UNIVERSITY OF VAASA

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PRODUCT LIFECYCLE MANAGEMENT IN DEGREE LEVEL TEACHING WITH TEAMCENTER PLM SOFTWARE

Master´s Thesis in

Industrial Management

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ABBREVIATIONS

ALM	Application Lifecycle Management
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CEO	Chief Executive Officer
CMMI	Capability Maturity Model Integration
DXF	Drawing Exchange Format
EDM	Engineering Data Management
ERP	Enterprise Resource Planning
FDS	Functional Design Specification
IoT	Internet of Things
IS	Information System
MCAD	Mechanical Computer Aided Design
MBD	Model Based Definition
MES	Manufacturing Execution Management
MOM	Manufacturing Operations Management
NPI	New Product Development
OTD	Order-To-Delivery
PDM	Product Data Management
PEID	Product Embedded Information Device
PLM	Product Lifecycle Management
ROA	Return of Assets
ROI	Return of Invests
STEP	Standardized Data Exchange Format
STL	Stereolithography
VAMK	Vaasa University of Applied Sciences

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TIIVISTELMÄ

Tuotteen elinkaaren hallinnan käyttö Suomalaisessa valmistavassa teollisuudessa on lisääntynyt viime vuosina merkittävästi. Käytön laajentumisesta huolimatta Suomen korkeakoulut eivät ole vielä täysin ottaneet käyttöön ohjelmistopohjaista käytännön opetusta. Yleinen tilanne on, että tuotteen elinkaaren hallintaa opetataan vain teoria tasolla, ja vaikka tuotetiedonhallinta ohjelmisto olisikin käyttöönotettu, se toimii pääasiassa datan tallennuspaikkana. Tuotteen elinkaaren hallinta ohjelmiston opetuksen puute vaikuttaa negatiivisesti valmistuvien opiskelijoiden PLM osaamiseen. PLM järjestelmän etuja ovat lisääntynyt kommunikaatio, kontrolloidut prosessit ja yhteinen tiedonlähde. Tämä tutkimus keskittyy löytämään merkityksellisimmät fokus alueet tuotteen elinkaaren hallinnan teoria opetuksessa ja käytännön opetuksessa. Tulokset perustuvat aineistoon joka on kerätty Suomalaisen valmistavan teollisuuden PLM asiantuntijoilta.

Tämä tutkimus keskittyy merkittävimpiin ja tärkeimpiin PLM teoria alueisiin, mutta myös Suomen valmistavassa teollisuudessa käytetyimpiin PLM järjestelmän aplikaatioihin, prosesseihin ja käyttötapauksiin. Teamcenter PLM järjestelmä käyttöönotetaan ja konfiguroidaan tukemaan korkeakoulu opetusta. Tutkimuksessa selvitetään tämän hetkinen valmistuvien opiskelijoiden tietämys ja annetaan suosituksia kuinka PLM opetus tulisi järjestää Suomen korkeakouluissa. Sekä teoria opetus, että käytännön opetus on huomioitu tukimuksessa. Tärkeimmät Teamcenter PLM järjestelmän ominaisuudet käyttöönotetaan ja konfiguroidaan opetuksen tueksi. Järjestelmän vaatimukset perustuvat 35:een Suomen valmistavassa teollisuudessa toimivan yrityksen vaatimuksiin. Tärkeimmät Teamcenter PLM ohjelmiston ominaisuudet, prosessit ja käyttötapaukset huomioidaan tutkimuksessa. Teoreettisen opetuksen tärkeimmät osa-alueet selvitetään kyselyn avulla Suomen valmistavan teollisuuden PLM asiantuntijoilta. Tutkimuksessa hyödynnetään Design Science Research metodia. Tutkimuksen lähtökohtana on kirjallisuus analyysi, joka antaa taustatietoa tukimukselle. Tässä tutkimuksessa annetaan suosituksia PLM opetuksen järjestämisestä Suomen korkeakouluissa, sekä suositellaan Teamcenter PLM ohjelmiston käyttöönottoa ja konfigurointia tukemaan tuotteen elinkaaren hallinnan opetusta.

AVAINSANAT: Tuotteen elinkaaren hallinta, Teamcenter PLM ohjelmisto, korkeakoulu opetus

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ABSTRACT

Despite the situation that product lifecycle management is heavily used in Finnish manufacturing industry, some Finnish educational institutions have not implemented practical PLM system functionalities into educational program. Common situation among educational institutions is that PLM training is mainly theoretical. Even when PLM software is implemented it is mainly used as data storage system. However, PLM system is much more than data storage. The lack of effective product lifecycle management training environment influences negatively to graduated students PLM skills. Increased communication, control of processes and single source of information are main benefits of a PLM system. This research studies the most relevant focus areas in Product lifecycle Management theoretical and practical teaching based on the requirements gathered from Finnish Manufacturing Industry.

This research is focusing on the most important theoretical PLM focus areas, but also the most common practical PLM applications, processes and use cases in Finnish manufacturing industry. Based on the requirements of Finnish Manufacturing Industry, Teamcenter PLM software is implemented and configured to support practical degree level teaching. Research clarifies the current PLM knowledge of graduated students and gives recommendations about degree level PLM teaching arrangements. Both theoretical and practical teaching are considered. Based on the findings gathered from 35 Finnish manufacturing companies, relevant PLM use cases, processes and application are implemented to support Product Lifecycle management education with Teamcenter PLM software. Furthermore, the importance of different theoretical PLM topics is clarified based on the opinions of PLM professionals. This study utilizes design science research method to gather empirical data from different manufacturing companies. The foundation of PLM research presented in literature review provides the framework for this study. These studies provide the background information about PLM and how the implementation of PLM system can provide business benefits. This research proposes configured Teamcenter PLM environment for Finnish educational institutions to serve as a foundation of PLM system. Furthermore, the suggested PLM artifact is demonstrated, evaluated and communicated to specified target audience.

KEYWORDS: Product lifecycle management, Teamcenter PLM software, Degree Level Teaching

1. INTRODUCTION

During the known history there has been events which are nowadays called as industrial revolutions. Utilization of steam power can be seen as first revolution, electricity as second and computers the third one. Nowadays there is discussion about Industry 4.0 and digitalization, which can be seen as fourth industrial revolution. Product development and manufacturing will change again, like happened in earlier industrial revolutions.

Product Lifecycle management (PLM) can be seen as information driven system which aim is to control all aspects of product from beginning of lifecycle to the end of lifecycle. PLM system refers to software which enables creating, modifying, accessing and manipulating product related information. PLM system ability is to gather fragmented product information into integrated PLM environment. System can also be seen as integration of business processes to manage product through the lifecycle. (Grieves 2006: 32-33)

PLM systems serves as company information backbone. (Hadaya & Marchildon 2012: 559-560) Product lifecycle management (PLM) as concept is rather new. The concept wasn´t introduced until the late 1980s. Current approach towards digital information in context of PLM was introduced in the beginning of 21st century. Moreover, the popularity of PLM system was not raised until 21st century. (Fielding, McCardle, Eynard & Hartman 2014: 123-125) At the moment there is still confusion between terms PLM approach, PLM system and Closed Loop PLM system. (Hadaya et al. 2012: 559-560)

1.1 Research gap, problems, objectives and limitations

PLM approach requires PLM system where information flows effectively inside and outside the organization. Original goal in PLM systems was to move from isolated set of tools and information containers to one interactive system which can communicate with other systems as shared platform. Because of this information amount and flow what PLM system contains, some institutions, universities and PLM vendors see PLM systems as

next leading system among enterprise software. (Hadaya et al. 2012: 562) Furthermore, there has been interests to move towards more standardized PLM systems. (Alemanni, Destefanis & Vezzetti 2010: 3)

Perhaps because of the short history of Product Lifecycle Management, general information about product lifecycle management is rather limited. General concepts, processes and applications are presented in existing literature. However, information about specific PLM software actions, use cases, processes and configuration are rather limited. Furthermore, the most common Teamcenter PLM system high level business applications, use cases and processes in Finnish Manufacturing industry are unknown.

Government decree about university of applied sciences (1129/2014) 4§ is stating that aim of the studies is that graduated student has extensive knowledge and practical skills to operate in working life. In case of PLM system, many companies in Finland are already using PLM system in their daily activities. Recently, there has been raising interest in Finnish academic institutions towards the teaching of PLM systems. However, PLM as a concept is rather extensive and most common PLM setup in Finnish Manufacturing industry is currently unknown. Degree level studies should focus to the most relevant theoretical PLM topics, but also most common practical PLM system applications, use cases and processes. Therefore, this study aims to clarify the theoretical and practical PLM focus areas and develop an artifact to support degree level PLM teaching with Teamcenter PLM software. Research aims to find answers for following research questions.

1. What is the current PLM knowledge of graduated students and how teaching should be arranged in degree level studies?
2. What are the most common Teamcenter PLM high level solution areas?
3. What are the most common Teamcenter PLM software applications, use cases, and processes in the most common Teamcenter High Level solution areas?
4. What PLM and digital manufacturing features are planned to be implemented or piloted among Finnish Manufacturing industry in next five years.

5. What should be the theoretical and practical PLM teaching focus in degree level with Teamcenter PLM Software.

Answers to these research questions provide specification to Teamcenter PLM system development. Based on the answers of research questions following actions take place.

- Specified Teamcenter PLM system installation and configuration to support PLM teaching in degree level.
- Documentation and Demonstration of installed and configured Teamcenter PLM environment. Detailed instructions are created in text and video format.

Installed and Configured Teamcenter PLM System can be used in degree level teaching according the system demonstration.

Research questions 1-5 must be answered before proceeding the installation, configuration and demonstration actions. It is important to examine and understand the current knowledge of graduated students, but also Teamcenter PLM software applications, use cases and processes in Finnish Manufacturing industry in order to create Teamcenter PLM software configuration for degree level teaching. Aim of this study is to find relevant PLM approach for degree level teaching and develop PLM training environment by using Teamcenter PLM software. Overall idea is presented in Figure 1.
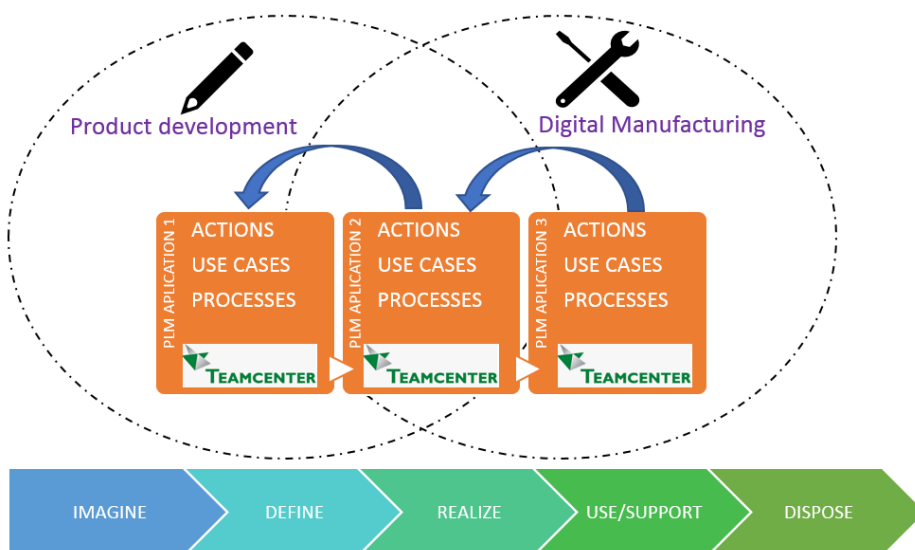
Figure 1. Overall research territory.

Product lifecycle management can be used in many different industries like Energy & Utilities, Consumer Products & Retail, Automotive & Transportation and Insurance & Financial. This research will focus mainly to Finnish manufacturing Industry. Furthermore, focus is in product development and digital manufacturing concept. Other concepts like enterprise resource planning are in minor role.

The available amount of Teamcenter product Lifecycle management software applications, use cases and processes is considerable. Aim of this study is not to cover all the possibilities of the software. This study is concentrating the most common applications, use cases and processes used in Finnish Manufacturing Industry. Furthermore, future interests and plans in extension of Teamcenter PLM software solutions are also considered. Siemens PLM software digital industry solutions product portfolio is rather extensive. Even though some of the digital industry solutions are integrated to Teamcenter PLM, those solutions are mostly excluded from this research.

1.2   Research methods

Saunders is presenting the research approach by using different layers in a circle. Layers listed from the outer perimeter are called Philosophies, Approaches, Strategies, Choices, Time Horizons and Techniques or procedures. Saunders is describing these layers as *"research onion"* which is illustrated in Figure 2. Each layer must be considered when planning the research. (Saunders, Lewis & Thornhill 2009: 106-107)
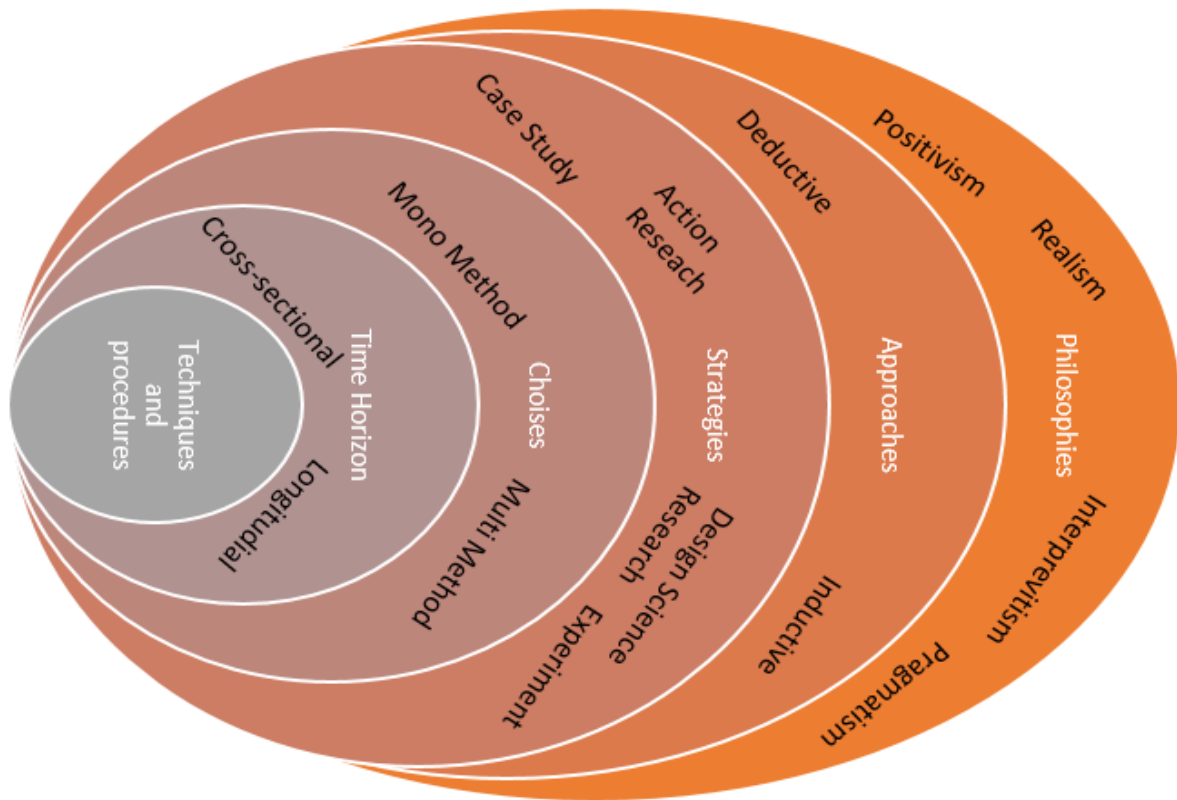
Figure 2. Research context according Saunders et al.

Philosophical mindset for this study this pragmatic. Product lifecycle management system with PLM software is definitely a complex setup and due to company specific configurations and customizations it is definitely difficult create general PLM system configuration with general use cases and processes. However, it is difficult to accept the assumption that companies have totally different product data, processes, use cases and solutions when they all operation in context of manufacturing industry. At least some level of PLM system generalization and standardization should be possible to do. Therefore, in the beginning of the research mindset is pragmatic.

The approach for this study is inductive. First step will be secondary data collection and analyze. Second step is primary data collection and analyze. Third step is to define and develop PLM applications, use cases and processes in Teamcenter PLM system. Design science research method has been selected as a research strategy. Hevners design science research context with Peffers practical design science research method process will be

followed precisely. Design science research method enables that research questions will be answered. Data collection will be done by using mixed method. Both qualitative and quantitative data will be gathered and analyzed. Secondary data with cross-sectional time horizon will be used. Data is collected and analyzed to present certain snapshot of time.

