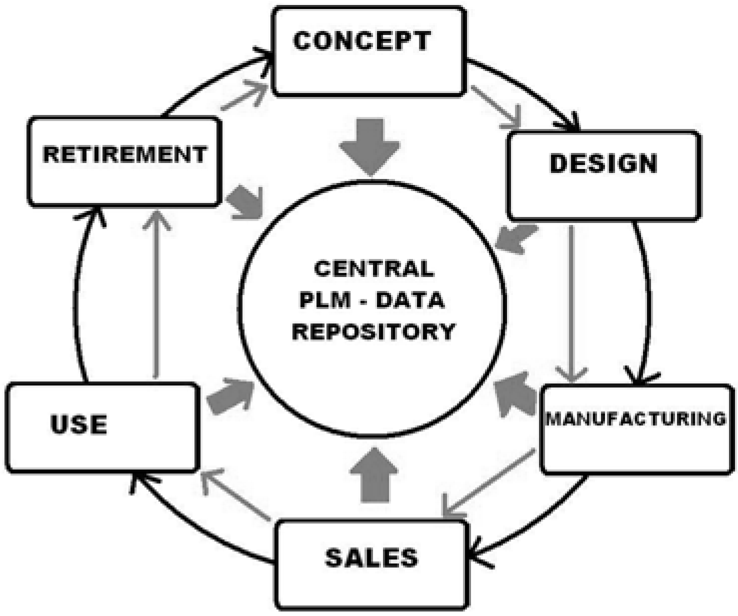


Figure 4-2 Gathering information from all over the products lifecycle to central PLM repository

If the PLM system and CAD program are coupled together, the information is already saved to the databanks in a rightly structured form. In such cases, the reuse of the knowledge from previous designs is made easier. Probably in the future PLM and CAD are integrated so tightly that the problem won't be the availability of the information. Design engineers would have access directly to all relevant information saved to the PLM system. However, in most cases information needs to be converted to design specifications and parameters before it is usable. Rather than directly accessing various PLM-information from the design phase, a possible solution would be to create a knowledge converting unit where every piece of useful information would be analyzed at once. The resulting output would be design parameters, which can sent further to detailed design. This would prevent the possibility that some available information wouldn't be considered. Also the process of knowledge converting would be better defined and more easily defined. What would be then the best solution for the converting unit? The unit needs to have access to PLM data repository and more importantly the resulting knowledge needs to have functional connection to the design phase.

At the moment, one of the problems with the information flows is that the information is mostly flowing only to the next phase in the lifecycle or other connected processes during the lifecycle. Of course it isn't necessary for all the sections of the company to have, all the product information throughout the complete lifecycle. An example of how the information is going back and forth within the products lifecycle is seen on the figure 4-3.

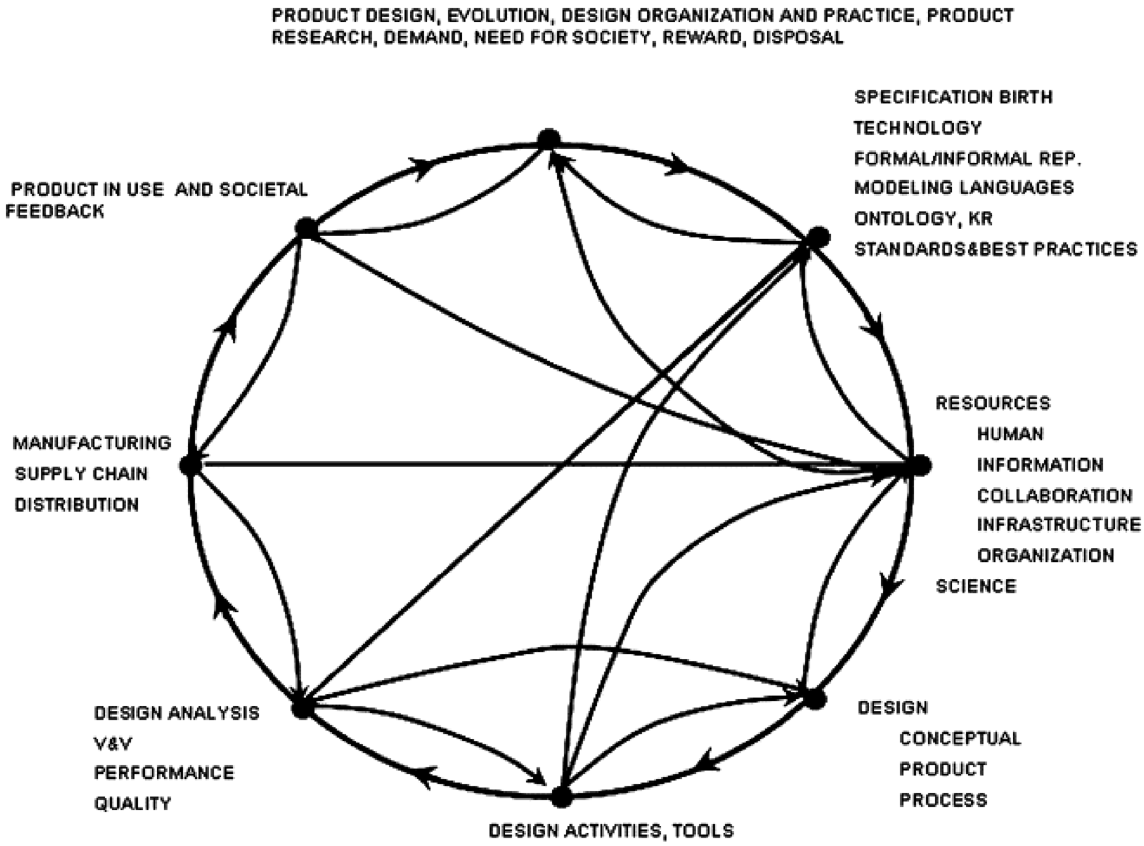


Figure 4-3 Information flows in products life (Sudarsan et al. 2005)

Regardless of product development case (new product development or improving previous design) the specifications of the product need to be created and presented in a certain formal way. This product information is necessary for design engineer that he is able to do the required work. As already mentioned in the chapter 3 and 4.1, concept and design phase of a product lifecycle are often overlapping each other, and have a tight connection between them. This product information flow, between the two phases, is a natural and already existing way to bring information to design process. For bringing all different aspects and voices from the lifecycle to design, this flow will offer a great ready channel bring information to use. Instead of directly accessing the saved knowledge in the central PLM-data repository design engineer will get the knowledge among the other specifications and design needs.

First the knowledge will be brought to the knowledge converting unit, where it would be changed to a formal representation that a knowledge based CAD tool could use for making the design. This suggestion for an information flow and placement of the knowledge in the concept phase of the lifecycle are seen on the figure 4-4.

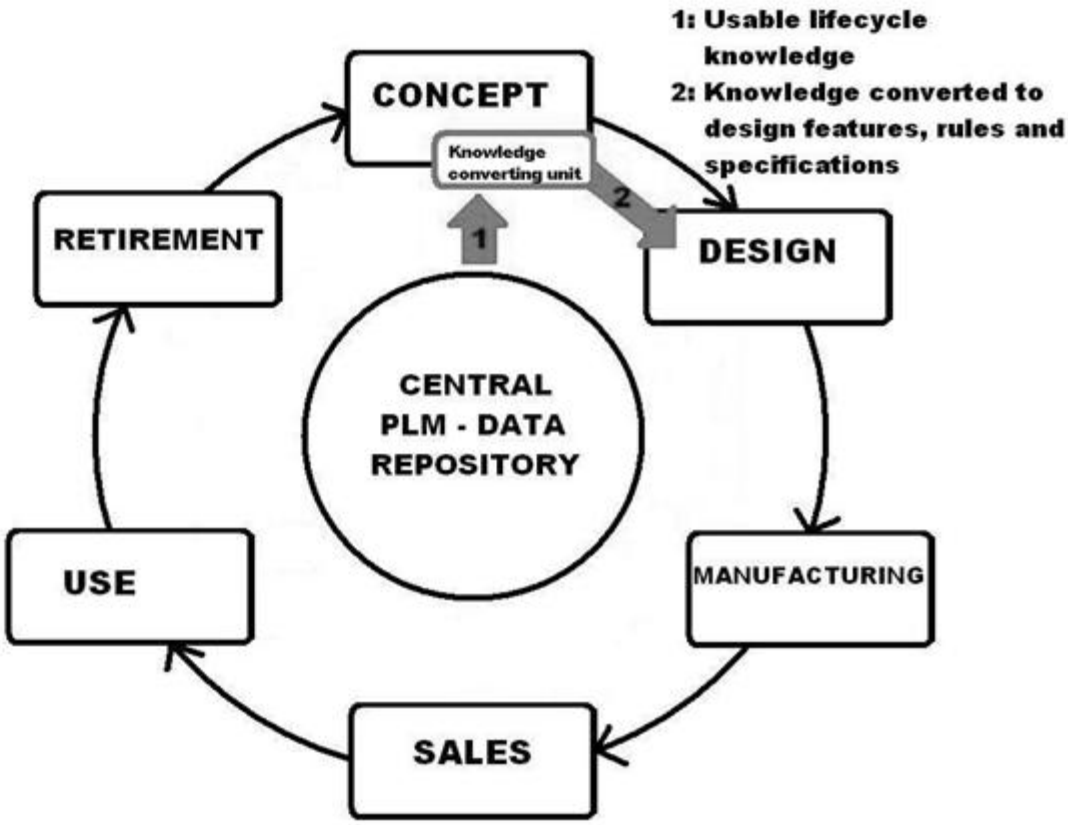


Figure 4-4 Suggestion for the information flow from PLM data repository to design

Advantages of the converting unit are:

- Knowledge converting coupled together with the other product specifications/requirements creation.
- Natural information flow to send the resulting knowledge further to design.
- Centralized knowledge converting which makes it:
  - Easier to control and define
  - All the information will be considered together.