2.1   Vaasa University of Applied Sciences

Research is done in co-operation with Vaasa University of Applied Sciences (VAMK). VAMK is Finnish university of applied sciences which provides mainly Bachelor´s level degrees. Health care, social services, technology and international business are main educational areas in VAMK. VAMK vision is "*to be an energetic, attractive, and international learning and research community, which operates in close professional partnership with the region's working life supporting the region's success*" Aim is to respond the needs of working life by training experts for companies. VAMK has also a teaching laboratory which provides a platform for students to learn latest technology. VAMK combines theory and practice in education with close co-operation with working life. Furthermore, co-operation between VAMK and international educational institutions provides internationality to Vaasa campus. (Vaasa University of Applied Sciences 2019)

2.2   Siemens PLM software and industrial product portfolio

Siemens PLM software is a global vendor for digital industry solutions. According Siemens PLM software CEO Tony Hemmelgarn the aim is to "*help companies deliver solutions faster to solve their business problems in ways that otherwise could not have been done before.*" Siemens PLM software product portfolio supports the ongoing digital transformation era. Siemens PLM software product lines include multiple software solutions. Siemens PLM software products are NX, Solid Edge, Mindsphere, Tecnomatix, TIA portal, Simcenter 3D, MES/MOM Mentor Graphics, Polarion and Teamcenter PLM. Teamcenter PLM software serves as backbone for Siemens industry solutions like presented in Picture 1. NX and Solid Edge are Computer aided 3D design software which include also Computer aided Manufacturing (CAM) and Computer aided

engineering (CAE) solutions. Mindsphere is cloud based IoT solution which can be used in Closed loop PLM by connecting e.g. machines, systems, plants and product into internet. Tecnomatix is Digital Manufacturing solution which includes e.g. manufacturing process planning, plant simulation and plant layout design. Tia portal allows to connect machines and processes to software. Simcenter 3D provides tools to manage simulation data which can be used predict product performance. Manufacturing operation management (MOM) is used to control manufacturing process. Solution includes planning and scheduling tools and manufacturing execution management tools. Mentor Graphics provides different tools for electrical design automation management. Polarion ALM is solution which provides opportunity to define, build, test and manage complex software systems. Teamcenter is adaptable Product lifecycle management (PLM) solution. (Siemens PLM 2018). Siemens PLM product portfolio is presented in Figure 3.
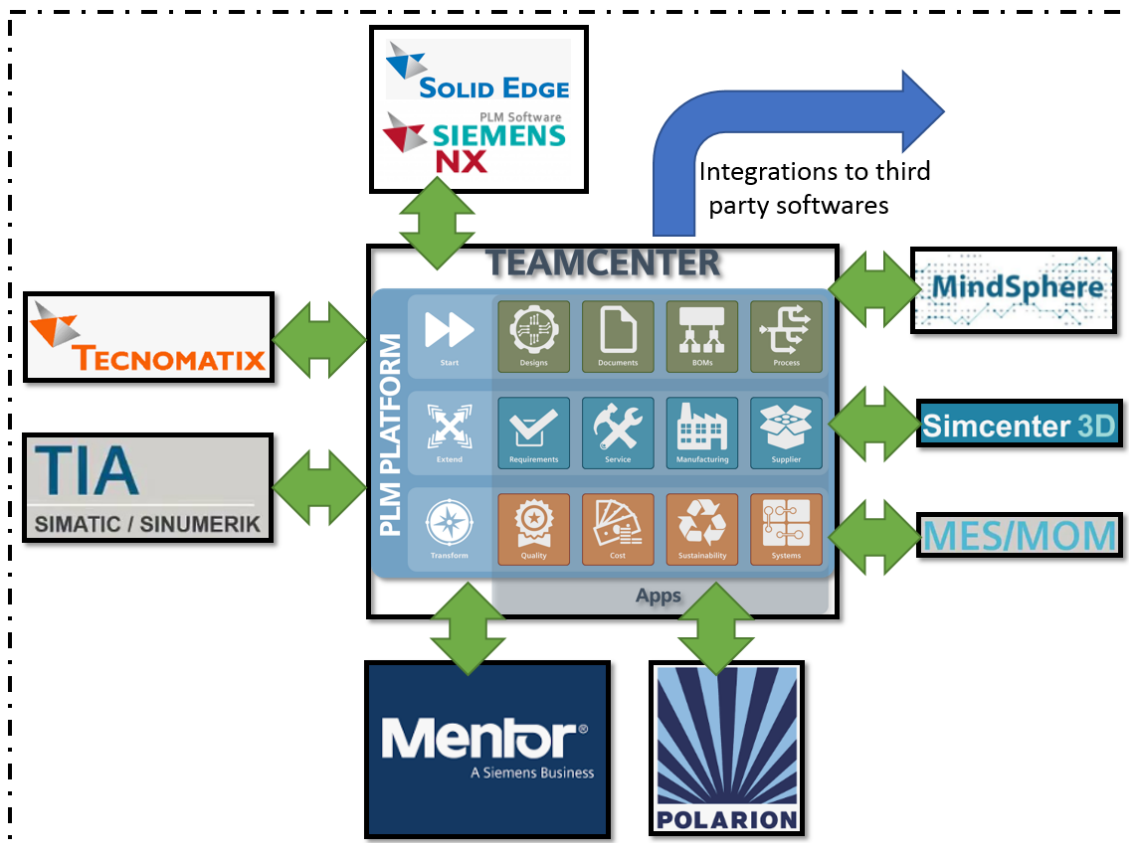
Figure 3. Siemens PLM software product portfolio.

2.3   PLM teaching as research topic

Need for PLM education has also been noticed among researchers. Fielding, McCardle & Eynard has discussed about PLM education in the article *"Product lifecycle management in design and engineering education: International perspectives"*. Paper is presenting PLM educational perspectives from USA and France. PLM education quality has raised since PLM vendors started to co-operate with universities in order to provide required skills and practices to students. Furthermore, PLM education conferences has been arranged in co-operation with PLM vendors and universities. Industry has had a possibility to discuss with academic representatives about the content of PLM education (Fielding et al. 2014: 123-127).

However, is has been recognized that PLM is relatively new topic in education and has not been integrated heavily with design/engineering education. Therefore, existing gap between needed skill and available workforce has been recognized. The implementation of PLM software in education provides needed skill for future professional. (Fielding et al. 2014: 123-127)

Holistic approach in product lifecycle management education is needed. Furthermore, students must know the benefits and reasons of PLM approach. Adoption of current PLM processes and practices is not enough. PLM strategy must also be considered in education. Suitable pedagogy and approach to education as well as link between knowledge and real-life projects is needed. Recommendation is to have broad and deep PLM learning environment to train wide range of skills rather than specializing to one single area. There are five different areas where special attention should be paid. Furthermore, holistic product development should be educated by including four disciplines. These areas are presented in Table 1. (Fielding et al. 2014: 123-128)

Table 1. PLM focus areas.

NPD Focus area in PLM	Explanation
"New composite areas"	Mixing areas and creating new disciplines based on industry needs
"New Concentrations"	Adopting Holistic approach towards design by covering whole product lifecycle
"New Inter-functional areas"	Linking design, engineering and manufacturing
"Inter-college collaborations"	Understanding both business aspect and engineering aspect in PLM
"New colleges and universities"	Create new higher education establishment, to develop specialists

Furthermore, approaches presented in table 2 can be used to support the education in these areas. (Fielding et al. 2014: 127)

Table 2. PLM educational approaches.

Approach to support	Explanation
"Integrating Software tools"	Introduction of PLM tools
"Interactive projects"	Real-life PLM projects
"Specialty Rotations and dual technical tracks"	Collaboration between universities and disciplines
"Synchronizing graduate-undergraduate programmes"	Knowledge sharing among groups

First PLM MSc programme was developed in France. Programme is developed based on lifecycle model presented in Figure 5. Aim of the programme was to respond the need of PLM education addressed by industry. Programme has been developed based on feedback from industry. High employability rate has served as a proof that programme has been successful. However, future vision is to introduce PLM in all Product Development

studies. There is a need to educate PLM to wider group of students. (Fielding et al. 2014: 128-130)

Conclusion of the research paper states that there is a clear need for practical PLM education. Education must provide the skills which are needed in Industry. Software tools for education are also needed, and one possibility is to use virtual platforms to save money and time. Education should concentrate on good practices of PLM. Recommendation is to provide holistic PLM education to provide relevant skills to students. Close co-operation between industry and educational industry is needed to respond industry demands. (Fielding et al. 2014: 130-132)

Munenori Kakehi, Tetsuo Yamada, Ichie Watanabe have released paper about PLM education by using e-learning. They suggest three areas to include into PLM learning. First area is Information flow and business processes, second area work content in each business process and third area is the ability to apply these PLM skills into business. (Kakehi, yamada, & Watanae 2009: 489-482)

2.4   Structure of the study

This thesis studies product lifecycle management teaching in degree level studies. Current knowledge and skills of graduated students are clarified based on opinions of PLM professionals working in Finnish manufacturing industry. Furthermore, opinions about PLM education arrangements are also asked from PLM professionals. Both PLM theoretical education and practical software education are considered in this research. Theoretical and practical PLM teaching focus areas are studied by using questionnaires and secondary data. Based on the results selected focus areas are studied further by using focus group interview. Specified Teamcenter PLM system is installed and configured to meet the requirements. Defined use cases must be possible to accomplish in the systems and evaluation of the system is based on the demonstration.

Research structure is following publication schema for design science research study which has been introduced by Gregor S. and Hevner A. 2013. The thesis is divided into six chapters.

Chapter 1 of this research presents general background, overview of the study, justification, goals and objective, but also some limitations. Furthermore, chapter 1 presents the importance of topic and related research questions. Chapter 2 presents literature review with theoretical background. Existing theories and general information about product lifecycle management are presented in this chapter. Aim of the literature review is to be wide and extensive product lifecycle management information package, since it can also serve as theoretical teaching material foundation in degree level teaching. Chapter 3 describes the selected methodological approaches in more detailed level. Selected design science research approach is explained with reference to existing authorities. Data collection and analyze is described in this chapter. Chapter 4 presents the results of this research, but also artifact description with relevant use cases. Chapter 4 is divided into five different sub chapters according Peffers et al. design science research method guidelines. Research results, artifact development, demonstration, evaluation and communication have separated to own sub chapters. Chapter five contains discussion about the results and how they are related to objectives of the research. Learning outcomes, noted limitations, theoretical and practical significance of results and future research are discussed in this chapter. Chapter 6 is final chapter which contains the conclusion of this study. Main findings and their importance are repeated in this chapter.

2. LITERATURE REVIEW

This section introduces theoretical framework of this study. Basic concepts, existing knowledge and research finding are presented in this chapter.

3.1 Product Development

One of the most important activities in product life is product development. Many decisions concerning manufacturing, usage and recycling are defined in product development phase. About 80% of the cost of the product is defined in development phase. Development time and cost varies greatly from product to product. Some surveys indicate that half of product development project fail because product is late from market or fails in market. (Stark 2011: 52-53)

Product development can be divided into six different stages which are presented in Figure 4. Planning phase is starting point for product development. Requirements and goals should be clearly stated after planning phase. In concept phase few alternative solutions are selected for further development. System level design phase brings more focus to specifications and plans. After this phase detailed specifications should be ready that actual detailed design can begin. Detailed design phase generates all the needed details for manufacturing and testing. Testing and refinement phase, or prototyping phase tests the results of detailed design. Design is evaluated and tested during this phase. Corrections to designs are done if any issues occur. Last step is production ramp up phase, where the actual manufacturing phase is started. (Ulrich & Eppinger 2012: 12-16)

Figure 4. Product Development Process.

Product development is important part of new product introduction. Successful product development management has huge impact to product quality, cost, development time, development cost and development capability. (Ulrich et al. 2012: 2-3)

3.2   Digital Manufacturing

Lower prices, smaller orders, short lifecycles, multiple suppliers and government regulation have forced manufacturing companies to seek efficiency to their actions. Therefore, Product lifecycle management capabilities have raised interest among manufacturing industry. Digital manufacturing is a system where behavior of real manufacturing system can be prepared and simulated. Basic actions are creation, validation, monitoring and controlling of manufacturing operations by using 3D Data, simulations, databases and networks. Manufacturing process planning provides quick way to plan part allocation and material usage. Furthermore, manufacturing process decision can be evaluated quickly and therefore time and cost are reduced. Digital manufacturing is one of the key solutions of PLM. (Kim, Lee, Kang & Noh 2010: 1028-1030)

3.3   Product Lifecycle Management

The earlier concepts of Product Lifecycle Management (PLM) were called engineering data management (EDM) and product data management (PDM). These earlier concepts and solutions were created because of growing amount of design files in manufacturing industry, mainly generated by Computer Aided Design (CAD) systems. Growing amount of design files raised challenges like storing and controlling files, version and revision control, control of product structures and managing relations between CAD parts, assemblies and drawings. Concept Product lifecycle management was the next step after EDM and PDM concepts. Product Lifecycle Management enables the systematic control of the product during its life from the first idea of product until the stage when the product is recycled or disposed. The scope of PLM system is much wider than EDM or PDM systems. PLM can be seen as holistic approach to manage product related information

during its lifecycle. Information can be e.g. Items, Documents, Product Structures, requirements, specifications, changes, manufacturing data, simulation data, supplier data and environmental information. (Sääksvuori & Immonen 2002: 1-3) Furthermore, PLM can be seen as strategic approach with three different dimensions. First Dimension is *"universal, secure, managed access and use of product definition information"*. Second dimension is *"maintaining the integrity of that product definition and related information throughout the life of the product or plant"*. Third dimension is *"managing and maintaining business processes used to create, manage, disseminate, share and use the information"*. (Kiritsis 2010: 479-482)

The central element of PLM system is creating, managing and storing company product related information. Product is the focus point in the system. All the activities in the system are somehow related to product and product data. Nowadays companies have considerable amount of product related data which causes that effective data management is important. Product are complex, volume of produced products is huge, and products are often configured customer specific products. Product related data is electronically managed by using PLM software, which enables searching, reusing and accessing the latest version of product data possible. (Sääksvuori et al. 2002: 3-6) PLM system serves as the backbone of product information (Yi-Ming 2017:68)

Different industry areas have different kinds of products. Product may refer to fast moving consumer goods, pharmaceuticals, software, financial product or heavy machinery. Therefore, PLM can be used in many different industry areas. Company size may also differ. Requirements and extend of PLM can vary but fundamentals remain the same. (Stark 2011: 13-15)

Product Lifecycle Management, or its abbreviation PLM is general concept for systematic method to control product related information. Officially the abbreviation PLM is not referring to any specific computer software, but in daily language the abbreviation often refers also to information system which is developed to support product lifecycle management. Software supports the process of creating, handling, sharing and storing product related information. (Sääksvuori et al. 2002: 6-11)

3.3.1 Product Lifecycle Phases

Product lifecycle can be divided to five different minor phases. Product has very different form or state in each lifecycle phase. Five minor phases of the product lifecycle are imagine, define, realize, use\support and dispose. Each lifecycle phase is presented in Figure 5. (Stark 1-3) Categorizing can be done also to three different major phases. Major phases are called Beginning of Lifecycle (BOL), Middle of lifecycle (MOL) and End of lifecycle (EOL). Usually in BOL and MOL phases include data creation by CAD/CAM/CAE software. (Kiritsis 2010: 479-482)

IMAGINE   DEFINE   REALIZE   USE/SUPPORT   DISPOSE
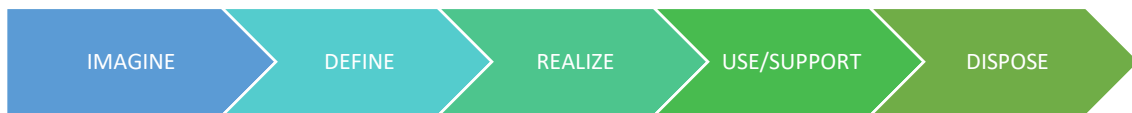
Figure 5. Product Lifecycle phases.

Some experts define PLM and it cycle little bit differently, but the meaning remains the same. Even if universal definition of PLM would be created, there would still be need for additional descriptions to fulfill the meaning. Grieves for example presents product lifecycle as circle and defines product lifecycle stages as plan, design, build, support and dispose, like presented in Figure 6. (Grieves 2006: 40-41)

Plan → Design

Dispose   Information Core   Build

Support
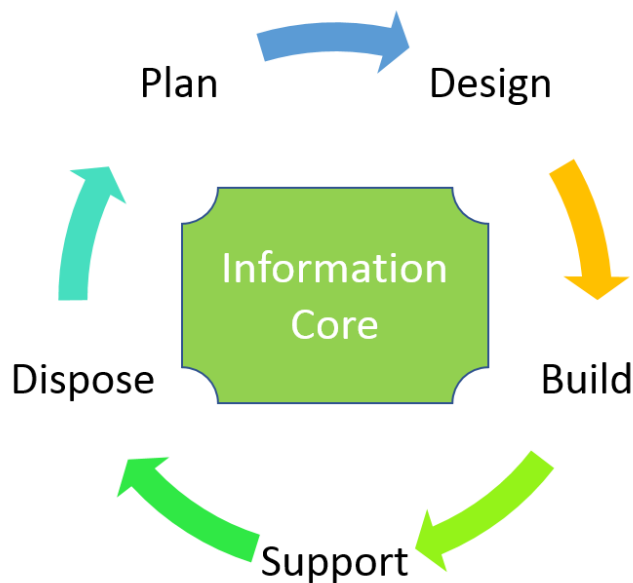
Figure 6. Grieves definition about product lifecycle management.