In order to make the information flows and the whole process even more effective, it could be partly automated. KBE application should also automatically search parts on a data repository or form the knowledge converting unit. For this problem, (Pugliese et al. 2007) are proposing an approach based on a specific coding of parts and assemblies. The code should represent the main information on the specific component; in other words, code should not give information only on geometrical aspects, but also information on other aspects related to the component and how and why the component is created in a particular manner. For example, a product part should be coded using numbers for the dimensions, but also alphanumerical characters, which provide information on the morphology, assembly procedures, adaptability for a specific use, etc.

4.2.3 Platform for converting the information for usable knowledge

This chapter is introducing what kind of platform would the suggested knowledge converting unit need? How is it included in PLM system? According to (Abramovici 2007) PLM methods can be divided into three groups:

- Information management
- Process management
- Application integration.

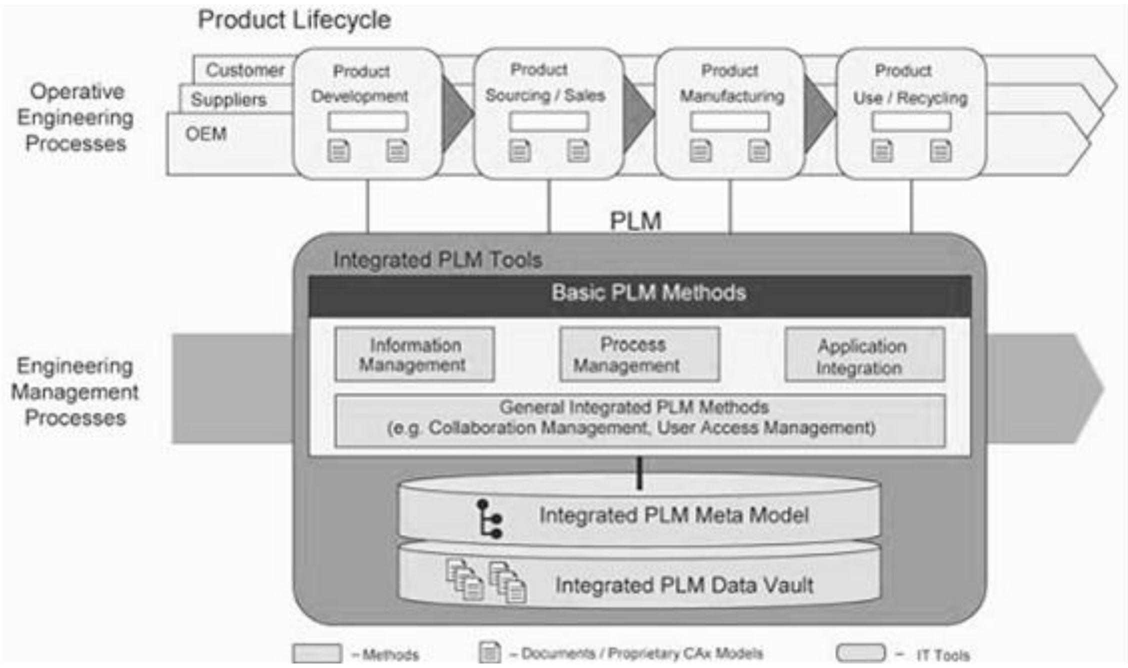


Figure 4-5 Components of the product lifecycle management (Abramovici 2007)

Application integration means the different interfaces between applications. (Abramovici 2007) For example: CAD, Computer Aided Manufacturing, other

Computer Aided Engineering applications, or integrated enterprise software's such as ERP. The newest PLM solutions have already combined the PLM for example with CAD design and offer a direct connection between PLM databanks and design. This enables simultaneous design because the data is available to necessary people who have access to the PLM-system. This kind of application integration is used at the time mostly to store and share the knowledge among the company. In the frames of this thesis, it isn't possible to study the actual integration of a possible knowledge converting unit, CAD system and the whole PLM system. This requires advanced skills with the IT-tools and program development. However with the increasing demand for PLM systems that includes every application used in the company in the system, the application integration will definitely be one of the main developing goals of future PLM-solutions.

(Abramovici 2007) is also suggesting that to the application integration between PLM and CAD, should be also included the company's current configuration management. With the help of configuration data, the engineer can more easily find the changes, old product structures, and which functions of the design are relevant to each other.

When summing up the suggestions made in chapter 4.2.1 and 4.2.2 will be seen that the knowledge platform that integrates PLM and KBE enhanced CAD will need to have following features:

- Integration with PLM data repository which is used for data acquisition (possibly partly automated).
- Interface that enables:
    - Information analyzing.
    - Use of different knowledge converting tools and methodologies.
    - Design optimizing methods.
- Integration with the design phase, which enables:
    - Connection directly to KBE enhanced CAD (possibility to give codified knowledge as an input).
    - Connection with product development section.

Although the use of KBE techniques enables the use of automation in the design process, human actions can't be fully replaced in the process. This was discussed in the chapter 2.3.1 Limitations of KBE. Because of the complexity of design problems, also the use of knowledge converting unit can't be fully automated, and the process needs to have someone responsible.

Platform will be managed by a knowledge engineer. This kind of position should require not only a lot of experience in engineering skills but also IT and basic programming skills. Creation of design rules and scripts in the CAD knowledge modules require use of basic programming (CATIA used as an example in the chapter 2.4). Ideally the platform manager will access the information from the PLM data repository. In simplest cases (for example: change requests in geometrical values), the engineer will directly give the changed design parameters, as a codified knowledge to the CAD.

One of the main perks of the use of knowledge based design is the time reducing effect when less routine tasks needs to be done. Engineers have more time to think that what are the needed changes, and with what values we should try to change the design, instead of losing the time by doing the changes in CAD program themselves. Time can be used more valuable by innovative tasks of what should be changed and then analyzing the design changes that CAD program has created with the given values.

With the use of his experience, the engineer could also define needed design changes in little bit more complex design needs. For example: new performance requirements in product functions that are not affecting the other functions. By using his judgment, the engineer can give possibly improving design parameters for CAD. The automated design process will create the new design. Because of the time saving the process gives, the engineer has better possibilities to find out the required changes without the increase in total product development time. In order to get different what-if designs the engineer could try several scenarios where different sets of values and rules where adapted. Afterwards the new designs should be reviewed again in order to find out which changes had most favorable results. Then again the process should be gone through that the new values for the target of improvement would be optimized and in order to get the best end product. This kind of test-review cycle is best used for problems that don’t require major changes to the product. Of course, same kind of iteration process of finding the changes for improvement is already happening in many companies, but with the automated design process, and proper use of available knowledge it should be much faster than any previous way of doing the redesigns.

With the increasing use of KBE technologies in the future, it is possible that more and more of design engineers are required to have skills in the knowledge engineering. According to (Krause 2007) in the future the design engineers can be sorted in two categories:

- “Build time” engineers
- “Implemention” engineer or “design engineers”

With the term “build time” is meant engineer who is focusing on creating new innovations. New ways to assemble body frames, new materials, etc. Their task is to create new generic models structures. These models then will be used by the other type of professionals. Implementation engineers are focusing on the parts that need to be currently developed. Their task is to reuse the generative definitions and change the current version of the product to match the needed specifications or configurations. These kinds of specialist are also the ones, who could be responsible for the knowledge converting process as a knowledge design engineer.

Of course, it isn't an ideal situation that basically all the responsibilities of knowledge usage in the product development process in the company are been given to one or more knowledge experts. More desirable situation should be that the process could be simplified so that any design engineer could use available information and the help of automated design process. For a company that is just starting to take advantages of PLM and KBE techniques, a knowledge converting unit managed by knowledge experts, would however be probably easier way for the beginning. After company's processes and available information is more specifically defined, and other engineers have gotten used to KBE and the methodologies used for knowledge converting, could the converting unit be fully integrated part of the product development process. Dividing the KBE responsibilities would make the process more effective.

In summary, the one responsible for the knowledge platform and converting unit will have for example following tasks:

- Gathering the information coming from different sources along the products lifecycle. Take all the different aspects and voices into consideration.
- Analyzing the available information:
    - Most simple cases → direct interaction with KBE enhanced CAD by Creating scripts, design rules and other usable design parameters and giving them as inputs.
    - Somewhat simple request for improvement → use of engineering experience to create different what-if-designs, which will be modeled, analyzed and optimized.
    - Complex design needs → use of available information, and converting it with the help of design tools and methodologies (discussed in the chapter 4.2.4).
- Communication with product development process.
- Management of the knowledge platform.