Plan phase includes product development early steps. Product requirements and functions are defined and gathered as specifications. (Grieves 2006: 41)

Design phase starts the concept design and eventually prototyping. Product engineering will finalize the design by creating exact specifications based on concept design and prototypes. Product is fully specified. Components must fit together, and product must be consistent. Different kind of analyses and simulations are conducted to guarantee that product meets the requirements specified in planning phase. (Grieves 2006: 42)

Build phase is started after product is fully specified. Manufacturing engineers analyze the specifications and product structures to clarify which manufacturing operations must be done in which order. Final step is assembly of the product. Usual cycle in many companies is that first product is built, ramp-up is started, and finally actual mass manufacturing. In some cases, also the tools for production must be designed. Furthermore, manufacturing engineer must design how to build product with given tools and equipment. Sometimes it may be necessary to change the design of product because of manufacturing. (Grieves 2006: 43-44)

Support phase begins after manufacturing. End users, sellers and distributors use the product information to clarify product functionalities, specifications and instructions how the product should be used to maintain its functions. Service department need the product information in maintenance, malfunction or failure situation. Furthermore, support phase information can be very useful since it tells if the product is designed correctly and functions like specified. (Grieves 2006: 44)

Dispose Phase is the final state of product. Product is disposed and recycled. Information about product structure and materials are important for efficient recycling. Feedback from recycling can be used in future product development. After disposal product cycle starts from beginning when next version of the product is planned to build. (Grieves 2006: 45)

Management is needed in each lifecycle phase to guarantee that product is profitable to company. Furthermore, responsibility about the product management may be vary in

different lifecycle phases. In one lifecycle phase marketing department may be responsible and in another phase engineering department. However, main task is to maintain common product information even when every department objectives and working methods may vary. (Stark 2011: 1-3)

3.3.2   Closed-loop PLM

Traditionally product lifecycle has presented as chain of activities. Haddaya et al. (2012: 560-562) has mentioned as typical activities in this chain "*conceptual design, detailed design, prototyping, design verification, process planning, tool design, tool manufacture, production planning, components production, quality control, assembly, delivery, maintenance, customer service, disassembly and recycling*" However, traditional chain approach has been challenged by introducing the concept called closed-loop PLM. The objective of closed-loop PLM is to close information gaps in later product lifecycle. (Kiritsis 2010: 479-483). Product data from MOL and EOL has been traditionally difficult to capture and analyze. New possibilities provided by Product embedded information devices and wireless technologies were notified in closed-loop PLM approach. Closed-loop PLM approach includes Product Embedded Information Device (PEID) which is attached to product. (Daaboul, Duigou, Penciuc & Eynard 2016: 1065-1066). PEID contains product related information and therefore enables feedback loops to earlier lifecycle phases. (Hadaya et al. 2012: 561-564) Traditionally the control of product is lost when product is sold. With closed-loop PLM, service, maintenance and recycling data are examples which will be covered by closed-loop PLM. Actors like managers, designers, service, maintenance and recycler can obtain, manage, control and track information about the product. Closed-loop PLM feedback loops are illustrated in Figure 7. (Kiritsis 2010: 479-483)
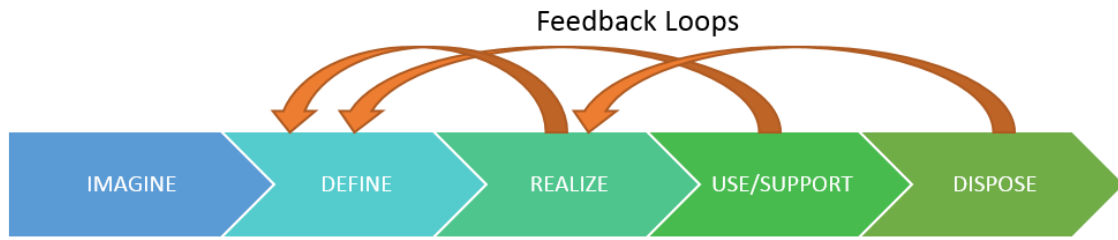
Figure 7. Closed-loop PLM

Information about the product after it is sold can be obtained by using different technologies. Barcodes and Radio Frequency Identification (RFID) technologies are two possible options. Both technologies can be used for lifecycle monitoring which is needed in closed-loop PLM approach. However, barcode technology provides read only property. Various data can be measured from the product by using sensors. Examples of this data are temperature, pressure, humidity, acceleration or velocity. With closed loop PLM approach this data can be recorded and transferred to earlier lifecycle phases. (Kiritsis 2010: 482-485)

Some PLM software have technical constraints which cause that entire product lifecycle cannot be supported. However, some case studies already suggest that products with PEID device have been successfully integrated to PLM software functionalities and therefore entire product lifecycle can be supported. (Hadaya et al. 2010: 559-560)

3.3.3   Main characteristics of Product Lifecycle Management system

First main characteristic in PLM system is singularity. PLM system is single source of information where unique and controlled version of product information is located. Singularity issue arose together with development of computers, because data was easy to duplicate in digital format. Changes to product may be very quick so there is a need that only one unique controlled version of data exists. Lack of singularity causes errors, wasted time, material and energy. PLM system implements a solution to singularity issue. It provides single source of data which is unique in the system and modifications are controlled by check-in and check-out functionalities. (Grieves 2006: 77-81)

Second main characteristic in PLM system is correspondence. In context of PLM correspondence is defined as strong link between physical product and the data of that product in PLM system. Geometry, properties like weight, color and material are existing in physical and virtual world. Approach allows information of the product to be searched and used when physical product is not available. Even when physical product is available, information system saves time, effort and cost in information searching. Other aspect for virtual information is data reuse possibilities. Virtual product information can be used as a template when designing new, similar product. (Grieves 2006: 81-83)

Third main characteristic of PLM is cohesion. Concept cohesion referrers the situation where we have different representations of product depending on the view. Product view can be e.g. mechanical, geometrical or electrical. However, all views represent the same product. Moreover, change in one view may cause changes to other views. For example, change in electrical view may cause changes to mechanical view. This is called cohesion between views. If these views are not controlled, it causes lots of troubles to product when changing the views independently. Situation is getting even more complicated in modern complex product environment where e.g. software is part of the product. Small change in software may have radical impacts to other functionalities of the product. PLM system is able to maintain this cohesion between views. (Grieves 2006: 83-86)

Fourth main characteristics of PLM is traceability. Traceability is the history of the product. Usually work is continuous, we rely on what has been done earlier and continue from that. Traceability reveals the successful changes but also unsuccessful changes. Traceable history allows to jump back in time to some snapshot of the product. Furthermore, product history can be analyzed and actions evaluated to enhance future processes. In some industries like aerospace traceability is legal regulation. (Grieves 2006: 86-89)

Fifth main characteristic of PLM is reflectiveness. Reflectiveness relates to mirror between virtual and physical world. Changes in another world should reflect to other world. PLM can capture these changes. When information is needed there is option to investigate virtual model in PLM and therefore save time, energy and material. The

extension of virtual world possibilities makes reflectiveness easier. With "As Built" product information reflectiveness creates great value. (Grieves 2006: 89-91)

Sixth main characteristic of PLM is Cued Availability. Cued availability refers the information and process flow from virtual world to real world. This is important in information mirroring between real and virtual world. Information in virtual world must be searchable and accessible when it is needed. Furthermore, information should be presented automatically in correct situations without searching the information. PLM system provides foundation to solve this problem. (Grieves 2006: 91-93)

3.3.4   Product

Grieves states that PLM is about the product. Product and product information is main concern of PLM. Supply chains, or other domain expertise may have influences to PLM, but main concern is still the product. (Grieves 2006: 35) Product Lifecycle contains many different detailed stages. Information flows in each stage can be complicated. Contextual model of Product and its phases are presented in Figure 8. (Jun, Kiritsis & Xirouchakis 2007: 858-859)
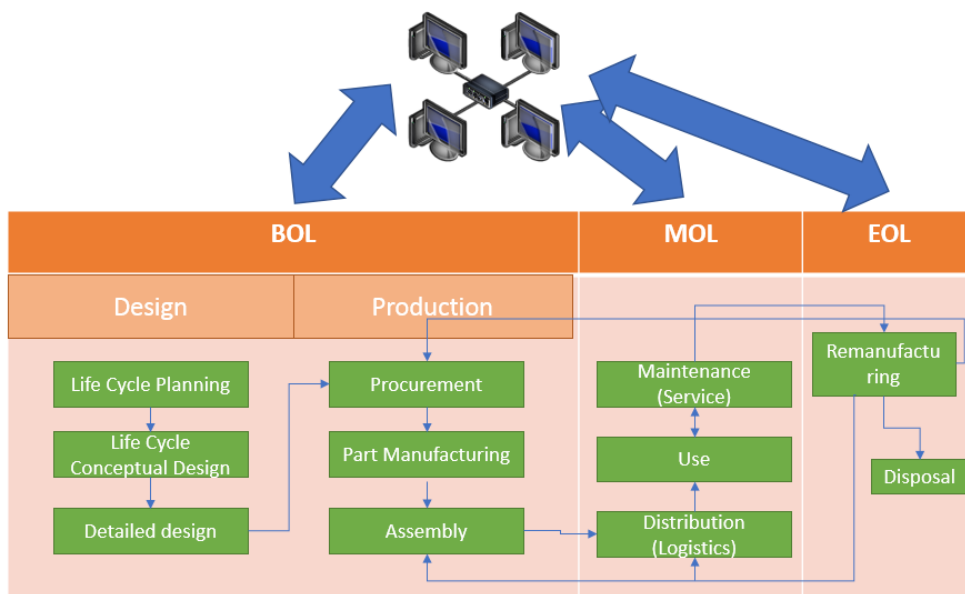
Figure 8. Product during different stages.

In modern world product can be tangible product, service or intangible product. (Sääksvuori et al. 2002: 1). Therefore, list of products what PLM can manage is extensive. Products are more often complex products with many parts and functions. Even though products are complex, the operation of the product should be easy to end user. One challenge in many companies is that some products have become so complex that singe person has difficulties understand them. Single product is more often a mixture of mechanical, electrical and software solutions. Therefore, it is extremely important that the control of product is maintained during its lifecycle. Other challenge is that product lifecycle can be very long with some products, for example in case of aircraft. Due to long lifecycle, many changes may occur in the product. Old technologies may be replaced with new ones, original vendors may disappear and also data format in Information system applications may change. Environmental issues have been growing topic since 1960s. Issues in the end of product lifecycle are often taken into account in design phase of the product. (Stark 2011: 30-32)

Companies want to have a great product and product deployment capability in order to survive in highly competitive business environment. However, developing a great product is not easy and to avoid additional difficulties companies must operate as effectively as possible. There are many problems which should be avoided during product lifecycle. Table 3 is presenting examples of these problems. (Stark 2011: 43-54)

Table 3. Product related problems during the lifecycle.

Imagine	Define	Realise	Use/Support	Recycle/Retire
Lack of Ideas	Project late	Poor factory layout	Poor communication	Poor Documentation
Uncontrollable	Uncontrolled changes	Scrap	Data out of control	Incorrect identification
Missing applications	Requirements not clear	Rework	Missing services	Lack of control
Ideas Pirated	Unclear processes	Wrong data versions	Product recalls	Low recycle rate

These problems with products may serious consequences to company. Loss of customers, high cleanup costs, negative publicity or even death or injury can occur if control of product is lost and problems occur. (Stark 2011: 54-57)

Furthermore, trend is that new products should be released very quickly by maximizing profit and minimizing the used labor. If product related processes are acting slow, company is unable to fulfill these objectives. PLM system is essential tool to respond these challenges. (Vezzetti, Violante, Marcolin 2014: 889)

3.3.5   Product Data

Concept "Product Data" means all data related to product itself, but also the data related to processes which are used during the lifecycle, for example manufacturing. Data may be characteristic of product, structure of the product, process related to product, or regulatory data. Data is created and managed in each lifecycle phase. However, product or product data is not taking care of itself automatically. Without managing the created data chaos is inevitable. Organizing data and keeping data organized is key element of PLM. Examples of this data presented in Table 2. (Stark 2011: 115-116)

Table 4. Examples of Product Data

CAD Geometry	Exploded Views	Service Manuals
Drawing	Simulation Data	Test data files
Bill of Material	Layouts	User Manuals
Analysis models	Machine libraries	Process plans
Change Data	Mounting Data	Sketches
Costing Data	Diagrams	Wiring Diagrams

PLM can manage product information apart from the location. Nowadays it is normal that product information source is outside from the actual owning organization. Company outsourcing models have caused situation that product information boundaries are not

existing anymore. (Grieves 33). Furthermore, data may be in different formats and created with different software versions. Solution requires interoperability between PLM system and different applications. PLM system can use relations to manage different data formats. Term associativity is also used, which means that these pieces of information are linked integrated sets. (Alemanni, Destefanis & Vezzetti 2010: 2-3)

Product information can move forward and backward in Product Lifecycle. Both information flows are important in product chain. (Hadaya et al. 2010: 561-562) Main focus of the product data has traditionally been BOL phase, since data is easy to access. This data is mainly operational data which has been used to enhance product quality. MOL phase has been less focused because of the problems in information flow. Data access from field services has been very limited before new wireless network technology. However, today these limitations are not valid anymore, but recording and using MOL data is still very limited. Steps to utilize this product usage data from MOL phase are: define product usage data, monitor working products, gather product usage data, modelling, manipulation and analyzing. (Shin et al. 2015: 551-553)

Product data can be categorized based on the lifecycle phase. Furthermore, categorizations can include input or output data type. Categorization may be helpful before using any data analytic methods. Examples of this categorization are presented in Figure 9. (Li, Tao, Cheng & Zhao 2015: 671-673)

BOL			
Category (Input)	Main Data (Input)	Category (Output)	Main Data (Output)
Customer demands	Prod. Configuration	Design specification	Material List
MOL			
Category (Input)	Main Data (Input)	Category (Output)	Main Data (Output)
Maintenance info.	Spare part list	Maintenace plan	Tools, places, dates
EOL			
Category (Input)	Main Data (Input)	Category (Output)	Main Data (Output)
Maintenan. history	Installed Date	Dismantling info	Disposal cost

Figure 9. Product information categories.

Another aspect to product information categorization is to provide specific and needed information to relevant parties without providing irrelevant information. Aim is to protect people about overload of unnecessary information. One option is to use system which organizes the information into three knowledge models, product model, manufacturing model and library model. Product model contain engineering related information like geometry, architecture and functionalities. Manufacturing model contains manufacturing capabilities, processes and resources. Library model contains best practice methods. (Gunendran & Young 2010: 5886-5888)

Internet of Things (IoT) means connection of physical product with Internet. IoT solution is required to control huge amount of real-time data. In context of PLM, IoT based solution can be used to collect data from unique product in mobile environment by using wireless network. (Cai, Xu, Xie, Qin & Jiang 2014: 1558-1559) Data provided via IoT can be object movements, interactions or sensor data. Vision is that this data would be linked to PLM system. (Kubler, Främling & Derigent 2014: 82-83)

Contemporary topic among all the data is the concept "Big Data". In many areas amount of data is increasing exponentially. However, utilization of big data in product lifecycle management is lacking. Moreover, common situation is that manufacturers are not storing big data or have very little understanding how data could be used. This situation has negative influences in PLM since all the relevant data is not recorded and therefore not used. Benefits of big data could occur e.g. in manufacturing and service by assembly process optimization, yield increase and meeting of customer expectations. Many suggestions by different research papers has already been published. (Li et al. 2015: 667-668)

There are several possibilities to use Big Data techniques in PLM. BOL phase examples include turning needs into specific functions, making final decision about products, monitoring product quality and simulating products. Potential big data applications in MOL phase include Online enquiries of products, tracing of products, warehouse management, corrective maintenance and preventive maintenance. EOL phase

applications possibilities include product life time predictions, product recovery optimization and enhancing resource savings in recycling. (Li et al. 2015: 674-681)

However, there are several challenges to utilize big data in PLM. Challenges include Data collection, data storage, data processes, practical PLM platform for big data, security of data and data visualization. (Li et al. 2015: 681-682)

Since 3D CAD/CAM/CAE tools are heavily used during product lifecycle, 3D models have become richer data sources. Increasing amount of product data is stored in 3D model and therefore 3D model has become central data source in PLM environment. One concrete action in this approach is replacing the 2D Drawings by using 3D annotations Product and Manufacturing information (PMI) Modules. (Camba, Contero, Company & Pérezb 2017: 611-612) An approach to PLM data is model-based definition (MBD). Central idea in MBD is that all process related information would be stored into 3D model. Engineering, manufacturing, technical documentation and service data would use 3D model as single source of information in their processes. Advantage in this approach is that information is provided from single source. Opposite to this approach is that data is divided in PLM system into different datasets, like 3D, 2D, Master form and material form. (Alemanni et al. 2010: 3-4)

3.3.6 PLM in context of functional organization structure

Common approach in organization modeling is that organization is divided into functional departments, like sales, engineering, manufacturing etc. There are certainly some advantages with this approach, but there is also disadvantages. Dividing the functions causes information silos into organization. Information remains unshared in these silos. Furthermore, information is duplicated and it is inconsistent. Each silo may be independent and every department may have own information systems. Costs and additional hazard is caused when unconnected silos exists. PLM system can solve this problem by connecting functional organization departments together. PLM systems serves as a backbone for all product related information. Organizational functions are

connected in systematic and managed way. Figure 10 illustrates this change. (Grieves 2006: 65-71)
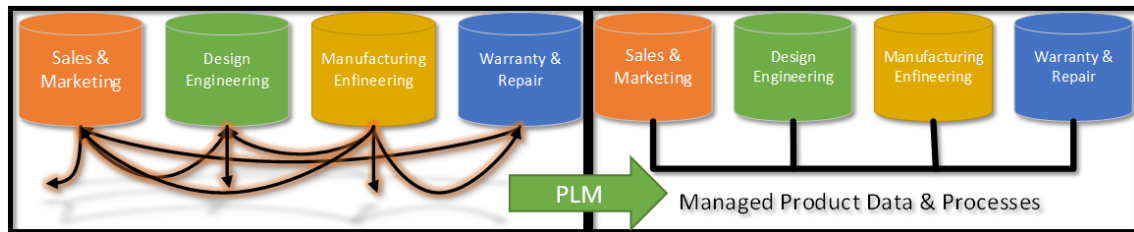
Figure 10. Organizational silos and PLM solution.

PLM system can be used in many different organizations, like companies and government institutions. Nowadays PLM software have many different applications and functions which can be used to solve different kind of problems in organization. However, main focus in PLM systems has long time been engineering and manufacturing functions. PLM system evolution towards holistic product lifecycle management has also increased the utilization in other areas of organization like sales and after sales. Moreover, subcontractors and partners can also connect to same PLM system. Figure 11 illustrates the organization structure and product processes. (Sääksvuori et al. 2002: 36-37)

In case of manufacturing business, two common processes are New Product Introduction (NPI) process and Order-To-Delivery (OTD) process. Products in NPI process are more standardized products while products in OTD process are more individual and customized. Since the product and product data is partially same in both processes, ODD and NPI are heavily connected in Sales, Procurement, Manufacturing, Delivery and Service functions. Existing information must be communicated to relevant parties. (Sääksvuori et al. 2002: 35-37)
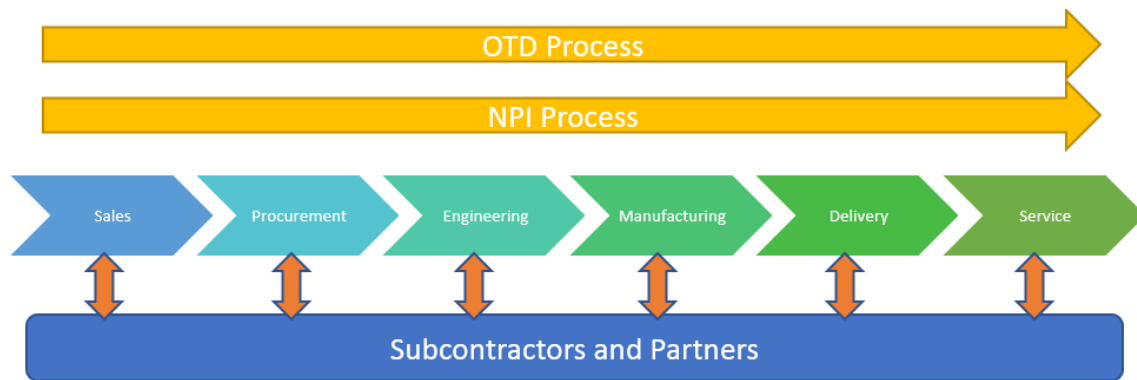
Figure 11. Organizational Departments and Product Processes

Marketing, sales and procurement could benefit much from PLM, especially in OTD area. Marketing material can be created and stored in PLM system. Customer specific product require product configuration, and PLM is platform which is suitable for that. Product and configuration rules may be very complex in some cases. OTD product may need specific product structure, part list, documentation, specifications and manuals. If already existing data is accessed and reused through PLM systems and with slight modifications usable to OTD product, OTD process is accelerated greatly. Common solution is defined and built sales configurator. Wanted product features are selected from sales configurator and as an output configurator creates needed product structure and other defined documentation. Rules of the configurator allow or disallow the selection of features of the product. Therefore, configurator and rules must be maintained constantly. (Sääksvuori et al. 2002: 40-41)

Engineering department have traditionally been the core of PLM and therefore most of the existing solutions and features serve Engineering activities. Reason may be that Engineers create massive amount of product data, like presented in Table 4. When managing status of files, items, workflows, changes and product structures for thousands of items, the process of managing and controlling data in efficient way becomes very difficult. Level of management and control of information affects directly to quality. (Sääksvuori et al. 2002: 36-37)

Manufacturing department has not traditionally been as interested about PLM and engineering department. There have been several claims that PLM system functionalities are too limited in manufacturing functions and link between engineering and manufacturing department has too many difficulties due to geographical, organizational and information flow views. However, it is possible to build bridge between engineering and manufacturing departments. There are certainly many advantages when using PLM in manufacturing department. Engineers can rapidly inform production about the changes in product, create production planning and distribute latest versions of drawings. Production can manage production machines, manufacturing process, quality data, calibration data and production plans. (Sääksvuori et al. 2002: 37-39)

After sales is an area where usage of PLM has been increased strongly. Many companies have found after sales as a new profitable business area. Rapid product development and changes set challenges to spare part and service management. Because of the development in wireless technology, PLM system can be used to access items, documents and product structures from different sites and fields. Complete documentation and information about the product is available in PLM system if network can be accessed. With PLM system it is also possible to adjust who has access to information. Therefore, partners and sub-contractors may have access only to data which is relevant to them. Furthermore, attention must be paid to user privileges and data security. (Sääksvuori et al. 2002: 40-41)

Partners and subcontractors are examples when connection to main organization in needed. Third party organizations can connect directly to company PLM system when network is available. Therefore, latest product data is available also external parties. However, main challenge is the difference of software and data formats between third party and company. Solution to this problem requires data conversion tools and formats like STEP, DXF and STL. (Sääksvuori et al. 2002: 40-44)

3.3.7 Drivers and Benefits of Product Lifecycle management system

Environment has changed much in past 30 years. Firstly, company sizes have grown dramatically. For example, in 1973 General Electrics revenue was 12 Billion dollars while in 2003 revenue was 134 Billion dollars. In these kind of company scales PLM system is mandatary requirement that information can be managed. Secondly, companies have more products and products are more complex than 30 years ago. Complexity increases the amount of data and PLM system can manage that data effectively. Thirdly product cycle times have decreased dramatically. Long development times are over. Amount of product information is increased when cycle time decreases. Furthermore, decreasing cycle time forces to eliminate slack. Fourthly, globalization has changed the way how product information is handled and also brought new competitors from developing countries. When small product development team worked in local factory, common meetings were enough to keep tract of the development. After globalization, design centers are spread out to different locations which affects directly how product development is managed. Fifthly, government regulation force companies to keep better track about their products. Regulations in product safety, warranty and environmental regulations force companies to react the regulations. These six external business environment drivers cannot be controlled by organization management and therefore they force companies to get benefits from PLM system. (Grieves 2006: 95-109)

Since the external business environment cannot be controlled inside the organization, changes must happen inside the organization. Main changes are related to productivity, quality, innovation and collaboration. (Grieves 2006: 95-109)

Productivity refers to the ration of outputs and inputs. As formula productivity can be presented as $\text{Productivity} = \frac{\text{Units}}{\text{Time}*\text{Rate}+\text{Energy}+\text{Material}+\text{Information}}$. Since PLM systems facilitate the availability of product information, PLM system can decrease time, energy and material significantly. This is directly affecting the productivity ratio. In context of PLM system **innovation** can be divided to product innovation and process innovation. Decreased cycle times force companies to innovate in product and process side. One

innovation enabler is availability of information. Therefore, as information collector, organizer and coordinator PLM system is one element of innovation enabler. Aim of process innovation is reduce time, energy and material in process. Since PLM system main concern is product related processes, it serves as innovation enabler also in process side. **Collaboration** has traditionally meant *"working together at the same place in same time"*. However, definition has changed away from the same place and time. People from different locations at different time must work with same product. PLM enables this kind of collaboration by providing single source of information and collaboration context. **Quality** has many meanings, but in context of PLM relevant definition would be "*characteristics of the product meeting its specifications*". Therefore, the information about correct product specification is crucial. Multiple versions of product components may cause issues in products. PLM systems with singular and consistent product information presents solution to this issue. Furthermore, virtual world can be used to analyze, test and simulate wire range of options and possibilities cost effectively. (Grieves 2006: 109-116)

Since companies cannot affect to changing external business environment, changes must happen inside the organization. However, company executives and managers are interested only about capital expenditures. Therefore, PLM external and internal drivers must be transferred to financial terms, e.g. to Return of Investment (ROI) or Return of Assets (ROA). In case of PLM system, ROA is is preferred. Grieves has developed IT Value Map which can be used to present full scale picture about PLM system impact to Income, Revenue and Cost. IT Value Map presents if IT system is having positive, moderate or negative impact to ROA. Figure 12 is presenting PLM value map. (Grieves 2006: 117-127)
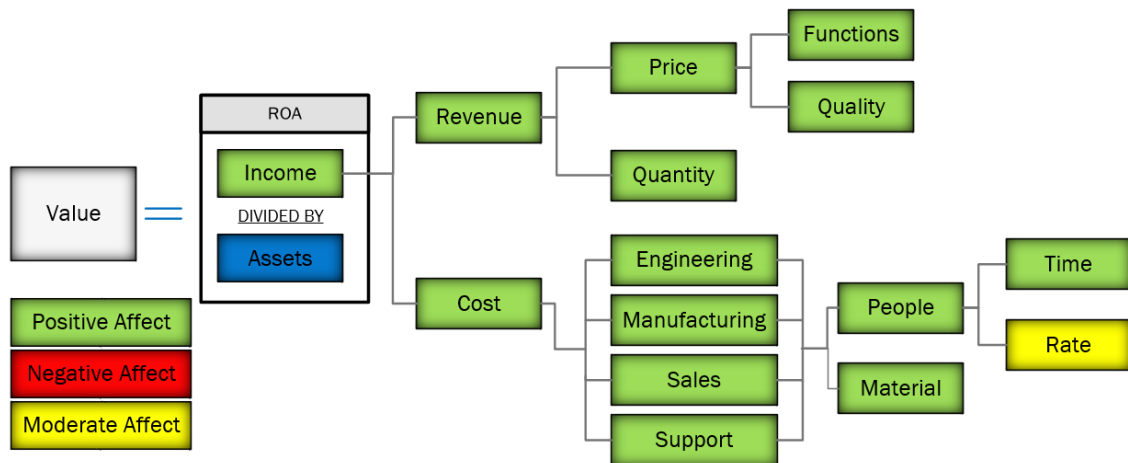
Figure 12. PLM system Value Map.

Growing global competition forces companies to to change processes and work more efficiently. Many changes, shortening lifecycles and individually customized products are common phenomenon. Companies also face more often situations like short delivery times, globalization, company merges, short development time, tight quality requirements, legislation and regulations. (Sääksvuori et al. 2002: 91-94) Also concept TQCSEFK has been introduced. Abreviation comes from the words *"fastest Time-to-market, highest Quality, lowest Cost, best Service, cleanest Environment, greatest, Flexibility, and high Knowledge."* PLM system is part of the solution in TQCSEFK goal. (Li et al. 2015: 668)

First major improvement is in communication. PLM system is a great solution to improve internal and external communication. Communication can be direct communication or data communication. Benefits from successful communication are often indirect. In general can be stated that quality, effectiveness and speed are increased through effective communication. (Sääksvuori et al. 2002: 91-104)

Second major improvement is time savings. Central element in PLM system is organizing the data. Cooper & Lybrand studied engineers use of time in 1994 and results are illustrated in Figure 13. (Sääksvuori et al. 2002: 91-104)

The Engineers Use of Time
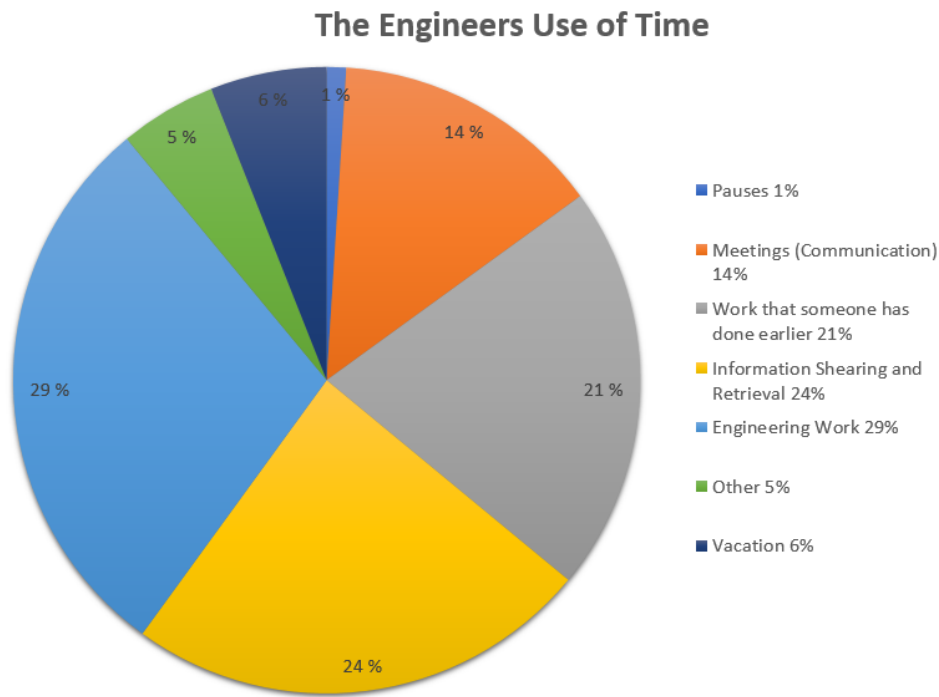
Figure 13. Engineers use of time.

Significant improvements to efficiency can be gained with effective PLM system. PLM system data searching functionalities can decrease time used to information retrieval. PLM system as organized data storage decreases rework significantly. More effective communication vie PLM system decreases time needed for meetings. (Sääksvuori et al. 2002: 91-95)

However, efficiency will not improve automatically by just implementing PLM system. PLM system is only tool, employees must use the system correctly to gain benefits from it. Converting the PLM benefits directly into financial units may be difficult. Financial benefits of PLM can be categorized to savings and increased earnings. (Sääksvuori et al. 2002: 94-102)

Even though PLM can provide many benefits, some industry level studies seems to indicate conflicting results on Product development performance. One suggestion is that PLM system influence to performance in not totally understood. (Yi-Ming 2017:67-68) However, analyze of 137 manufacturing companies revealed that excellent Product

development performance with PLM system can be achieved thorough effective process management capacity, coordination capacity and absorptive capacity. PLM system has been able to improve these capabilities. (Yi-Ming 2017:78-80)

PLM can approach can provide significant improvements to companies. Shorth term impacts have already been identified, like cost and time benefits. However, many companies have not yet got the full benefit from PLM approach. Reason for this is that companies have been unsuccessful to implement all MOL and EOL phase benefits. (Hadaya et al. 2010: 559-560)

3.3.8   PLM system actions, use cases and processes

The traditional definitions of process is that *"A process is an organized set of activities, with clearly defined inputs and outputs, that create business value".* Processes are usually organized to smaller sets like processes, sub-processes, sub-sub processes and activities. Furthermore, each activity has its own tasks, responsibility person, different roles, checklists and deliverables. Coherent and organized processes enable effective way of working in organization though the product lifecycle. (Stark 2011: 147-149)

There are many different product related actions in PLM system. Table 5 presents examples of common actions in PLM system. (Stark 2011: 147-149)

Table 5. Common product related actions in PLM system.