The use of different design tools and methodologies has been mentioned several times as a way to create usable design knowledge for more complex problems. The actual tools and methodologies will be more detailed introduced in next chapter. These techniques will show the actual process happening in the suggested knowledge converting unit when dealing with complex design problems. Later also a workflow diagram for the knowledge converting unit will be introduced. It will summarize the suggestions made in the chapter 4.2.

4.2.4 Methodologies for knowledge converting

In the chapter two, a methodology to give knowledge a formal presentation was introduced. MOKA methodology offers way to create formal and informal models that describe the product and process structures with the help of MOKA ICARE forms. With the created models the knowledge could be transferred and used in KBE enhanced CAD systems (For example program in this thesis: CATIA *Knowledgeware*, also a generative model based on MOKA methodology needed to be created).

Also a suggestion for an information flow for available PLM information was made. Information would be directed from central PLM data repository through a knowledge converting unit to design process. Converting unit would be included into to normal product specification process before the detailed design phase of the product. What should then happen exactly in this converting unit? How the available information is been converted to the formal presentation and design parameters?

(Torres et al. 2010) are suggesting a knowledge based framework that is enabling the information converting process, by adding in it a support for different design tools. Suggested design tools inside the framework are Quality Function Deployment (QFD), Failure Method and Effect Analysis (FMEA). By integrating the use of these tools with the creation of product structure, functional requirements coming from all over the lifecycle, key design characteristics, geometric and other design parameters, can the product information be defined and knowledge captured into MOKA based knowledge methodologies, and further on, into the knowledge based design process and KBE enhanced CAD.

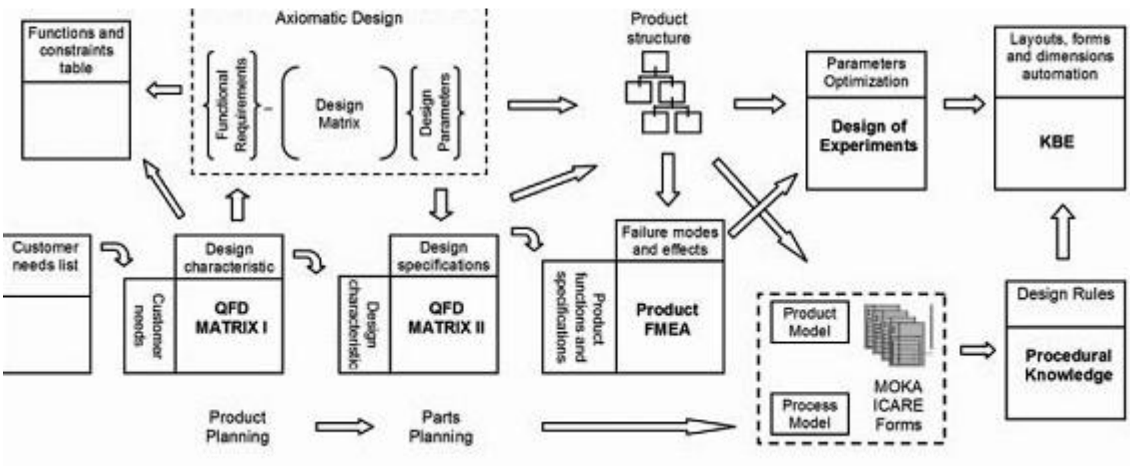


Figure 4-6 Information flow where different design tools (QFD, FMEA, etc.) are integrated with MOKA and KBE system. (Torres et al. 2010)

Figure 4-6 shows the information flows suggested by (Torres et al. 2010) for the integration of different design tools. Methodologies, tables and design tools represented in the figure are:

1. Customer/stakeholders needs list.
2. QFD Matrix I (used in product planning).
3. Functions and constrains table.
4. Axiomatic design matrixes.
5. QFD Matrix II (used in parts planning).
6. Product FMEA.

7. Product structure.
8. Parameters optimization.
9. MOKA methodology.
10. Design rules.
11. KBE system.

Next, the methodologies, design tools and information flow in the suggested framework will introduced more detailed.

1. Customer/stakeholders needs list

In the figure 4-7 can be seen the different voices that affect the product development process when considering the whole PLM process. It is not easy task to pleasure all of the needs. Often an improvement in the other aspect will require the other properties to get slightly worse. An important task is also to find the proper balance that takes into consideration every branch included. Chapter 4.1 introduced more detailed the information that is received from different parts of the lifecycle. Every phase has its own needs that need to taken into consideration in the design process. This information from various sources is been used in the knowledge converting framework as a base for creating the QFD matrix.

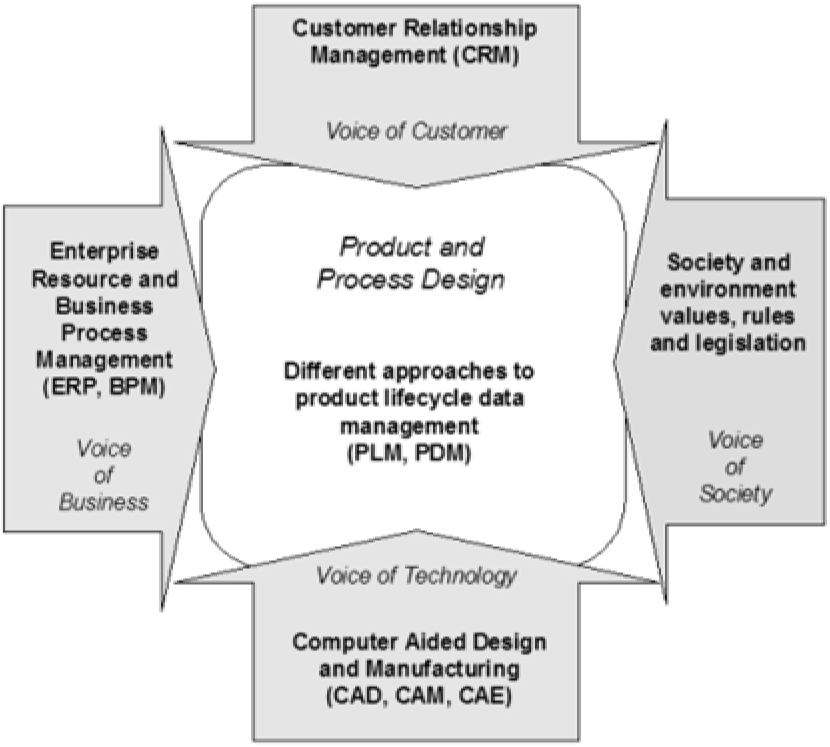


Figure 4-7 Different sources of voices that product and process design need to take into a consideration during the products life. (Lillehagen n.d.)

2. QFD Matrix I

Quality function deployment (QFD) is been described as a “method to transform user demands into design quality, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process.” (Mizuno 1994)

QFD is been designed to help product developers to get the viewpoints of different stakeholders to the product design. It helps to transform the voice of the customer (and also other voices described in the previous section) into engineering characteristics. QFD uses different kinds of graphs and matrixes for describing the needs and characteristics. One of the most used tools of QFD is “House of Quality” that defines relationships between the needs and product capabilities (Mizuno 1994). In the proposed framework (Torres et al. 2010) are using clutch system part as an example product. QFD Matrix I used in the example (based on House of Quality). The matrix for the part is been seen in the figure 4-7.

		Design characteristics								
		The cushioning and filtering the engine vibrations	Absorption of energy	Torque capacity	Wearing and friction	Size and rotation volume	Fixation and assembly to the vehicle	Progressivity at engaging	Defusing by over torque	Mechanism of engage and disengage
Customer needs	Comfort at engaging	9	1	3				9		3
	Progressive starting of vehicle	3						9		3
	Does not produce slipping and shuddering	3	3	9	9			1		1
	To produce little noise	3		3		3	3			3
	Easy to assemble					3	9			1
	To protect the transmission								9	3
	Low cost	9	3	9	3	3	1	9	3	9
	Reliable and safe performance	3	9	9	3		3	1	9	3
	High durability		9	1	9					9

Figure 4-8 Example of a QFD Matrix I for a clutch (Torres et al. 2010)

From the figure can be seen customer needs (information from PLM) on the horizontal axel, and design characteristics (dependant also of the product) in vertical axel. The numbers are rankings, which rank the most important needs. Instead of customer needs, the QFD matrix can use same way the needs from different parts of the product lifecycle described in the chapter 4.1. For example: need for better ergonomics from assembly, need for better recyclability, etc. This way QDF Matrix can serve as a great starting point for using information from all the different voices.

QFD Matrix I is been used for general Product Planning. It gives answers to questions: “what is the purpose of a part?” and “why is it needed?” With the help of the acquired function requirements, can the process go further and Functions and Constrains table, and an Axiomatic design table can be created.

3. Functions and Constrains table

Functions are used to describe the ways and actions that the product does. A function corresponds with an active verb that executes an action on an object, or to an object. Constrains are values that specify the conditions in which the action is executed. For example (Torres et al. 2010):

- Function: transmit rotational movement – speed and torque.
- Constrains: engage/disengage, deaden vibrations, soften start, etc.

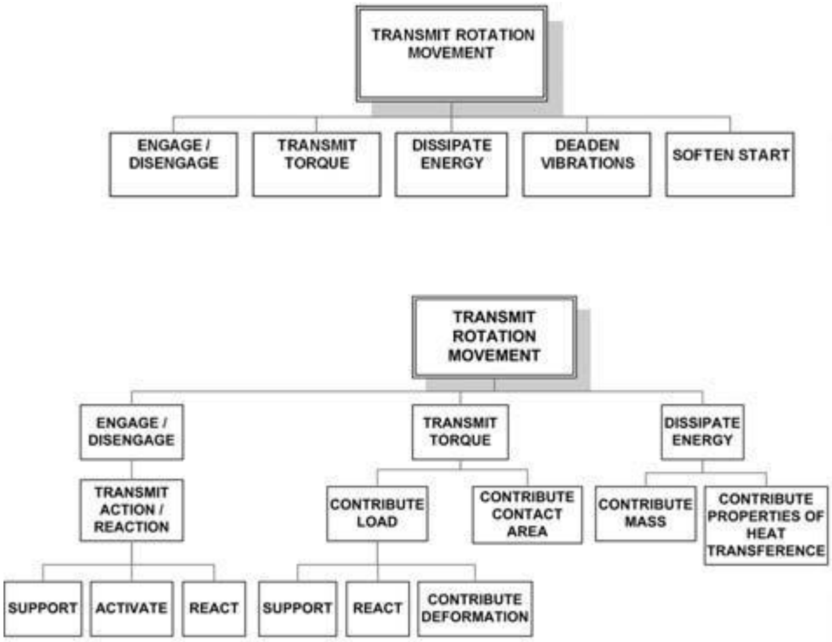


Figure 4-9 Example of Functional requirements of a clutch. (Torres et al. 2010)

With functions and constrains table the general functions of the product will be listed and used later on for help, when creating the product structure.

4. Axiomatic design

Axiomatic design table a systems design methodology that uses matrix methods to systematically analyze the transformation of customer needs into functional requirements, design parameters, and process variables (Suh 2001). The method gets its name from its use of design principles or design Axioms (i.e., given without proof) governing the analysis and decision making process in developing high quality product or system designs (Wikipedia (b) 2010). Axiomatic design table can be created with the help of QFD Matrix I and it gives out design parameters, which can be used as design specifications in the QFD Matrix II, the next phase of the suggested framework (see figure 4-10). The parameters are also later used, when creating an overall product structure.

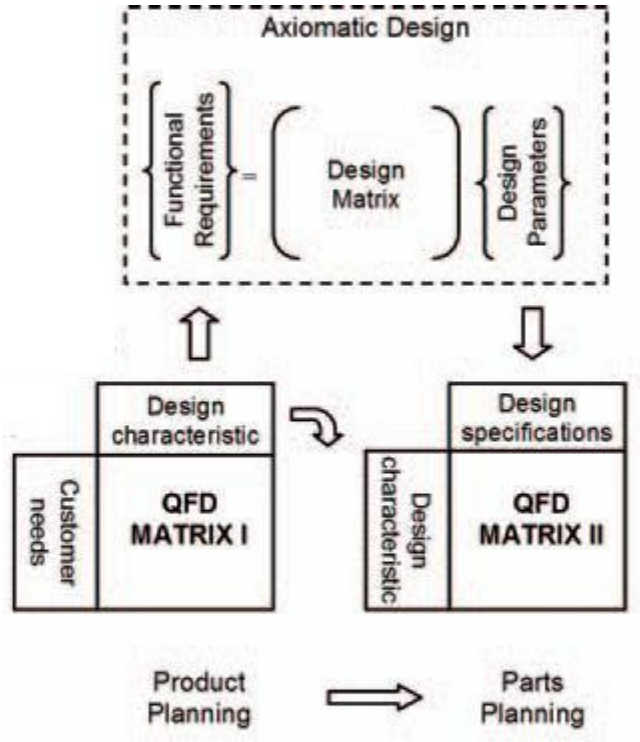


Figure 4-10 Connection between Axiomatic Design and QDF matrix I and II. (Torres et al. 2010)

The figure 4-11 shows an example of design parameters created in the Axiomatic design process. The comparison between Functional requirements (figure 4-9) shows a high relation between the two. Design parameters offer already a good base for creating a product structure. However, before the parameters can be used with a CAD tool, they need to be first transferred to geometric parameters and definitions.

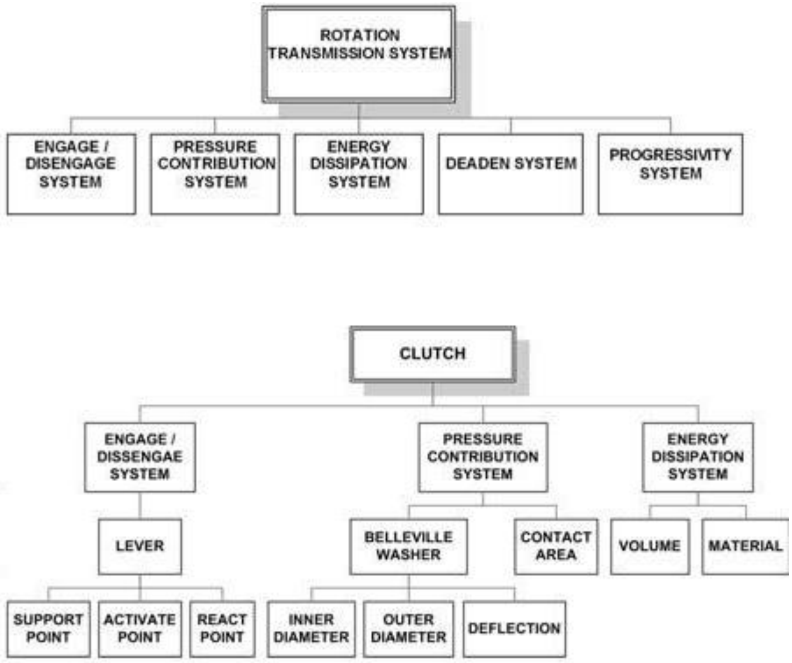


Figure 4-11 Example of Design parameters of a clutch. (Torres et al. 2010)

At top level, design parameters are black box generic subsystems that required to be investigated to identify or propose possible physical principles to be used. Physical principles must fulfill the Function requirements. ‘Identify’ refers to sequential design and ‘propose’ refers to creative design. At this stage, top-level constraints derived from the type of product should be considered to identify/propose a suitable physical solution. The constraints derived from a sport car would be different from the ones derived from a heavy truck. Such constraints will allow specifying constraints (qualifiers) associated with each function requirement in the second function requirement level. Example when the torque range needs to be transmitted. It can be expressed by two numerical values (min, max) and its associated unit of measurement. (Torres et al. 2010)

5. QFD Matrix II

With the help of QFD Matrix II, the Design characteristics (figure 4-12: horizontal lines) and Design specifications (vertical lines) are used to create functions and specifications for the product. Again a table based on the House of Quality is been used. In this phase the part planning is been made.

		Design specification						
		Clamp load in pressure plate	Average radio of load application	Thermal resistance	Lever ratio	Rotation volume	Bearing load	Weight and material of pressure plate
Design charact	Absorption of energy	1		3		3		9
	Torque capacity	9	9	3	3	9		3
	Wearing and friction			9				9
	Size and rotation volume	9	9			9		9
	Rapidity in gear changing				3		3	
	Mechanism of engage and disengage				9			

Figure 4-12 Example of a QFD Matrix II, parts planning (Torres et al. 2010)

Product specifications and functions can be used together with the created design parameters tree to define the final product structure tree. Design specifications are also used for creation of Product FMEA.

6. Product FMEA

A Failure Modes and Effects Analysis (FMEA), is “a procedure in product development and operations management for analysis of potential failure modes within a system for classification by the severity and likelihood of the failures” (Wikipedia (c) 2010). FMEA helps to identify the potential failure modes based on past experience. With the FMEA techniques the possible problems that can affect customers, can be defined. Effects of the failures are analyzed in order to study consequences. As already described in the chapter 4.1, a lot of information from FMEA can be found useful for the design process. The suggested framework by (Torres et al. 2010) shows, in which part of the knowledge converting process this information can be used.

FMEA provides an analytical approach, when dealing with potential failure modes and causes. Possible failures in a design are for example:

- Safety causes
- Performance failures
- Quality and reliability problems

FMEA provides an easy tool to determine which risk has the greatest concern, and therefore an action is needed to prevent a problem before it arises. The development of these specifications will ensure the product will meet the defined requirements and customer needs (Wikipedia (c) 2010). FMEA uses different factors to describe failure and to rank different failures in order find out the most critical ones. The FMEA factors are:

- Function description.
- Failure mode (description of the failure).
- Failure Effect (consequences of the failure).
- Severity rating (rating used form non-severe to unsafe failures).
- Causes.
- Occurrence rating (how likely/often the failure takes place).
- Current controls.
- Detection rating (how likely the failure is detected).
- Critical characteristic.
- Risk Priority Numbers (RPN). RPN is created from:
    - Severity
    - Occurrence
    - Detection ratings
    - Shows areas of creates concern for the failure.

FMEA is been used for: (Wikipedia (c) 2010)

- Development of system requirements that minimize the likelihood of failures.
- Development of methods to design and test systems to ensure that the failures have been eliminated.
- Evaluation of the requirements of the customer to ensure that those do not give rise to potential failures.
- Identification of certain design characteristics that contribute to failures, and minimize or eliminate those effects.
- Tracking and managing potential risks in the design. This helps avoid the same failures in future projects.
- Ensuring that any failure that could occur will not injure the customer or seriously impact a system.
- To produce world class quality products.