Manage feedback	Define BOMs	Design Products
Identify requirements	Simulate parts	Use Products
Configure Products	Make parts	Maintain Products
Disassemble products	Make changes	Measure Progress
Specify Products	Define design rules	Project Management
Plan manufacturing	Test Parts	Prototype
Assemble Parts	Upgrade products	Validation
Replace Parts	Report progress	Plant maintenance

Action in the system itself is not completing the task. Usually interaction between user and system is needed. These interactions when system user solves specific action by using the system are called use cases. Use case contains detailed steps how the specific action is completed. For documenting the use cases standard format is use case description or diagram like presented in Figure 14. Several use cases are needed to describe the whole process. (Stark 2011: 164-169)

Use Case Number: 1
Use Case Name: Login into system
Vesion: 12.0
Description: This use case contains detaled steps hot to login into system
Purpose: System access
Actors: User 1
Assumptions: Login successfull
Pre conditions: User account has been creted into system
Normal flow of Events:
        Step 1: Start the application
        Step 2: Type username
        Step 3: Type password
        Step 4: Click Login
Post Conditions: Succesfull login
Alternative flow: None
Special Conditions: Windows single sign on
Notes: Every user must test the use case

- Start application
- Type username
- Type password
- Click Login

Figure 14. Common documentation methods for use cases

Specific actions in PLM system form processes. Processes of different sizes and importance but also purpose exists. In different business environments PLM processes are not exactly the same. When working with products, projects or orders the processes are different. Most common high-level PLM processes are mapped to Product lifecycle. These processes are product idea process, product realization process, product support process and product phase out process. (Stark 147-150) Haddaya et al. presents various list of processes but basic meaning remains the same. There processes are *"idea management, requirement management, product structuring, product program planning, change management, project controlling, risk management and quality controlling"* (Hadaya et al. 2010: 559-560)

First task with processes is to understand the current processes properly. Second task is is to insure that processes are defined and documented. Third task is re-engineer processes to fit into digital world. (Grieves 2006: 143-147)

Process has many characteristics which need to be defined properly and clearly. Purpose of process, objectives, scope, inputs, outputs, boundaries and neighbor processes need to be extremely clear the process is efficient. Furthermore, participants, roles and their activities must be clear. Hesitation and confusion are faced if process has any unclear areas. (Stark 2011: 149-150)

Documenting existing process is often called process mapping, process charting or process flow charting. Documented process is clear for everyone and well understood process enables to improve the process. Process modeling refers to activity of creating models for new processes. Process mapping, modeling and measuring activities are called Business process management (BPM). Structure of the process which includes the activities can be presented in activity flow or hierarchical process structure like in Figure 15. (Stark 2011: 161-166)
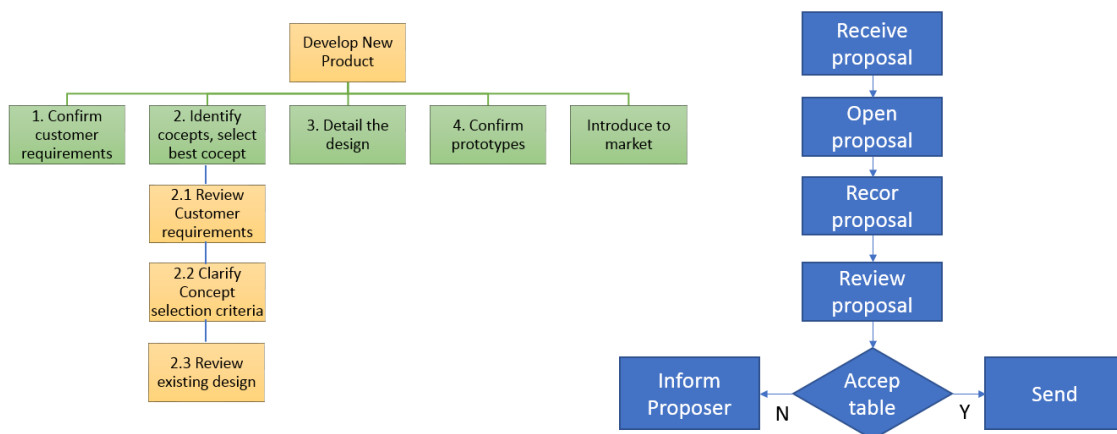

Figure 15. Hirarcical process description and Activity Flow.

3.3.9   General PLM system applications

Since the scope of Product lifecycle management is the whole lifespan of the product, there is many PLM system applications which to use in different lifecycle phases. PLM

applications are used in PLM processes. Different vendors have some same, but also different applications. There are thousands of different applications in PLM environment. Therefore, one problem is to identify which applications are most relevant in which processes. Each application must be properly understood to decide if it fits to PLM solution. Some commonly known PLM applications are listed in table 6. (Stark 2011: 171-183). CAD applications are very common in PLM. Designing, simulating and validating the product with 3D CAD software is possible. Furthermore, 3D applications are helpful in manufacturing planning, work instructions creation and simulation-based validation. (Alemanni et al. 2010: 1-2)

Table 6. List of common PLM applications

BOM applications	CASE Applications	ECM Applications
CSM Applications	CIM	EDM Applications
CAD Applications	Data exchange Application	FEA Applications
CAE Applications	DECM Applicatiuons	Gemetric Modeling app.
CAID Applications	Digital Manufacturing app.	Haptic Applications
CAM Applications	DMU Applications	IM Applications
CAPE application	EDI applicatins	IPM Applications
CAPP application	EDA Applications	KBS Applications
LCA Applications	Part Catalogue applications	Portfolio management app.
MRP 2 Applications	Part Libraries	PDM Applications
NC Applications	Phase-Gate Applications	Project Management app.
Rapid Prototype app.	Simulation Aplications	Technical publis app.
Requirements manag. App.	SCM Applications	Translations man. App
Reliability manag. Appl	TDM Applications	Virtual reality applications
Virtua Engineering app.	Virtual Prototypin app	Visualization applications
Viewing applications	3D scanning applications	

Because of the huge amount of different applications it is practical to structure applications into different groups. Grouping and describing can be done in many ways.

One option is to categorize the applications by focus groups. Example of this categorization is presented in table 7. (Stark 2011: 187-188)

Table 7. PLM applications categories by groups

General	Design Focus	Manufacturing focus
Viewers	Requirements management	Rapid prototyping
Project Management	Computer-aided-design	NC programming
Document Management	Electronic-design-automation	BOM Management
Visualization	Idea Management	Tool Management

Another way to categorize PLM applications is by type of application. Example of 13 different application types are presented in table 6. (Stark 2011: 187-189)

Table 8. Type of PLM applications

Idea Management Applications	Supplier-oriented applications
CAE/CAD/CAM Applications	Process Definition & Management app
PDM Technologies	Project and Program Management
Visualization/Viewing	Portfolio Management
Collaboration Software	Regulatory/Compliance/Standard app
Data exchange & Interoperability app.	Integration
Customer-oriented applications	

Third way to categorize applications is by dividing applications to Generic PLM applications and task specific PLM applications. Table 9 is presenting this categorization. (Stark 2011: 187-189)

Table 9. General and Task Specific PLM applications

Generic	Task Specific
Data/Document Management	Product Portfolio Management

Part/Product/Configuration Management	Idea Generation Management
Process/Workflow Management	Requirements and Specifications Manag
Program/Project Management	Collaborative product definition manag
Collaboration Management	Supplier and Sourcing Management
Visualization	Manufacturing Management
Integration	Maintenance Management
Infrastructure Management	Environment Health and Safety
Product Idea Management	Intellectual Property Management
Product Feedback Management	

PLM capabilities can be extended with integrations. PLM and ERP systems common key IT solutions. PLM and ERP can be seen as complementary systems. (Grieves 2006: 56-60) Integration between PLM and ERP system allows data sharing between these systems. However, there is several different ways to integrate these systems. Level of integration affect directly to complexity, functionality, scope and cost of integration. (Prashanth & Venkataram 2016: 2269-2278)

Fully functional PLM system requires comprehensive integration and information exchange between other systems or tools. Only few PLM software providers can provide such solution. Most software providers have only limited integration packages. Furthermore, support for these tools is limited. Common PLM solution is still relying only to PLM – CAD integration. Incomplete PLM application and integration capabilities makes PLM system implementation difficult. Moreover, manufacturing activities are not focal point in PLM system. (Kim et al. 2010: 440-441)

3.3.10 PLM Vision and Future Roadmap

Coherent approach for PLM system implementation is needed for successful implementation. Approach includes mission, objectives, vision, strategy and plan. Mission can be defined in business context as *"the special task or purpose for which company is destined."* Objectives are *"aims or goals aimed at of striven for"*. Vision can

be defined in industrial context as *"mental image of something in the future"*. Strategy can be defined as *"A general method for achieving specific objectives"*. Plan is similar that strategy, but more detailed. Plan is *"A detailed method for achieving specific objectives"*. Figure 16 is illustrating the steps. (Stark 2011: 327-331)
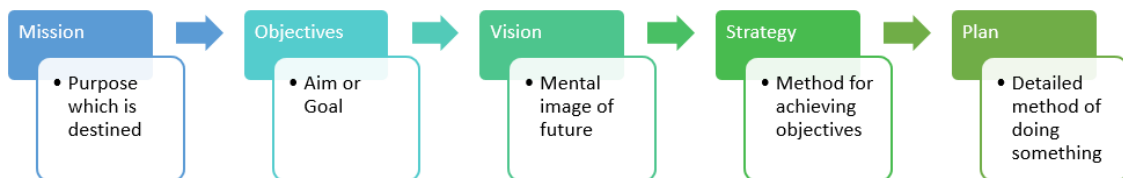
Figure 16. PLM Vision and Roadmap

PLM objectives can be expressed by company management. Objectives can be e.g. total control of products during its lifecycle, low environmental footprint of product or become fastest product developer in the business. (Stark 2011: 333)

It is difficult to see far into future, so it may be appropriate to develop 5 years vision for PLM. PLM Vision is a forecast for future actions and situation. Effective working requires that target destination is known. Defined PLM vision will enable decision makers and other participants have clear picture about objectives and scope of PLM system development. PLM vision is company specific. Furthermore, PLM vision should be concrete, coherent, complete, clear and consistent. Properly defined PLM vision is starting point for PLM strategy. (Stark 2011: 327-332)

PLM strategy is also company specific. PLM strategy is important because it describes how the objectives are achieved and by which resources. Furthermore, strategy can be divided to PLM strategy and PLM implementation strategy. PLM strategy is describing the future environment and PLM Implementation strategy is describing how to get that point. Implementation strategy is starting point for implementation plan. (Stark 2011: 187)

PLM Plan is detailed description of PLM system which includes actions, processes, data, equipment, applications and human resources. Plan defines detailed actions, objectives, timing and needed financial inputs. After plans are completed the implementation can take place. (Stark 2011: 349)

3.3.11 PLM system development and Implementation

PLM software vendors have different kind of software packages. Companies with huge resources have possibility to implement much PLM functionalities. However, small and medium size companies have more limited resources, and therefore have only limited amount of PLM functionalities available. (Mickaël & Frantz 2015: 140-141) It is also recognized that technological constraints of some software cause that entire product lifecycle cannot be supported. (Hadaya et al. 2010: 559-560)

Although PLM software plays important role in PLM implementation project, people, practice and processes must be remembered. Central elements in OLM project are people, process & Practice and Technology. All of the elements must be considered to enable effective PLM Implementation. Key elements are presented in Figure 17. (Grieves 2006: 129-134)
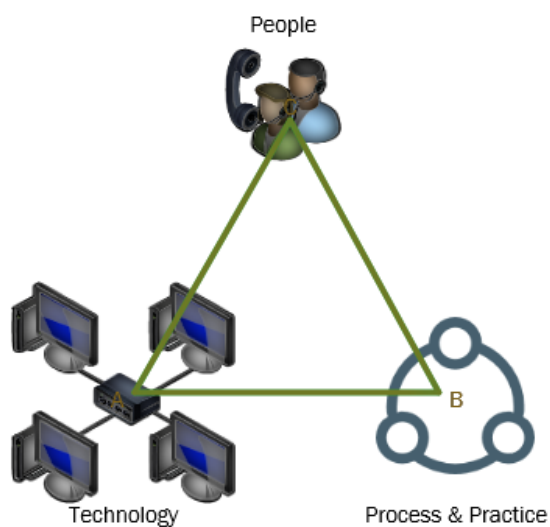

Figure 17. Key elements in PLM Implementation.

Once preparation and planning of PLM system is finished, implementation stages may take place. The goal of the project is to organize daily work better and work more efficiently (Sääksvuori et al. 2002: 67-68). Deployment time of PLM system can vary from several months to several years. Timeframe depends about approach, chosen software and size of the company. (Vezzetti et al. 2014: 899). Skilled people in the project are one key to success. PLM implementation project should not be treated as pure IT-project. Typically there is four high level steps in PLM project which are illustrated in Figure 18. (Sääksvuori et al. 2002: 67-68)
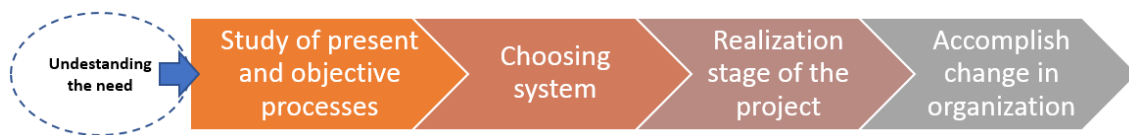
Figure 18. PLM Implementation steps.

Trigger for change can occur in many forms. Reasons like sudden external or internal impact to company, change in management, merging and acquisition or even new owner of company can trigger the implementation for PLM system. Reasons for change can be also long-term reasons. Product lifecycle and data problems may occur during long time period and suddenly situation cannot be tolerated anymore. At that chaos it may be seen that company cannot continue with current tools and ways of working. (Sainsbury et al. 2002: 68-69)

First task in PLM implementation is to plan and define the use of product information and related processes. Actual PLM system as a tool will the bring discipline to these matters. However, starting point for this task is often bad. Operations in company may have reached the point that nobody understands the the operations anymore. (Sääksvuori et al. 2002: 70-72). Therefore, first task is to describe the present AS-IS state of data and processes. After that targets for the future can be set. Practical tool for this task is PLM maturity model. Maturity model as a tool is designed determine readiness or maturity for change. Since PLM system implementation may be very extensive change in organization, it can be divided to smaller steps by using maturity model. Maturity model

is presented as evolution to different growth phases. Improved maturity outputs in PLM are effectiveness, predictability and control. Several different maturity models are existing, but common elements in all models are number of maturity levels, level description, summary of features of the levels, elements of activities in each dimension and description about activities which might be performed in the level. Traditional model is Capability Maturity Model Integration (CMMI). That model consists of five different maturity levels which are Initial, Repeatable, Defined, Managed and Optimizes. Each maturity level contains key process area with related activities. When listed activities are performed, that serves as indicator that maturity level is achieved. Example of this model is presented in Figure 19. (Vezzetti et al. 2014: 899-902)

Level	Maturity Level	PLM Key Process area and activities
1	Initial	"PLM Topic has been recognized and its importance agreed. Work must be done to define and develop te PLM concept and standards. However, at present, there are no defined approaches concerning lifecycle management; all lifecycle and product management issues are resolved by individual case-by-case basis."
2	Repeatable	"Lifecycle and Product management processes have developed to the stage where similar procedures are followed by different people undertaking the same task. There is no formal development, definition, training or communication of standard processes; all responsibility is left to individuals. There is a high degree of reliance on individual knowledge and therefore erors occur."
3	Defined	"Processes and basic concepts are standardized, defined, documented and communicated through manuals and training. However, the human factor is important, there is no end-to-end PLM process supporting IT systems, all work is completelly or partially manual from the process point of view. IT systems support individual parts of processes. The PLM processor basic PLM concpts are not best-of-the-breed, nor they are uniform throughout the corporation, however they are formalized."
4	Managed	"It is possible to monitor and measure the compliance between processes and to take action where processes are not functioning well. Processes and concepts are under constant improvement and provide best practises. IT systems support PLM processes well. Process automation is used in a partial or limited way. Processes and concepts are developed through clear vision throughout the corporation. The state of uniformity of processes is clear"
5	Optimized	"Processes and concepts have been refined to the level of best practice, based on continuous improvementand benchmarking with other organizations. IT is used in an integrated manner and process automation exists on an end-to-end basis."

Figure 19. Example of PLM Maturity model.

Maturity model levels presented in Figure 19 are general. It is possible to create more precise maturity level which is based on PLM functionalities. Figure 20 presents example of this. Each PLM functional area is described by using vector with dots. Each dot presents maturity level of that functionality. When combining the dots the result is PLM Maturity model. (Vezzetti et al. 2014: 899-902).
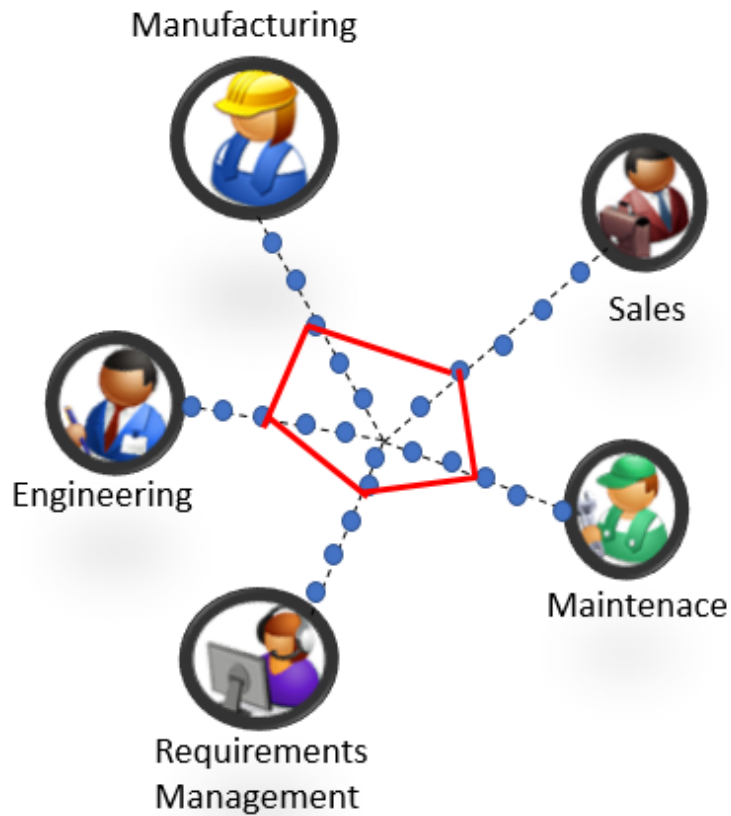
Figure 20. PLM functional specific Maturity Model

Second task is PLM system selection. If resources are not sufficient to invest full scale PLM system at once, smaller steps may be considered. Options like extending existing CAD or ERP systems and developing company processes and actions can serve also as PLM system implementation step. Selection of the system may take long time. It is important to make the choice by judgement, not by feeling. Decision should be considered carefully. Main steps in system selection are getting familiar with available systems, benchmark companies which use PLM systems, choice of pilot system, negotiation of commercial terms, timetables and project content. Main factor which affects the implementation time and cost is the amount of wanted customization. Advantage with customization is that features fit precisely to company needs. Downside with customizations is that they are expensive and may affect to system upgrades. Functional details in PLM system are important, but maintenance and ease of use should also be considered. (Sääksvuori et al. 2002: 73-74)

Third step is the actual implementation of the system which can be done by company itself or dedicated PLM partner. Even if company does the implementation by themselves, partner can be big help because of the long experience they usually have. PLM implementation project can be divided into smaller projects. It may be challenging to introduce all the new functionalities at once. Progress plan is needed to control the implementation schedule. Schedule can contain five different stages which are presented in Figure 21. (Sääksvuori et al. 2002: 75-77)

Figure 21. Five stages of project schedule.

PLM implementation requires technology infrastructure where the actual technology can be implemented. Selected PLM applications are implemented into infrastructure. PLM system can be configured and customized according the needs. (Grieves 2006: 152-157)

Legacy data from filesystem or other systems must also be considered. Decision can be that all data will be transferred or no data will be transferred. However, most common solution is some kind of compromise what will be transferred. Therefore, attention to the selection of the data which must be transferred must be paid. Transferring the legacy data causes more work in project and also more costs. (Sääksvuori et al. 2002: 75-77)

Fourth stage is accomplishing the change in organization. PLM introduction in organization requires many new practices, skills and capabilities. Furthermore, cultural and strategic changes in organization must also be considered. (Vezzetti et al. 2014: 899). When PLM system is successfully implemented and in place, change in organization must be achieved to succeed in PLM strategy. PLM system can affect hundreds of people in organization. However, most of these people may not involved in PLM implementation project. In these cases resistance against new system can be faced. Change is started when new ways of working, processes, operational models and systems are explained and demonstrated to organization. Development of expertise, support and training are natural

part of this change in organization. Also the fact that other users are information producers and others information users must be considered. Furthermore, some people may face temporary increase in workload during the implementation. Good management is needed to justify the changes. (Sääksvuori et al. 2002: 85-89)

3. DESIGN SCIENCE RESEARCH METHODOLOGY

Design science research methodology purpose is to create information system artifact that will solve identified problems in organizations. Therefore, interplay among IT and Business strategy as well as interplay among organization and IT infrastructure are needed. Fundamentally design science research is problem solving paradigm. (Hevner 2004: 75-78)

Design science research is especially useful in context of Information systems research. Information systems usually exists in intersection point of business, technology, people and organization. In design science research both behavioral-science paradigm and design-science paradigm are important. If only design science paradigm is considered, the danger is to create well-functioning information system artifact which is useless in organization. On the other-hand if only behavioral science paradigm is considered, the danger is failure to utilize technological capabilities and create ineffective information system artifact. The interplay and conceptual framework of Information system research is presented in Figure 22. (Hevner 2004: 98-99)

Environment includes people, organizations and existing technologies. This combination defines the problem. Business needs, goals, objectives and problems are defined by the people in the organization. Researcher perceives the problem or business need in this context. Knowledge base consists about existing research, theories, methodologies, tools, instruments and models. Based on environment and knowledge base new theories and artifacts are developed. Artifacts and theories must also be justified. Theories which are not useful in environment and artifacts developed for non-existent problems contributes very little to IS research. (Hevner 2004: 78-81)

Between Environment, IS research and Knowledge base there are cycles called Relevance cycle, Design Cycle and Rigor cycle. Relevance cycle is to collect requirements and do field testing. Design cycle is to conduct constant evaluation when designing artifact. Rigor cycle is used to gather relevant information from knowledge base and also add information based on the findings in IS research. (Hevner 2004: 78-81)
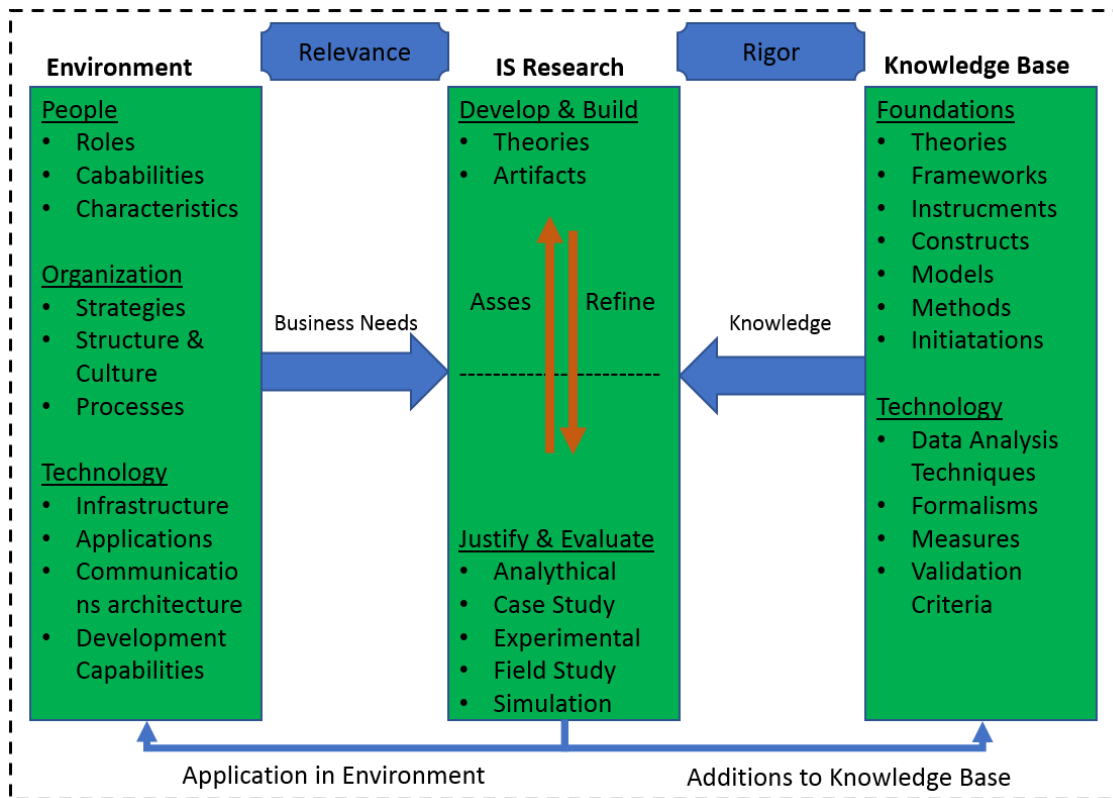
Figure 22. Information system research framework according Hevner et. Al.

Based on the prior studies of Hevner and other researchers, Peffers, Tuunanen, Rothenberger & Chatterjee proposed and developed a new, specific design science research methodology for information systems research. That research has provided commonly accepted practical framework to conduct design science research in context of information systems. Peffers et al. analyzed several design science research papers and created six step process model to conduct design science research. Process steps in the developed methodology are:

1. Problem Identification and Motivation
2. Define the Objectives for a solution
3. Design and Development
4. Demonstration
5. Evaluation
6. Communication

First activity is problem identification and motivation. Researcher specifies the research problem and justifies its importance. Breaking the problem into pieces may be necessary to clarify the complexity of the problem. Justifying the study motivates the researcher and it helps to understand the reasoning. (Peffers, Tuunanen, Rothenberger & Chatterjee 2007: 54-55)

Second activity is to define the objectives for a solution. Those can be both qualitative and quantitative. For example the description how the solution would be better than other ones or how the developed artifact supports the solution for the problem can act as objectives. Objectives should be rationally derived from problem description. (Peffers et al. 2007: 55)

Third activity is design and development. In this step new theories and artifacts are developed. Practical steps in this activity are determining artifacts architecture and functionalities, but also creating the artifact itself. Artifact is designed and created object which is solution to the research problem. (Peffers et al. 2007: 55)

Fourth activity is demonstration. Developed artifact is demonstrated and it should solve the presented research problem. Demonstration can be done in many ways, but it requires the skills to use the artifact for the research problem. (Peffers et al. 2007: 55)

Fifth activity is evaluation. The main question is how well the developed artifact solves the original research problem. Artifact is evaluated against the original objectives. Like demonstration, evaluation can be done in many different ways. Evaluation can be quantitative like measured response times or qualitative like satisfaction surveys. Evaluation results should provide decision if researcher should develop artifact further in activity three. (Peffers et al. 2007: 56)

Activity six is communication. The whole research should be communicated to relevant audience. In scholar publications standard structure of research papers can be used. (Peffers et al. 2007: 57)

3.1 Problem Identification and motivation

In order to give recommendations about degree level PLM teaching and develop suitable Teamcenter PLM environment it is crucial to find most relevant high-level solutions, applications, use cases and processes. Therefore, following questions should be answered before Teamcenter PLM environment installation and configuration can take place.

1. What is the current PLM knowledge of graduated students and how teaching should be arranged in degree level studies?
2. What are the most common Teamcenter PLM high level solution areas?
3. What are the most common Teamcenter PLM software applications, use cases, and processes in the most common Teamcenter High Level solution areas?
4. What PLM and digital manufacturing features are planned to be implemented or piloted among Finnish Manufacturing industry in next five years?
5. What should be the theoretical and practical PLM teaching focus in degree level with Teamcenter PLM Software.

Answers to these research questions will provide recommendations about theoretical PLM teaching content and arrangements in degree level studies, but also specification to Teamcenter PLM system development. Based on the answers of Research questions following actions take place.

- Specified Teamcenter PLM system installation and configuration to support PLM teaching in degree level.
- Demonstration of installed and configured Teamcenter PLM environment.

Installed and Configured Teamcenter PLM System can be used in degree level teaching according the system demonstration.

3.2 Define objectives of the solution

Research is started by clarifying the objectives and requirements for PLM artifact. The theoretical foundation is established by studying existing literature and writing literature review section.

First objective is to clarify the current knowledge and skills of graduated students and how Finnish Manufacturing industry PLM professionals would like to arrange degree level PLM teaching. This question is answered by using rating questions in questionnaire form. Target group is focused. Questionnaire is only meant for Finnish Manufacturing industry PLM experts selected from 35 Finnish manufacturing company. Companies are using Teamcenter PLM software in their daily activities. Detailed questions are presented in annex 1.

Second objective is to clarify what are the most common Teamcenter PLM system high level business solutions in Finnish manufacturing industry. This question will be answered by investigating secondary data from 35 different Finnish Manufacturing companies by using PLM vendor Configuration Management Database, Apache Subsystem and Functional Design Specification documentation (FDS). Companies are using Teamcenter PLM software in their daily activities.

Siemens PLM software presents high level business solutions in Siemens web page. Provided categorization was used as a foundation for research. List of available high-level solutions according Siemens are presented in Table 10. (Siemens PLM Software 2018)

Table 10. Teamcenter PLM high level solutions according Siemens PLM Software

Adaptable PLM Foundation	Product configuration
Bill of Materials Management	Product Cost Management
Change Management	Product requirements Engineering
Document Management & Publishing	Program Planning & Project Execution
Electrical Design Management	Search & Analytics
Environ. Compliance & Product sustainability	Simulation Management
Manufacturing Data & Process Management	Software Design & Asset Management
Materials Data & Lifecycle Management	Sourcing & Supplier Integration
Mechanical Design Management	Streamline Service Operations
Model Based systems Engineering	Visualization, & Virtual reality

Third objective is to clarify what are the most common Teamcenter PLM system applications, use cases and processes in the most common Teamcenter PLM high level business solutions. Based on the results of secondary data, but also opinions of Finnish Manufacturing industry PLM experts, five most commonly used Teamcenter PLM system high-level solution areas are selected for further investigation. Seven Teamcenter PLM system implementation specialist participated to structured focus group interview. Interview revealed the most common applications, use cases and processes in Teamcenter PLM system. Structured focus group interview template is presented in annex 2.

Fourth objective is to clarify what Product lifecycle management and digital manufacturing functionalities Finnish manufacturing companies are interested to implement in next five years. Degree level teaching is usually planned for certain future time period. Answer provides indication what knowledge and skills Finnish Manufacturing companies will be needing in the near future. This question was be answered by using open questions in questionnaire. Target group is focused. Questionnaire is only meant for Finnish Manufacturing industry PLM experts selected from 35 Finnish manufacturing company. Companies are using Teamcenter PLM software in their daily activities. Questionnaire is presented in annex 1.

Fifth objective is to clarify what should be practical and theoretical PLM teaching focus in degree level studies. Ranking questions were presented to PLM experts in questionnaire form. Teamcenter PLM system high-level solutions were ranked by using scale 1-5 based on importance of that solution. Furthermore, ranking questions concerned also theoretical teaching. Theoretical PLM teaching areas were ranked by using scale 1-5 based on importance of that area. Target group is focused. Questionnaire is only meant for Finnish Manufacturing industry PLM experts selected from 35 Finnish manufacturing company. Companies are using Teamcenter PLM software in their daily activities. Questionnaire is presented in annex 4.

Answers to research questions will provide knowledge about current knowledge of graduated PLM students and how PLM experts would like to arrange the PLM teaching in degree level studies. Importance of theoretical PLM teaching topica are ranked and

results provide the most important focus areas in theoretical teaching. Furthermore, answers to the research questions clarify how the specified Teamcenter PLM system should be installed and configured to support PLM teaching in degree level. Based on the most important Teamcenter PLM system high-level solution areas environment installations and configurations can be completed. Furhermore, the specified Teamcenter PLM system should be demonstrated by using specified Teamcenter PLM system applications, use cases and processes. Installations, configurations and demonstrations are done by exploring the Teamcenter PLM software, but also by reading Teamcenter PLM system documentation provided by Siemens PLM software. Figure 23 illustrates the research territory, objectives and data sources of the research.
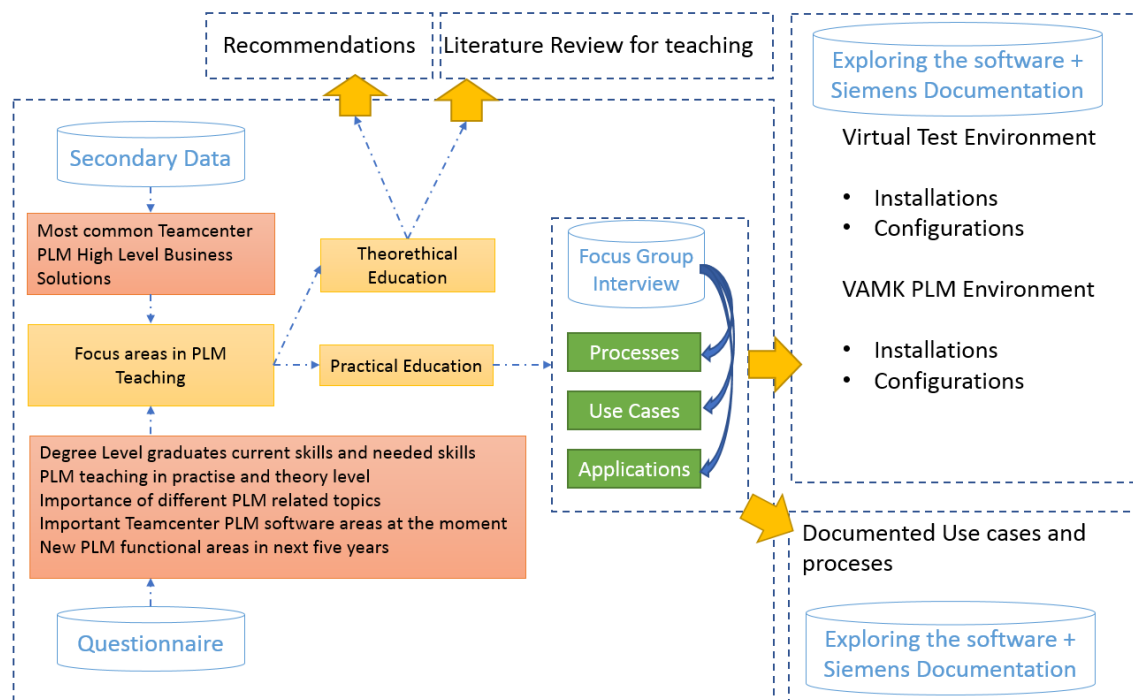

Figure 23. Objectives and Data Sources

Research context covers both practical and theoretical teaching. Literature review of this study can be used as foundation for theoretical teaching and configured Teamcenter PLM system can be used in practical teaching.

3.3   Design and develop

Based on the requirements revealed by research questions, Teamcenter PLM system is installed and configured to Virtual Environment. Virtual Environment is test and development environment. After successful installations and configurations in virtual environment, same functionalities can be configured to VAMK Teamcenter environment.

Installed and configured Teamcenter PLM systems should contain functionalities to run specified applications, use cases and processes. Teamcenter PLM system can be configured and customized in several different ways. Table 11 presents some of the tools which can be used in different kind of administrative tasks.

Table 11. Tools which can be used to configure and customize.