As seen above, the use of FMEA can bring great advantages for the design process. As a main advantage the FMEA data can be used for optimization of the created design parameters. In the suggested knowledge converting process from (Torres et al. 2010) is been created with the help of design specifications from QFD Matrix and the product structure tree.

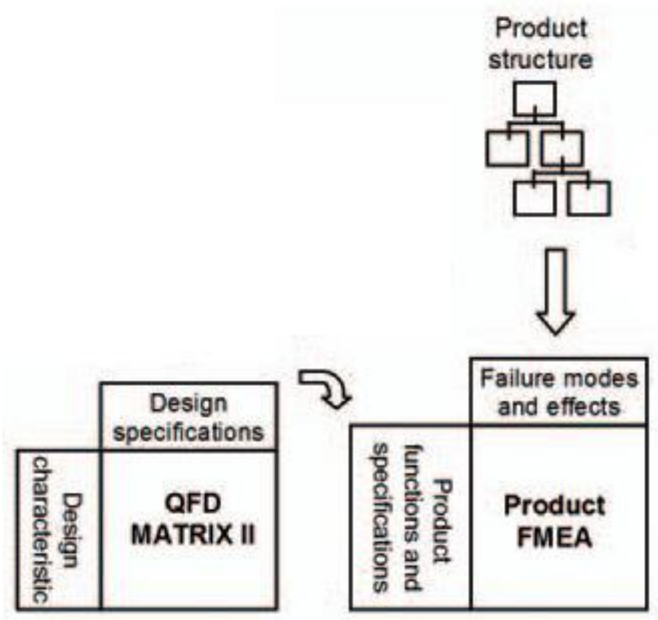


Figure 4-13 Product FMEA's connection to QFD Matrix and product structure (Torres et al. 2010)

7. Product structure

Product structure is often illustrated by a tree form. Structure shows relations between different items/parts of a product. Product structure is been created with the help of predefined product parameters and specifications.

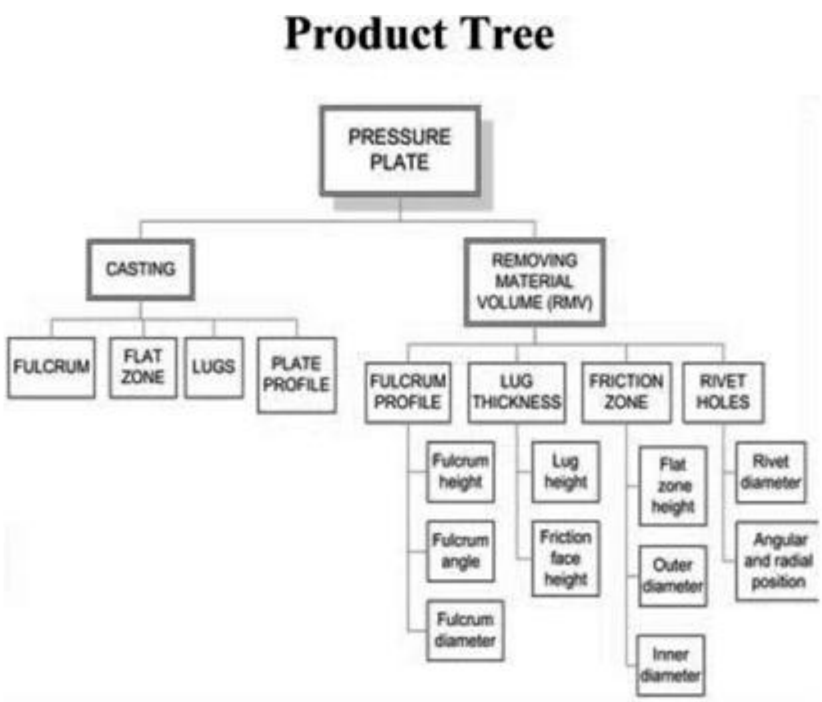


Figure 4-14 Example of a product structure of a pressure plate (Torres et al. 2010)

Created product structure can be used to help optimize the design parameters; also it offers valuable information for FMEA method (see above). More importantly for this thesis, the created product structure serves as a base for creation of formal and informal MOKA knowledge models (MOKA methodology introduced in the chapter 2.

8. Parameters optimization

The created design parameters will be then optimized by different methods. This will ensure that the final design will be as close as possible to the requirement given by definition of the design problem. (Torres et al. 2010) are suggesting use of Design of Experiments method for parameter optimization. Design of Experiments (DOE) is systematic approach to investigate systems or processes. A series of structured tests are designed. Then planned changes are made to the input variables of a process or system (in this case: design parameters to KBE system). With DOE there is a better possibility of testing the significance of the effects and the relevance of created models (Moresteam Toolbox 2011).

There are also other possible methods that could be used for parameter optimization. For example, Multi-disciplinary design optimization (MDO) is a field of engineering that uses optimization methods to solve design problems incorporating a number of disciplines. MDO methods include decomposition methods, approximation methods, different algorithms, response surface methodology, reliability-based optimization, and multi-objective optimization approaches.(Wikipedia (e) 2011)

9. MOKA ICARE forms, design rules and KBE system

Through all the methodologies described above, the final steps of converting the information to usable design knowledge can be done. With the help of product structure and other tables is possible to create MOKA knowledge models and ICARE forms. The MOKA techniques which were introduced in the chapter 2 won't be discussed more detailed anymore in here.

Using MOKA entity, constraint, and rule forms, the definition of the pre-form and the final design, their geometric and design parameters, and rules can be defined. Using KBE enhanced CAD module, the relations and formulas defined in the MOKA forms can be implemented. This will link design parameters and the geometric dimensions needed to generate the final design of the product.

Figure 4-15 Creation of MOKA models and ICARE forms.

For the integration of the different methods described above (Torres et al. 2010)) suggested a following framework (figure 4-16)

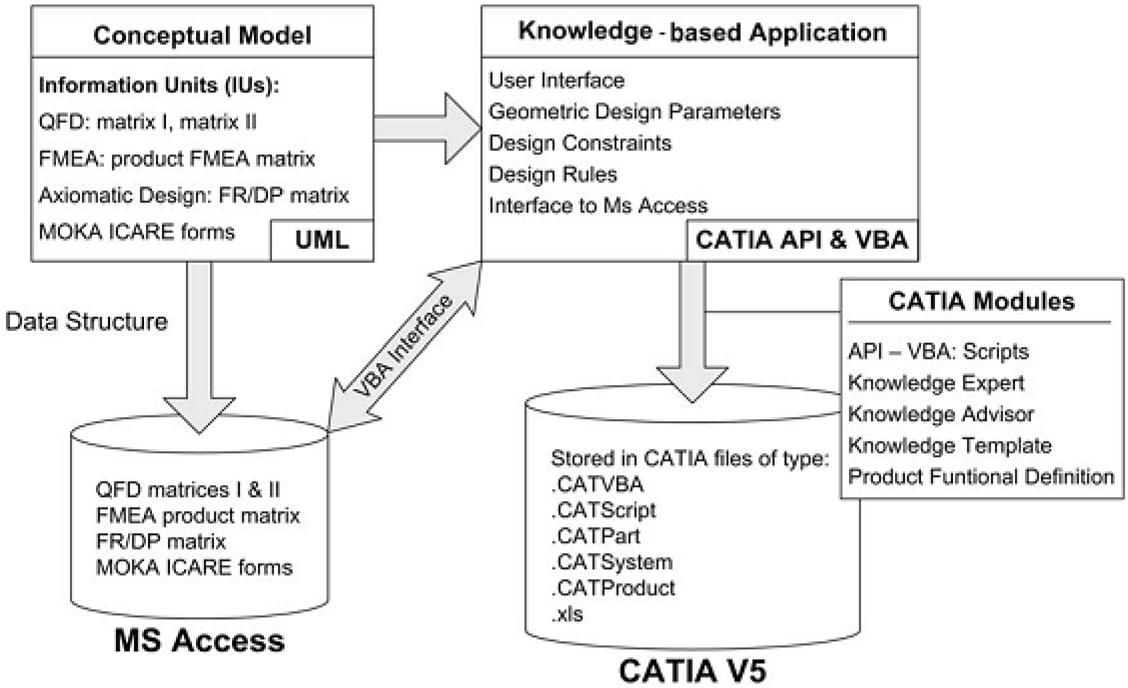


Figure 4-16 Framework for data transfer in the knowledge converting unit between design tools, database and KBE based CAD module. (Torres at al. 2010)

First the matrixes and forms were modeled to a conceptual model by using UML language. This model can be accessed from the knowledge based application, which is integrated with CAD, in order to create geometric design parameters, design constrains and design rules. In the case of CATIA V5 knowledge modules (Torres et al. 2010) suggest use of *MS Access* for the database system. CATIA V5 is based on Microsoft OLE technology, and integrating the CAD tool with a Microsoft database system *Access* achieves a continuous design information flow. For other KBE enhanced CAD modules some other database type can be a better choice.

After going through all the different techniques, even the complex design problems can be changed into corresponding design changes. The suggested framework seems like a lot of work. However, these techniques used for the process, are no new concepts. Many companies are using at least some of them already, if not all, in the product development process. Actual challenge for the framework would be just to combine them together under one platform and connected to the PLM system. This was also the platform requirements discussed in the chapter 4.2.2.

Other possibilities for design tools in the process

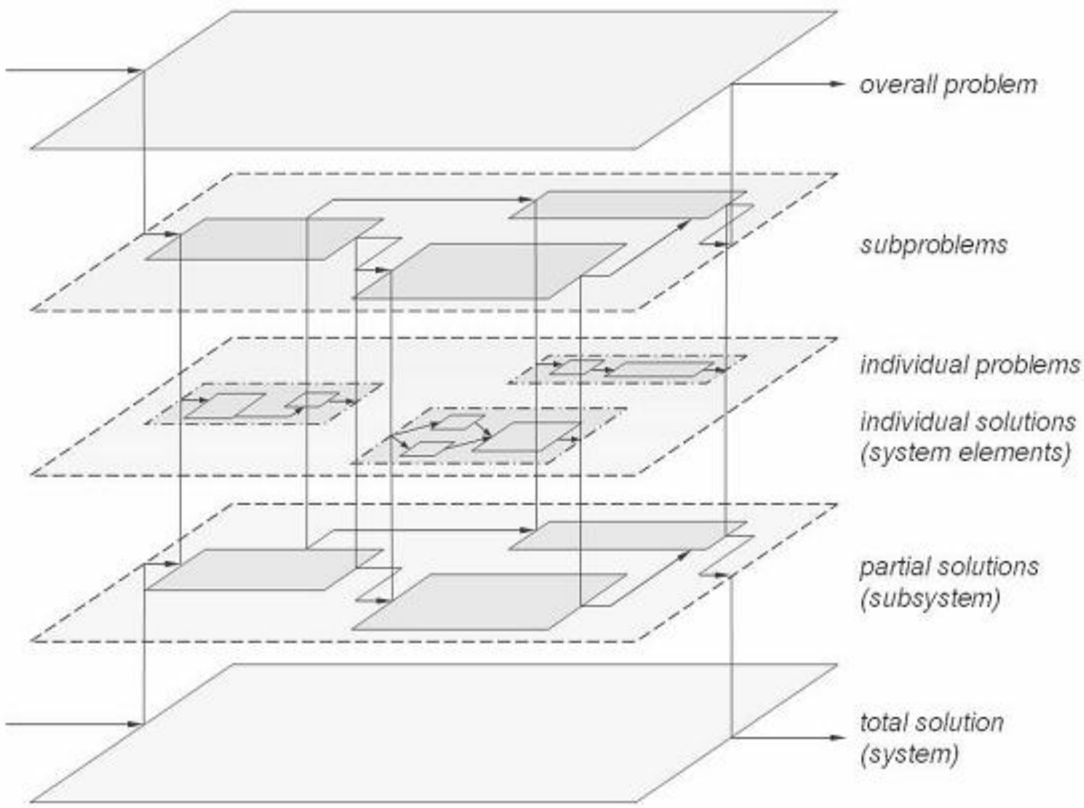
The suggested method above, offers good basis for knowledge converting in most cases. However, there are numerous other possible and helpful design tools that the framework doesn’t include, but are used by the companies. These tools could make the knowledge converting process even more effective. For example DSM method and breaking the design problem into smaller sub-problems could be definitely included into the process.

DSM – Methodology

For finding the dependencies between features and design parameters an engineer can use the DSM-method (Dependency Structure Method) where detailed list of dependencies between the parts and subassemblies are been gathered to a matrix. From the matrix can be seen which features are affecting each other, and this way the creation of the design rules and parameter changes for more than one feature can be found more easily. (Wikipedia (d) 2010)

Breaking the problem to smaller pieces

Analyzing information from the PLM often gives out the overall problem. Before the possible solutions can be found the problem needs to be often broken into sub problems. These individual problems can be then more accurately analyzed and the partial solutions for the sub-problems can be then found. If the whole scope of the problems is clear, the design engineer can find also the total solution for the overall problem (Danjou et al. 2008). This way every aspect of the possible reason and solutions for the problem will be analyzed. This process for structuring the problem in smaller subsystems can be seen on the figure 4-17.



4-17 Structuring the overall problem in order to find the total solution (Danjou et al. 2008)

Two tasks in design problem solving are: synthesis and analysis. Analysis has two main aspects: first, analysis on the overall layer which may be necessary to decide if certain requirements or constraints are fulfilled or if new requirements result from earlier problem solving steps. The second analysis task is related to the problem solving process: which problem solving step to do next, in which way to try to solve a selected problem, how to resolve a conflict, etc. design specific tasks can be characterized as: (Klein 2000)

- Select next sub problem to be solved.
- Analyze in which potential ways a selected sub problem can be solved.
- Decide in which way it will be tried to solve it actually.
- Resolve a conflict.
- Analyze correlations or potential trade–offs between requirements.
- Analyze new requirements resulting from a design description.
- Analyze if a certain requirement is fulfilled by a design description.

4.2.5 Workflow suggestion for knowledge converting unit

In this chapter a basic workflow suggestion for the knowledge converting unit and the ones responsible for it, will be represented. Workflow diagram is seen on the figure 4-18.

Figure 4-18 Work flow diagram for the knowledge converting unit

Beginning from the left corner above, the first task in the workflow is to access the information saved into PLM data repository. After that the engineer will analyze the information to find out what kind of design problem there. In the simplest cases, the required changes routine design tasks. In such cases the engineer will give the change orders directly as codified knowledge to the CAD (CATIA *Knowledgeware* in this case). As discussed, automated design by CAD could be used to make simple routine changes in the design. Different CAD systems use of course various methods and forms to represent the knowledge used in modeling, although the functions of the programs have often similarities. Automated design can be used, when the knowledge acquired isn't too complex, and the definition of the needed changes doesn't take longer than the advantages gained by using automated design. For CATIA *Knowledgeware* module these model representation codified knowledge forms are:

- Parameters
- Rules
- Formulas
- Features
- Checks
- Equations
- Scripts.

After the new combinations of new design parameters have been given to KBE enhanced CAD-system, and it has created the new versions, will the changes in design be checked and analyzed by a design engineer. The changes will be optimized so that the final improved design correlates with the required design problem described in the information. This iteration cycle (automated design →analyze→optimize→automated design) will be done until the best possible solution for the problem will be found. If the changes have accomplished the goals for improvement, can the new version of the product be approved and sent further to next step in its lifecycle (prototyping, tests, production, etc.).

Next possible way in the workflow is used in the cases where the design problem is little bit more complicated, but solution for the problem, doesn't necessary require use of different design tools. This is the case often when the problem only affects one single function of the product. After the engineer has analyzed the information, he will use previous experiences and design tools to define the possible solutions and to convert the information into formal design models and parameters. After the definition of new design parameters the next task is to choose if the changes can be made with the help of automated design, or should they be done by manual "normal" design process. Regardless of how the design is made, the next step in the workflow is the iteration cycle, where the design is again analyzed and optimized as long as the required improvements are been made, and the design can be approved and sent to the next phases.

Third way in the workflow is used when the design problem is so complex that the solution can't be found easily and more complex analyzing methods are required. In such cases, the information will be analyzed in product development teams and different design methodologies and tools will be used. This is the phase where knowledge converting unit is joined together with the design phase and the product development department of the company. The used methodologies include: innovation methods (brainstorming, TRIZ, etc.), design tools and methodologies (introduced in the chapter 4.2.4), product development systems (for example: systematic product development) and all the other possible methods used in the company inside product development. From this process, the acquired solution will again be again directed to either automated or manual design, and from there on further to the optimization process.

For more complex problems or requirements for improvement, the information from the PLM system won't provide an easy solution of the changes that need to be done. The more complex problems often will be solved also with more radical changes in the design, thus making the use of automated design less usable to create the changes. It could be used still to create some parts of the product, but more complex the design problem was, more likely it is that the solution requires also more radical changes.

In the cases where more than one kind what-if design was created, the best new version should be optimized in order to maximize the improvement. After the cases have been analyzed and it's been found out which case improved the product most, the designer should concentrate on it. Going through the design cycle once more would then result the best possible optimized outcome.

Often even the smaller changes require taking into consideration more than one of these aspects. This makes the tasks to find the proper changes more challenging, but with the help of automated design the engineer can afford to try out more different combinations of changes without the time used on the process getting too long. The possibility to create numerous what-if designs gives a great advantage to product development. In some case the changes are affecting so many functions that the limitations of automated design are reached, and the new design is easier to make in manual way, like in normal product design. Not all problems can be solved by giving new parameters to the CAD program, and sometimes the properties and features of the product need to be completely changed in order to get the wanted results. In these more complex design problems the use of knowledge based automated design can't be used. However, the availability of all possible information form products lifecycle analyzed by experienced engineers will definitely support the normal product development process.