Microsoft SQL Management Studio (Backups)
Microsoft Office Tools (For Documenting the artifact and theory)
Microsoft Visual Studio C++ (Server and Client Side code customizations)
Teamcenter Business Modeller IDE (Datamodel configurations)
Teamcenter Workflow Designer (UML editor for creating workflows)
Teamcenter Quary Builder (Configuration business based queries)
Teamcenter Organization (Manage Teamcenter Groups and Users)
Teamcenter Command Line Utilities (Administration tasks)
Teamcenter Preference editor (Change system preferences)
Teamcenter Command supression (Modify Teamcenter User Interface)
Notepad++ (For XML editing)
Tortoise SVN (For Configuration and version management)

Design and development work is completed in Oracle Virtual Box test environment before configuring VAMK PLM environment. Virtual environment can be used to develop and test needed functionalities without risking physical environment. Siemens

PLM software documentation is be used to clarify how the system should be installed and configured.

3.4   Demonstration & Evaluation & Communication

Installed and Configured Teamcenter PLM system must be demonstrated in order to show that results are acceptable. Demonstration is utilizing screen capture technology. Videos are recorded during system demonstration. Output is demonstration where both voice and video are used. For demonstration configured Teamcenter PLM system must be ready, use case steps must be clear and process steps must be clear.

Evaluation is done by using video recordings. Based on video recordings target audience can decide if solution is acceptable. Communication of the results are presented in the thesis. However, also other instructions were created for thesis instructor. Thesis is main communication format, but also video recordings of the system demonstration serve as communication channel of the results.

4. RESULTS AND ARTIFACT DESCRIPTION

General PLM related questions were asked from selected target group to clarify current and future situation of PLM education. First question in questionnaire was concerning the current PLM skills of graduated students. Only one PLM expert stated that PLM skills are good, 30 respondent opinion was that skills are reasonable and 36 respondent opinion was that skills are poor. Figure 24 is illustrating the results. Totally 67 PLM experts from Finnish Manufacturing industry answered to this question.
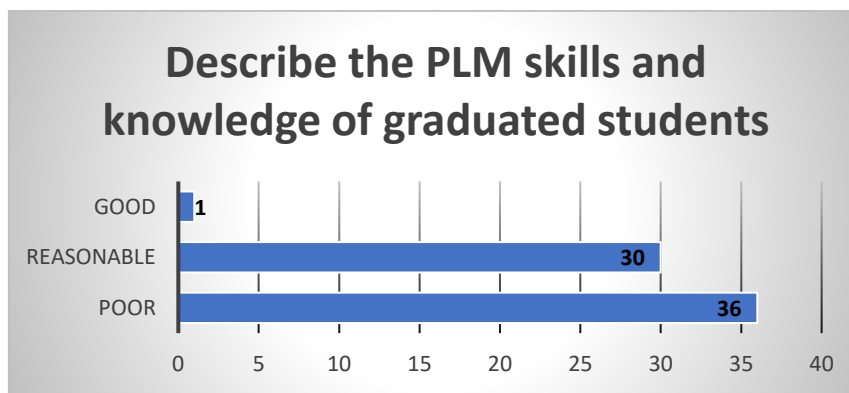

Figure 24. Current PLM skills of graduated students.

Second question in questionnaire was about PLM education method. Almost all PLM experts had opinion that both theoretical and software education should be provided to students. Figure 25 is illustrating the results. Totally 66 PLM experts from Finnish Manufacturing industry answered to this question.
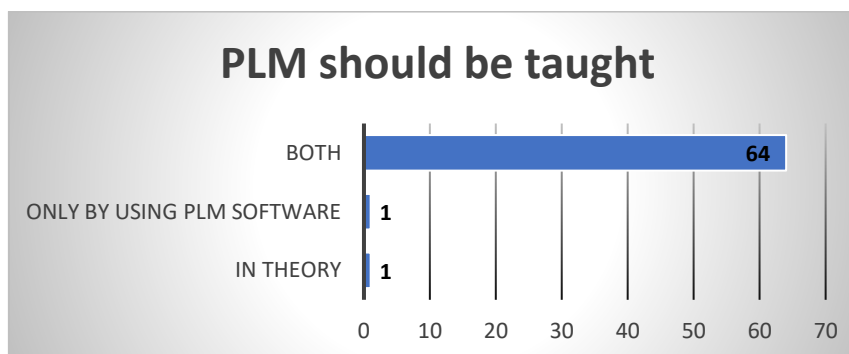

Figure 25. PLM education method opinions.

Third question was about arrangements of PLM education. Most of the respondents thought that PLM should be taught in specified PLM course, but it should be also integrated to other courses. Figure 26 is illustrating the results. Totally 68 PLM experts from Finnish Manufacturing industry answered to this question.

Figure 26. Arrangements of PLM education.

Fourth question was about Teamcenter PLM system usage in the future. Most of the respondents think that Teamcenter PLM system will be more heavily used in the company they are working at the moment. Picture 16 is illustrating the results. Totally 67 PLM experts from Finnish Manufacturing industry answered to this question.
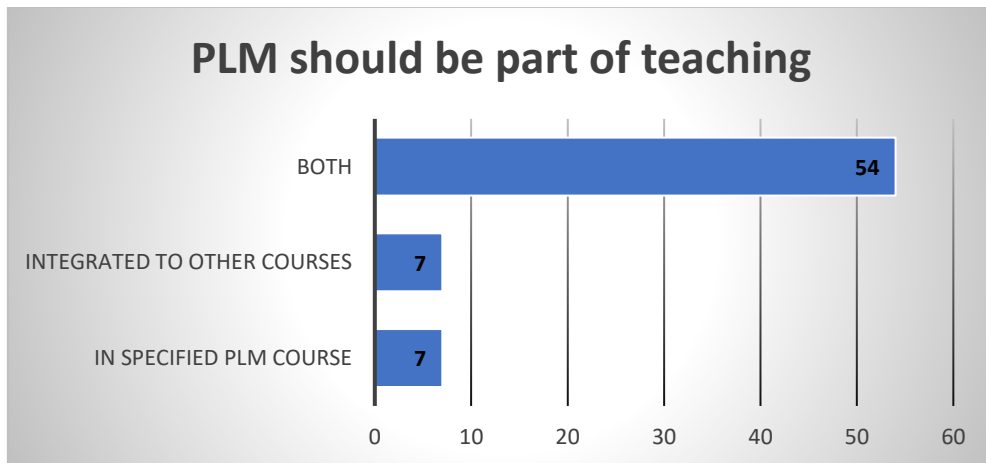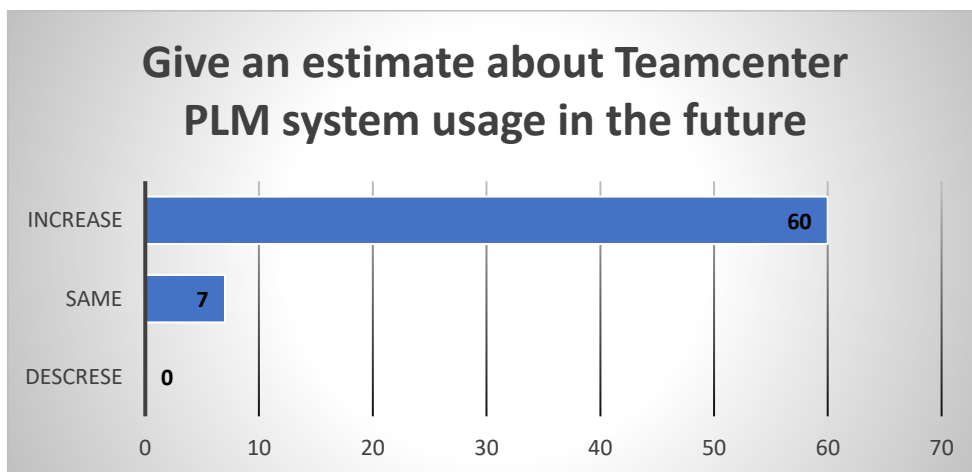

Figure 27. Teamcenter PLM system usage in the future.

Based on the results of these questions PLM teaching in degree level teaching should be increased, teaching should contain both theoretical teaching and practical software teaching in dedicated PLM course, but topic should also be considered in other product development and manufacturing courses. Furthermore, companies are going to utilize PLM system more heavily in the future, so more competent people are needed.

4.1 PLM Theoretical education

Questions concerning the PLM theoretical education were based on topics revealed by literature review. Wide range of PLM related headings were captured from literature and questionnaire was prepared based on those headings. PLM experts opinion about the importance of theoretical PLM topics are presented in Figure 28. Totally 63 PLM experts from Finnish Manufacturing industry answered to this question.
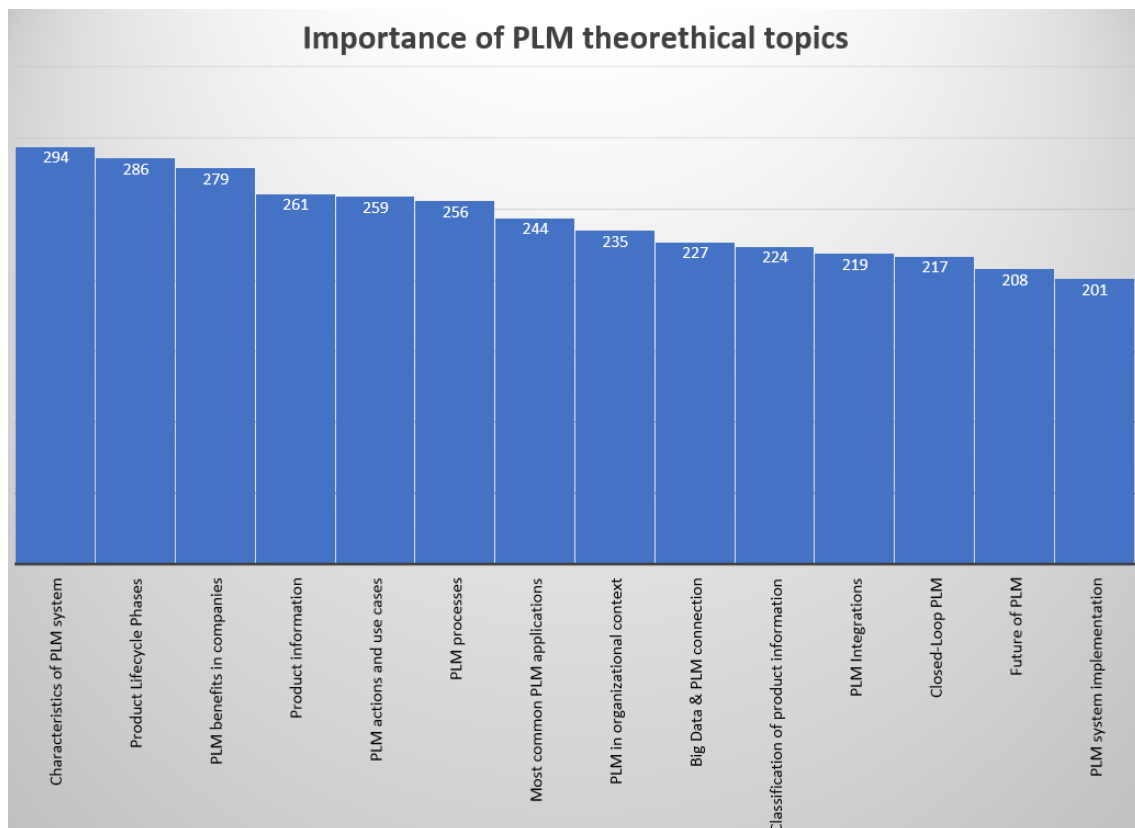

Figure 28. Importance of PLM theoretical topics.

Also open question was asked about the importance of other theoretical topics. PLM experts highlighted the basic understanding of PLM. Most common answer were the *"Most Common Practices and use Cases", "Basics", "Concepts and vocabulary".* Total list of answers is presented in annex 3.

Results indicate that top five areas in theoretical PLM degree level teaching should be characteristics of PLM system, Product lifecycle phases, PLM benefits and importance, Product information and PLM actions and use cases. Literature review of this thesis can be used as foundation for PLM theoretical degree level teaching.

4.2   PLM Practical education by using Teamcenter PLM software

Teamcenter PLM system specification is based on RQ1 – RQ5. Findings in most commonly used Teamcenter PLM system high level business solutions, applications, use cases and processes together with company opinions are used to create Teamcenter PLM system specification.

Secondary Data from PLM vendor indicates that 6 most commonly used Teamcenter PLM high level solutions are PLM foundation, Bill of Material Management, Mechanical Design Management, Visualization, Digital Mockup & Virtual Reality Management, Change Management and Product Configurator. These areas were selected for further analyze and artifact development. Solution areas are presented in Figure 29.
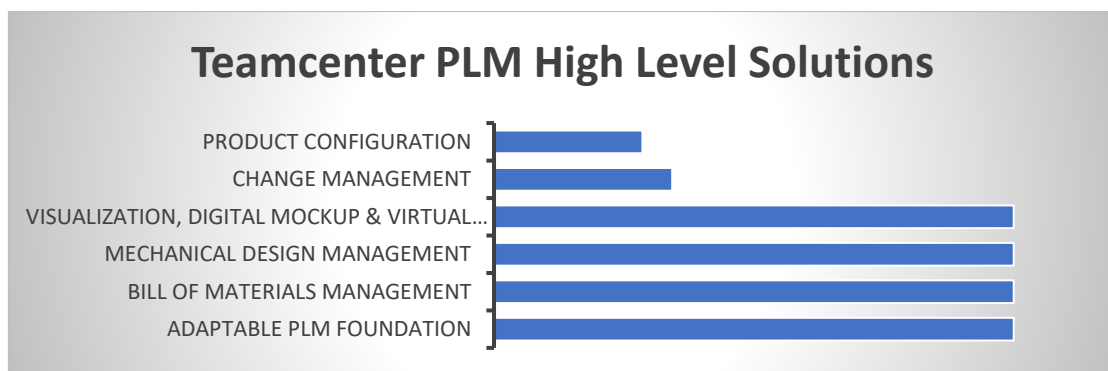
Figure 29. Importance of Teamcenter Business Solutions based on Secondary Data

Importance of Teamcenter PLM system Hight Level business solutions was also asked from PLM experts. Results are not exactly the same, but same six high level solution areas exist also in PLM expert opinions. Importance of Teamcenter PLM system high level solution areas based on answers of PLM professionals are presented in Figure 30. Totally 61 PLM experts from Finnish Manufacturing industry answered to this question.
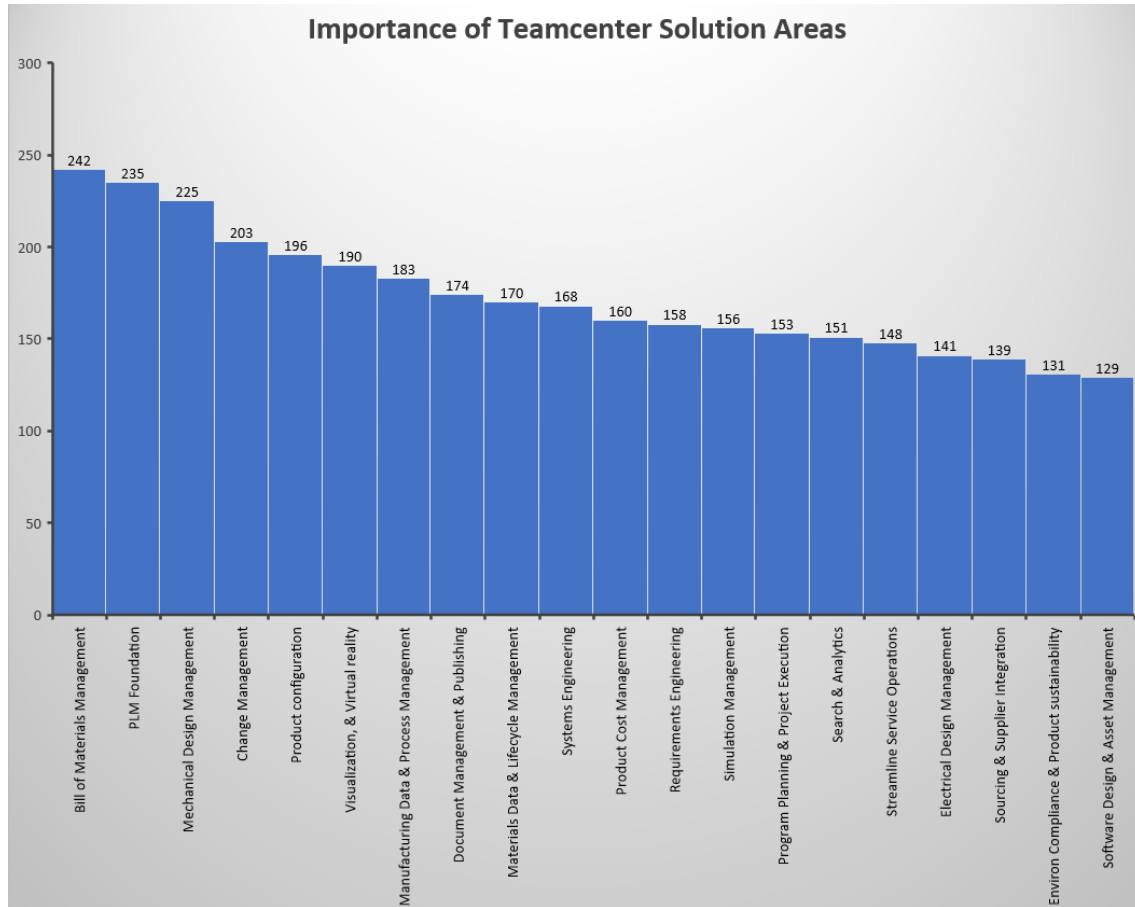

Figure 30. Importance of High Level Teamcenter Business Solutions based on PLM Professionals.