In many design tasks, the main problem is not to find ”any” solution, but one which is close to optimal with respect to a given design problem. Typically, this includes trade–offs between conflicting requirements and constraints, etc. Requirements can be very different in nature: easy ones like attribute constraints or complex ones like functional or behavioral constraints, or global ones, like: user friendliness, easy maintenance, etc. Requirements are typically not complete at the beginning of a design task, although with a well defined information process all the different available information at the moment can be combined together. Design problem solving is closely related to decision making. These decisions can have very different contents: to introduce a new entity, to give a value to an attribute, to assign a structure to a functional requirement. (Klein 2000)

Going through the different product development and innovation methods in order to change a feedback or failure analyze to a usable design parameters can be a very time consuming and difficult process. However it exactly the kind of innovative work that an engineer can now do instead of the routine tasks that are now done by design automation. The time used for the whole product development lifecycle would remain the same, but with the whole knowledge converting process integrated to the normal product development specifications creating phase, would it make the process more effective. Even though the work wouldn't result to anything useful for the design automation, it would probably sometimes result for totally new innovative ideas that bring new features to the old product. This more dynamic and generic product development process can be resulted if the PLM system is effectively used.

4.3 Summary

First part of the chapter four described detailed examples available product information from different parts of the product lifecycle. Earlier product information coming to product development has been often mostly information coming from the usage phase of products life. Of course feedback from product's users is and should also be one of the most important aspects to consider in the product development process. However, it's highly important that also the other phases of product's life will be considered in best possible way. Purpose of the detailed examples of the available product information is to remind that PLM offers such a great system for gathering usable product information way beyond of the normal customer feedback. This doesn't of course concern just the KBE enhanced design process, but also product development in general. Additional information through effective use of different DFX concepts, tests and concurrent engineering is already used in many companies to find the development targets. However, a lot of available information of product throughout its lifecycle, for example from services, other shareholders than customers, disposal or subcontractors, is not taken into consideration as well as effective PLM system makes it possible. As seen, there a still great deal of possible sources of product knowledge could be identified through use of PLM. The second part of chapter four addressed the most important question of the thesis. What kind of general system is needed to use this various types of information in KBE system like described in the chapter two?

In summary the system where available product information is converted to design knowledge uses three main steps:

- Acquiring the knowledge
- Product data management through PLM/PDM system
- Converting the knowledge in an Expert system.

Within these steps information goes through different phases of KBE lifecycle, and is identified, captured, defined, and formalized. Finally acquired parameters from relevant knowledge models can be used to give directly design parameters to CAD. For different phases of lifecycle, different methods for data acquisition are used to identify firstly the find out which product information is useful and which not. Secondly the design problems and relevant design specifications and characteristics are defined. Incoming information is organized and managed through PLM/PDM system. Within the PLM-system an Expert system, will be used to convert information to design knowledge. Knowledge converting process consists of the use of different already individually well known and widely used design tools and methodologies (for example QFD and FMEA). These methods used in a sequence result a well defined product structure which can be easily changed to a knowledge models through MOKA methodology introduced in the chapter two. With this process basically any kind of product information from the different phases of lifecycle can be converted to design parameters used in the KBE enhanced CAD.

5 CONCLUSION

The main goal of this thesis was to find methods that will connect Knowledge Based Engineering process and information gathered throughout a products lifecycle together through Product Lifecycle Management. Even though, no actual product examples from the industries were used, the goal of the thesis can be considered successfully fulfilled, because it introduces a basic theoretical framework and methods that should be easily adapted in any branch of an industry or scale of products. KBE is not a new concept, but integrating it with PLM, which will likely gain even more popularity in the future, will increase the advantages gained by new or already used knowledge based design systems.

In the final part of thesis a solution to the research goal was found. Actual process where information will be changed to CAD usable design knowledge through PLM was introduced. Three required main tasks were found: acquiring the knowledge, managing it through PLM/PDM and a creation of a system that converts the knowledge to usable forms. Some of the means for knowledge acquisition were introduced, when the different information sources were defined. For information and data management an information flow was suggested, where information would be first gathered to PLM central data repository, and from there then further to the third task (knowledge converting system).

A suggestion to include the knowledge converting unit in the concept phase was made. This way the acquired and converted design knowledge would have a natural information flow to the design process with the other product specifications/requirements that are already been created in the phase. This kind of converting unit would have a platform that is well integrated with the CAD, and supervised by a knowledge engineer. In most simple cases of design changes the engineer can interact directly with the CAD. However, for more complex process where information isn’t easily converted to design knowledge, a process is suggested. In the process, the source of the knowledge (for example customer needs), will be converted to a design knowledge usable in KBE enhanced CAD through different design tools. First different design matrixes are been created, for example Quality Function Deployment (QFD). With the help of these matrixes, design functions, specifications and parameters can be made. After that, a product structure could be created and another already well known design tool, Failure Modes and Effects Analysis (FMEA) could be used. After the use of these tools and optimization of the results, the knowledge has been converted to such a form that it can be easily used to create informal, formal, and generative knowledge models through MOKA, as described in the first part of the thesis. The thesis suggests also a workflow model that can be used as a basic model that can be then adjusted for different company's needs.

As seen, the connection between Knowledge Based Engineering and Product Lifecycle Management was created by using tools and methods that are already widely used in the industries. With small adaptations in the use of FMEA, QFD, and other tools, their output could be used as a base to bring information to KBE. Inside KBE the MOKA methodology was founded out to be the great tool for creating the knowledge models from the available information. The basic MOKA process remains the same for different CAD systems; only in the last steps changes in the process were needed. In order to understand the whole process, one must have basic knowledge of different concepts around KBE and PLM. Thesis introduces both of these concepts on their own chapters.

In the beginning of the thesis theory of KBE and the concepts it includes were introduced. With the help of the chapter a company can examine and recognize the various types of knowledge that are been used in the company's own processes. After this, the possibilities to use knowledge models and the support of different knowledge systems in the iterative design process can be surveyed. When dealing with design process, not only the amount of available knowledge is important. Also the quality of the knowledge affects greatly to the means that can be used to control and use the knowledge in the design process. The increased complexity of product knowledge provides a challenges to human intelligence, even if known engineering processes and methodologies are been used to help the design process. For this problem offers use of KBE often solution.

In KBE a computer software are been used for acquiring and reusing the knowledge on the product on an integrated way. Knowledge will be represented with different types of knowledge models depending on the system used. These models can be interpreted by computers, and used by engineers to create new product requirements and designs. As engineering process is an iterative process, the use of KBE as a part of it, requires also a repetitive cycle for the knowledge management. First step in the KBE system process is the *identification* of the knowledge, where the possible knowledge sources, usually product information, will be gathered and analyzed. In *justify* step the KBE process gets approval from the management. Next the raw knowledge is *captured* and structured in to user friendly model. After that the structured knowledge is *formalized* into a consistent, neutral and formal model, which enables the reusability of the knowledge. When the knowledge is in the formal model it will be *packaged* to suit the used KBE system, and after that *activated* and used. The six phases result in formation of a KBE system and enable its supervision and controlling.

Advantages of a KBE can be thoroughly used when it is integrated with CAD programs. Use of design knowledge in parameterization, creating design rules, geometric features and functions in CAD will reduce time needed for routine tasks, saves time, reduces costs, increases automation and shortens the overall product development cycle. When less time is used for routine design tasks, more time can be used for creative and innovative design work. One of the reasons that the costs of product development process will be lower is that the knowledge will be available already in the beginning of the process where the number of decisions is highest. This will result for less costly changes later in the process, because fewer changes in the design are needed.

There are however limitations where the KBE can be used. Complexity of engineering knowledge together with large diversity of special engineering tools provides a huge challenge for KBE techniques. The complexity and diversity of engineering knowledge requires a methodology for knowledge modeling that the different aspects and relations of the knowledge can be described. For many cases the process of defining the KBE processes requires too much work that it would be effective. Usually design problems are simple enough that they can be defined without use of KBE.

In this thesis, the knowledge module of CATIA CAD program was used to demonstrate what kind of methodology is needed when knowledge or product information is brought to knowledge based CAD system. With the help of different tools inside the knowledge module even the most complex design problems can be solved and savings are been made. For CATIA a MOKA methodology can be used to capture, formalize and package the knowledge. First in the methodology informal and formal are created, and product knowledge is represented in a structured way. These knowledge models are however not yet fully usable CAD programs. Depending on the used CAD a generative model needs to be created from the created formal knowledge model. This thesis shows how this kind of generative knowledge model is made for CATIA knowledge module.

Second part of the thesis was concentrated on PLM. PLM is a process where products entire life, its lifecycle, is been managed with a certain system. Like other processes such as Product Data Management (PDM), also KBE is a part much wider concept (PLM) inside the company. Product information is gathered throughout the products different life phases (conception, design, manufacturing, use, retirement, etc.). From this huge variety of information, the possibly useful part can be identified, and brought to a KBE system, where it will further processed and changed to design knowledge. This thesis gives examples of the huge variety of concepts, people, processes, tools, methods, technology, information and platforms that are included in the lifecycle of a product. Descriptions of the different phases of a lifecycle in this thesis are meant to be used as a help and guideline when defining the company’s own PLM and possible KBE processes. One chapter of the thesis is also been used to describe PDM, because its importance as data management tool in the whole information-knowledge transferring process. In chapter four every phase of the lifecycle was more thoroughly examined and actual examples of the product information gathered throughout product life were made. These examples can be again used as a guideline and help, when defining company‘s possible information sources.

When considering all these aspects, the connection between KBE and PLM could be made with rather moderate changes in the company's processes, if one decides to adapt the technologies. The bigger question is rather if the adaption of the knowledge based design process is needed in the particular case. In automotive and aerial industries the technologies have been proved to be effective when considering the cost and time savings. However, for less simple products and cases, the decision to adapt knowledge based design process isn't necessary always the most ideal. One must also consider the limitations of KBE, and the possible cost/reward ratio when taking full advantages of systems like PLM.

This thesis was very theory based, due the lack of possible case where the suggested methods could be tested. Also, a case where the theories would be put to practice would require time and effort for another master thesis. However, hopefully in the future, there would be a possible case where these suggested methods could be put into reality and the advantages of connection between KBE and PLM could be seen.

REFERENCES

Abramovici, M., 2007. Future Trends in Product Lifecycle Management (PLM). In *The Future of Product Development*. pp. 665-674. Available at: http://dx.doi.org/10.1007/978-3-540-69820-3_64 [Accessed December 15, 2010].

Alcyon, Alcyon Engineering: Need for KBE. Available at: http://www.alcyon.co.in/kbe_need.html [Accessed November 23, 2009].

CadFamily, 2010. Using the Knowledge Expert Language (KWE). Available at: http://ol.cadfamily.com/CATIA/English/online/kwxug_C2/kwxugat0018.htm [Accessed February 17, 2011].

Citius, 2011. Product Configurator Software. Available at: http://www.citiuscorporation.com/kbmax/product-configurator.html [Accessed June 15, 2011].

Danjou, S., Lupa, N. & Koehler, P., 2008. Approach for Automated Product Modeling Using Knowledge-Based Design Features. *Computer-Aided Design & Applications*, 5(5), p.622–629.

Dassault Systemes - a, 2007. Knowledge Advisor in a Nutshell. Available at: http://ps-2.kev009.com:8081/CATIA-B18/CATIAfr_C2/kwrugCATIAfrs.htm [Accessed February 17, 2011].

Dassault Systemes - b, 2010. Product synthesis: CATIA - Knowledge Expert. Available at: http://www.catia.cz/fileadmin/Pictures_Menu/Catia/Catia_V5/Product_Synthesis/pdf/KWE.pdf.

Dassault Systemes - c, 2010. V6 Portfolio - Dassault Systèmes. Available at: http://www.3ds.com/products/catia/portfolio/catia-v6/v6-portfolio/d/virtual-design/s/knowledge/?cHash=6cdee0cfd454b2b4bbd935030f3971cf [Accessed December 15, 2010].

Eigner, M. & Stelzer, R., 2009. *Product Lifecycle Management*, Berlin, Heidelberg: Springer Berlin Heidelberg. Available at: http://www.springerlink.com/content/p238k6/ [Accessed December 11, 2009].

Engelman, M., 2005. Fluent NEWS - Summer 2005 - How CAE fits into the PLM World. Available at: http://www.fluent.com/about/news/newsletters/05v14i2/a2.htm [Accessed December 16, 2010].

Fan, I.-S. & Bermell-Garciá, P., 2008. International Standard Development for Knowledge Based Engineering Services for Product Lifecycle Management. *Concurrent Engineering*, 16(4), p.271-277. Available at: [Accessed December 8, 2009].

Freeformer, 2006. PLM. Available at: http://en.wikipedia.org/wiki/File:Plm1.png [Accessed July 5, 2011].

Genworks, 2011. Genworks International: Knowledge-based Engineering and Beyond. Available at: http://www.genworks.com/sessions/258d1a35d33/index.html [Accessed June 15, 2011].

Klein, R., 2000. Knowledge Modelling in Design - the MOKA framework. In International AI in Design conference. Worcester.

Krause, F.-L. ed., 2007. *The Future of Product Development*, Berlin, Heidelberg: Springer Berlin Heidelberg. Available at: http://www.springerlink.com/content/978-3-540-69819-7/#section=321445&page=1&locus=52 [Accessed December 15, 2010].

Kusiak, A., 1993. *Concurrent engineering : automation, tools, and techniques*, New York: Wiley.

Lillehagen, F., Why is Industry Dissatisfied with PLM? « Active Knowledge Modeling. Available at: http://activeknowledgemodeling.com/2009/03/26/why-is-industry-dissatisfied-with-plm/ [Accessed December 16, 2010].

Mizuno, S., 1994. *QFD, the customer-driven approach to quality planning and deployment*, Tokyo Japan: Asian Productivity Organization.

MOKA Consortium, 2000. MOKA: A Framework for structuring and representing engineering knowledge. Available at: http://web1.eng.coventry.ac.uk/moka/default.htm [Accessed March 8, 2011].

Moresteam Toolbox, 2011. Design of Experiments (DOE). Available at: http://www.moresteam.com/toolbox/t408.cfm [Accessed June 15, 2011].

Nimtoth, 2011. NIMTOTH - Kadviser. Available at: http://www.nimtoth.com/kadviser.html [Accessed June 15, 2011].

Pahl, G. & Peitz, W., 2007. *Engineering design : a systematic approach* 3rd ed., London: Springer.

PTC, 2011. PTC - PLM-Software – Software für Produktlebenszyklus-Management. Available at: http://www.ptc.com/ [Accessed June 15, 2011].

Pugliese, D., Colombo, G. & Spurio, M., 2007. About the integration between KBE and PLM. In *Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses*. pp. 131-136. Available at: http://dx.doi.org/10.1007/978-1-84628-935-4_23 [Accessed December 9, 2009].

Ramón-Raygoza, E.D., Guerra-Zubiaga, D.A. & Tomovic, M., 2008. Methodology to Support a Collaborative DFX Process with Integration of PDM and Expert System Tools. *Advanced Materials Research*, 44-46, p.381-388. Available at: [Accessed January 8, 2011].

Rennet, A., 2002. *The Use of CATIA V5 KnowledgeWare in the Design of Forming Dies*,

Saaksvuori, A. & Immonen, A., 2008. *Product Lifecycle Management*, Berlin, Heidelberg: Springer Berlin Heidelberg. Available at: http://www.springerlink.com/content/978-3-540-78173-8/#section=145231&page=4&locus=77 [Accessed October 17, 2010].

Siemens, 2011. Open Knowledge Automation: Siemens PLM Software. Available at: http://www.plm.automation.siemens.com/en_us/products/nx/design/mechanical/open_knowledge_automation.shtml [Accessed June 15, 2011].

Simpson, J. & Weiner, E., 1989. *The Oxford English Dictionary (20 Volume Set)* 2nd ed., Oxford University Press, USA.

SIXMAXIM, 2011. SIGMAXIM, Inc. - Productivity Solutions for Pro/ENGINEER. Available at: http://www.sigmaxim.com/ [Accessed June 15, 2011].

Skarka, W., 2007. Application of MOKA methodology in generative model creation using CATIA. *Engineering Applications of Artificial Intelligence*, 20(5), p.677-690. Available at: [Accessed November 27, 2009].

Solidworks, 2011. 3D CAD Design Software SolidWorks. Available at: http://www.solidworks.com/ [Accessed June 15, 2011].

Stark, J., 2005. *Product lifecycle management: 21st century paradigm for product realisation*, Birkhäuser.

Stokes, M. & MOKA Consortium., 2001. *Managing engineering knowledge : MOKA: methodology for knowledge based engineering applications*, New York: ASME Press.

Sudarsan, R. et al., 2005. A product information modeling framework for product lifecycle management. *Computer-Aided Design*, 37(13), p.1399-1411. Available at: [Accessed November 25, 2010].

Suh, N., 2001. *Axiomatic design : advances and applications*, New York: Oxford University Press.

Technosoft, 2011. TechnoSoft Inc: Home. Available at: http://www.technosoft.com/ [Accessed June 15, 2011].

Tecneos, 2011. tecneos software - engineering, Variantenkonfigurator, CAD - automation. Available at: http://www.tecneos.de/ [Accessed June 15, 2011].

Torres, V.H. et al., 2010. Integration of Design Tools and Knowledge Capture into a CAD System: A Case Study. Available at: http://cer.sagepub.com/content/18/4/311.full.pdf+html [Accessed March 8, 2011].

Ulrich, K. & Eppinger, S.D., 2004. *Product design and development* 3rd ed., Boston: McGraw-Hill/Irwin.

VISIONKBE, 2011. VISIONKBE Home. Available at: http://www.visionkbe.com/ [Accessed June 15, 2011].

Wikipedia (a), 2010. Knowledge-based engineering - Wikipedia, the free encyclopedia. Available at: http://en.wikipedia.org/wiki/Knowledge-based_engineering [Accessed March 10, 2011].

Wikipedia (b), 2010. Axiomatic design - Wikipedia, the free encyclopedia. Available at: http://en.wikipedia.org/wiki/Axiomatic_design [Accessed March 9, 2011].

Wikipedia (c), 2010. Failure mode and effects analysis - Wikipedia, the free encyclopedia. Available at: http://en.wikipedia.org/wiki/Failure_mode_and_effects_analysis#cite_ref-0 [Accessed March 9, 2011].

Wikipedia (d), 2010. Design structure matrix - Wikipedia, the free encyclopedia. Available at: http://en.wikipedia.org/wiki/Dependency_Structure_Matrix [Accessed March 14, 2011].

Wikipedia (e), 2011. Multidisciplinary design optimization. Available at: http://en.wikipedia.org/wiki/Multidisciplinary_design_optimization [Accessed June 15, 2011].

Yang, K., 2009. *Design for six sigma : a roadmap for product development* 2nd ed., New York: McGraw-Hill.