Six most important Teamcenter PLM system high level solution areas are Bill of Materials Management, PLM Foundation, Mechanical CAD Integration, Change Management, Product Configurator and visualization. Results are quite similar than results revealed by secondary data.

PLM experts from Finnish Manufacturing industry ranged the importance of Teamcenter PLM system solution areas. In addition, also open question was asked from PLM experts. Open question was *"What practical TEAMCENTER PLM skills graduated student should have?".* PLM experts highlighted the basic understanding and most commonly used functionalities of Teamcenter PLM system. Four most common answers were *"Most Common Practices and use Cases", "Basics", "MCAD integration"* and *"Understanding why PLM system is used".*

These high-level solutions should be part of practical PLM degree level teaching by using Teamcenter PLM software. System design and development must contain these solution areas.

4.2.1 Teamcenter PLM system applications, use cases and processes

Teamcenter PLM system must be installed and configured to support practical degree level teaching. Five high-level Teamcenter PLM system solution areas were selected for Teamcenter PLM software implementation. Results from secondary data and questionnaire were used to select most relevant solutions. These selected solutions are PLM Foundation, Bill of Materials Management, Mechanical CAD Integration, Visualization and Change Management.

Structured focus group interview was used to clarify the actual applications, use cases and processes in selected Teamcenter PLM solution areas. Seven PLM system vendor Implementation Specialists attended to focus group interview. Content of focus group interview template is presented in annex 2. Focus group interview revealed applications, use cases and processes which installed and configured Teamcenter PLM system must be able to fulfill. Table 12 presents the results of focus group interview.

Table 12. Common Applications and Use Cases in Selected Teamcenter Solution Areas

My Teamcenter Application		
Create Item	Start Workflow	Classify Data
Modify Item	Approve Workflow	Attach Data to items
View Items	Search Functionalities	Check-In/Check-out
Download Data		
Structure Manager Application		
Create Structure	Add items to BOM	Remove Items from BOM
Modify BOMline notes	Modify Quantities	Modify sequence numbers
Mechanical CAD integration Application		
Create 3D Part	Modify 3D Part Design	Save Design
Create 3D Assembly	Modify 3D Assembly	Clone Design
Create 2D Drawing	Modify 2D Drawing	Replace components
Create PDF/JT/DXF	Fill Drawing Attributes	
Visualization and Digital Mockup Application		
Screen Capture	Hiding Components	Volume
Measure	Query	Proximity
View commands	Section	PMI
Change Management Application		
Create PR	Create ECR	Create ECN
Assign Participants	Attach Reference/Impacted/Solution Items	Start PR/ECR/ECN Process

Processes were also discussed in focus group interview. Common opinion among Teamcenter PLM system implementation specialist were that valid processes depend who is using the system. Typical roles for system users are either Data Viewer, Engineering User or Product Manager. Data Viewer is not creating or modifying data while Engineers and Product Managers can create and modify data in the system. Therefore, processes are built in such way that Data Viewer process contains all the use cases which are not requiring data creation or modification. Engineering process contains all use cases except data Approving. Product Manager process is the same as Engineering user process, but

Product Manager can also Approve Data and release it into manufacturing. It was also noted, that different use cases can be completed in any order, so the process is exactly the same each time when system is used. Process should be demonstrated in high level. More important is to demonstrate the actual use cases what are included in the process.

Detailed steps of use cases in the system are presented in chapter 4.4.4. Detailed steps are generated by exploring the functions of the system, but also by reading the documentation provided by Siemens PLM software.

Detailed high-level process steps are presented in artifact demonstration chapter 4.5 Demonstrations took place in four different screen capture videos. First video is Introduction video. Second video presents Data Viewer user use cases and processes. Third video presents Engineering user processes and use cases. Fourth Video presents Product Manager processes and use cases.

4.3   Future Interests in Digital Manufacturing and Teamcenter PLM System

Aim of this study was also to clarify future trends of PLM in Finnish Manufacturing industry. Questions we asked from PLM professionals to clarify the trends. Degree level teaching is usually planned for certain future time period.

First question was "*What new TEAMCENTER PLM SYSTEM features you think that your company is going to implement or pilot in next 5 years?"*. Four most common answers were Product configurator, Product Cost Management, Visualization and Change management. Full list of answers is presented in annex 3.

Second question was *"What new DIGITAL MANUFACTURING features you think that your company is going to implement or pilot in next 5 years?".* Four Most common answers were Technomatix Products (Manufacturing Simulation), Virtual Reality Applications, Additive manufacturing and Digital Twin. Full list of answers is presented in annex 3.

Third question was *"What functionalities you think will move from other systems to TEAMCENTER PLM system in next five years?"*. Four most common answers were Product Configurator, ERP functionalities, Project Management and Manufacturing Management. Full list of answers is presented in annex 3.

These questions reveal the current PLM trends in high level. If degree level education is planned for next five years, these areas should also be considered at least in theoretical level. Finnish Manufacturing industry will need skilled employees to work in these areas.

4.4   Design and Development of Teamcenter PLM system for Practical teaching

Testing and development phase contains the installation and configuration of the Teamcenter PLM system. Virtual machine built on Oracle Virtual box platform serves as development and testing platform for Teamcenter PLM environment. Microsoft Windows Server 2016 Standard serves as operating system for this virtual machine. Microsoft SQL Server Express 2014 as Teamcenter PLM Database. Microsoft Operating system and SQL server installation are required as foundation for Teamcenter PLM system. However, those standard IT system components are not focus areas in this study and therefore detailed installation steps are excluded from this research. Figure 31 presents oracle virtual server User Interface.
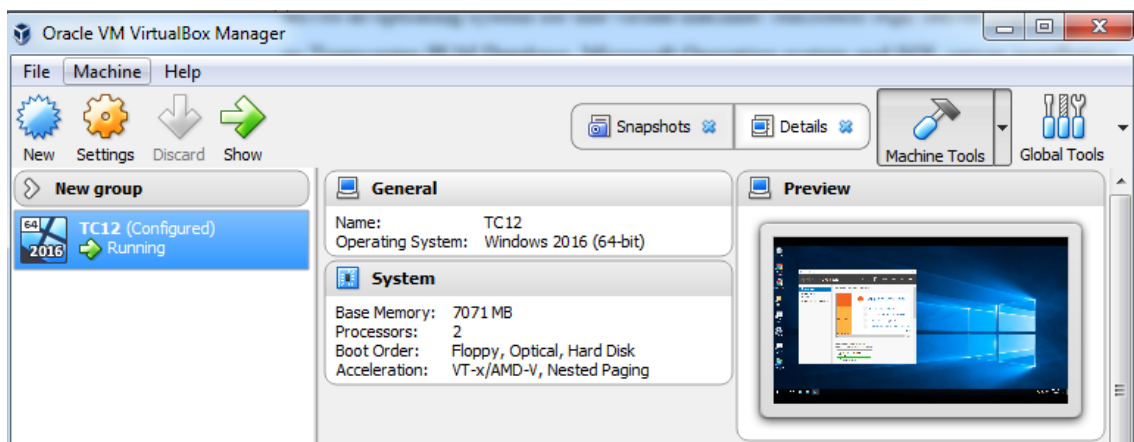

Figure 31. Oracle virtual server User Interface.

Teamcenter PLM system installation and configuration is only presented in high level. With any software implementation many small steps must be completed in order to create working software implementation. If further information is required, please refer to Teamcenter PLM system installation and configuration documentation provided by Siemens PLM software.

4.4.1 Teamcenter System Architecture

Teamcenter PLM system contains several components which must be installed and configured accordingly. Client tier provides Teamcenter rich client interfaces. Web tier responsible communication between enterprise tier and client tier. Enterprise tier provides pool for C++ server manager and server processes. Resource tier provides volumes, file servers, database and database servers. File Server cache provides data location which is close the user. File Client cache enables data access from workstations to server. Figure 32 illustrates Teamcenter Server Architecture.
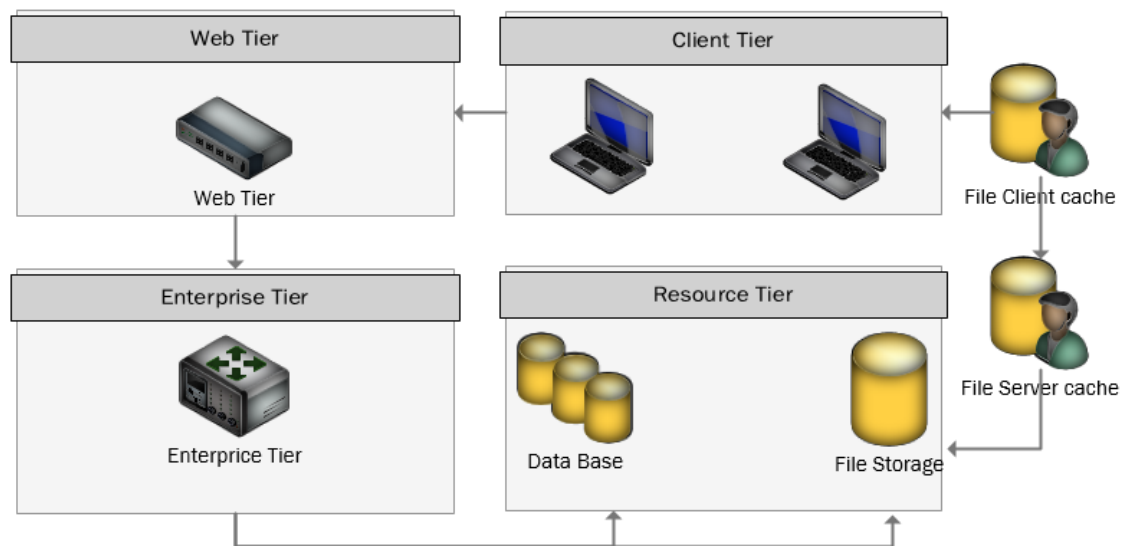

Figure 32. Teamcenter Server Architecture

Siemens PLM software delivers needed installation packages for Teamcenter Server architecture. However, also third-party components are needed. Examples of these third-

party components are Java, Microsoft SQL and Apache Tomcat. Those system components must be acquired separately.

4.4.2 Installation of Virtual development Environment.

Virtual Development environment installation requires two main installations steps. First step is Teamcenter Server installation. Second step is web tier installation. There are several technical possibilities to install and configure web tier since it requires also third-party component for data publishing. Apache Tomcat was selected to this environment since it is open source software and easy to install. Siemens PLM software provides documentation about the installation which can be followed during the installation. However, amount of possibilities and selections in installer is rather extensive, which sets challenges to installation of the software. Experience about Teamcenter installations is important in order to install proper Teamcenter PLM system.

4.4.2.1 Teamcenter Server Installation

Installation medias for Teamcenter were downloaded from Siemens PLM software Global Technical Access Center (GTAC). Installation Medias are .zip packages which must be extracted to Virtual Server. After unzip Installation Takes place by selecting tem.bat in "Run as Administrator mode". Installation User interface is presented in Figure 33.
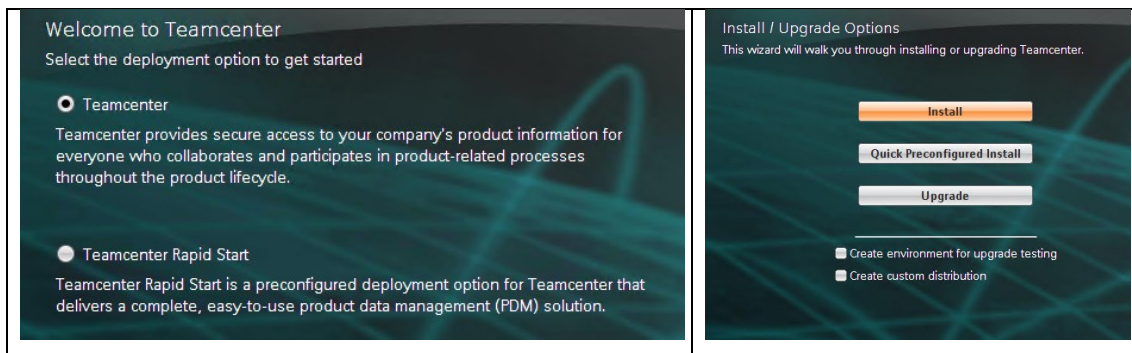

Figure 33. Installation UI

Installation Proceeds step by step in Installation User Interface. Detailed installation steps and selections are documented in annex 4. Installation was also documented by takin images from each step like presented in Figure 33.

Basic Solutions of the server side installation include Corporate Server, Active workspace server extensions, active workspace client and for administration purposest Rich client 2-Tier. Corporate server must be selected in every server side installation and in order to utilize active workspace also those components must be selected.

There are several mandatory steps in the installer which must take place. Even though these steps are important, gathered PLM system requirements does not affect to these settings. These steps are not depending about requirements since these steps must be taken place in any case when working Teamcenter PLM system is required. Server manager configurations, indexing service for searches, FMS/FCC settings, Database settings, Volume settings, FLEX License settings, Client communication configuration and other general port/path settings are mandatory. Threre are several things to consider when setting those variables. Windows Access to paths, free port numbers, supported java versions and Siemens recommendations about Teamcenter settings must be considered. Detailed selections are presented in annex 4.

Selection about Features to be installed is fully dependent about gathered PLM system requirements. To clarify, selected features determine which applications, use cases and processes can be used in Teamcenter PLM system. Secondary data about most commonly used Teamcenter PLM system solutions and industry opinnions gatheres by using questionnaire serves as foundation for selected features. Selected features are Active workspace client, document management client, relationship browser, Visualization server pool assigner, workflow, active content, NX Integration, Classification, Change Management, Mechanical CAD integration (MCAD) and Markup. Detailed list of selections are presented in annex 4. Succesfull Teamcenter Server side installation is illustrated in Figure 34.
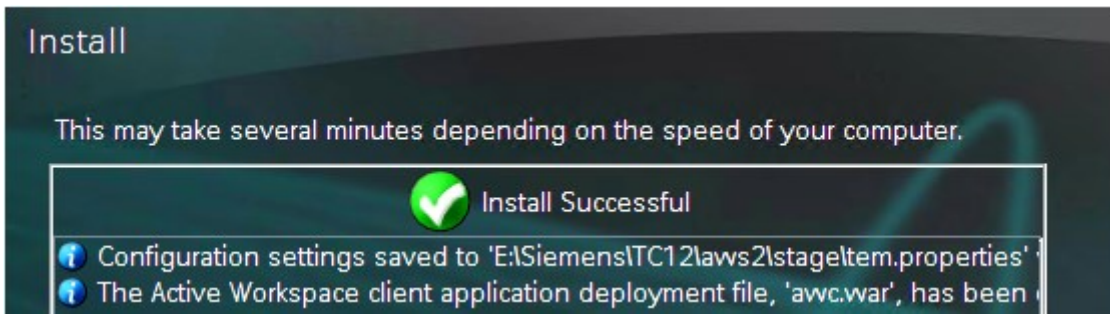
Figure 34. Successful Teamcenter Server side installation.

After all selections and options are checked, start button can be clicked to begin the server side installation. This is takin some time depending the speed of the computer. If any errors were made in selections, or options, installer may go to failure state. In that case additional adjustment is required. If selections and options are ok, installation is successful.

4.4.2.2   Teamcenter Web Tier Installation

Web Tier installation is required for Teamcenter communication between Enterprice Tier and Client Tier. Web Tier installation media is provided with teamcenter installation media. Detailed Installation steps are presented in Annex 6. Web Tier requires also third party component which is publishing the wanted content. Available options are .NET wetier, J2EE or Apache Tomcat. Like presented in Figure 35, Apache Tomcat was preferred since it is open source and commonly used solution. Tomcat Detailed installation steps are documented in annex 5.
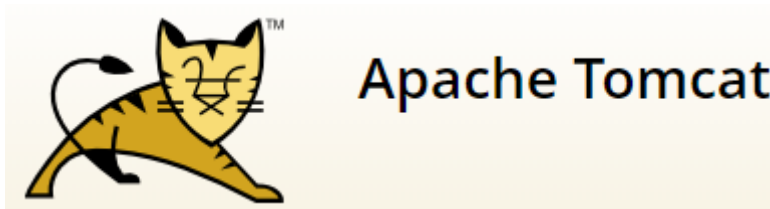

Figure 35. Apache Tomcat.

4.4.3 Overview about Teamcenter System Configurations

Teamcenter Server installation provides automatically most of the needed functionalities for degree level teaching. Needed functionalities are selected during the installation. However, installation is providing the functionalities as-is. Further Teamcenter PLM system configurations must be done by using other tools and system itself. In this section configurations are only presented in high level. Detailed configuration requires various steps in various places. If further information is required, please refer to Teamcenter PLM system installation and configuration documentation provided by Siemens PLM software. Documentation is providing detailed instructions and steps how system configuration can, and should be done.

Some additional attributes were configured into the Teamcenter PLM system Database. Attributes are created either by using Business Modeler IDE tool like presented in Figure 36 or like in this case by Classification administration application.

Business Object : Item

Property Name	Type	Storage Type	Inherited	Source	COTS
acl_bits	Attribute	Integer	✔	ⓑ POM_application_obje	✔
active_seq	Attribute	Integer	✔	ⓑ WorkspaceObject	✔
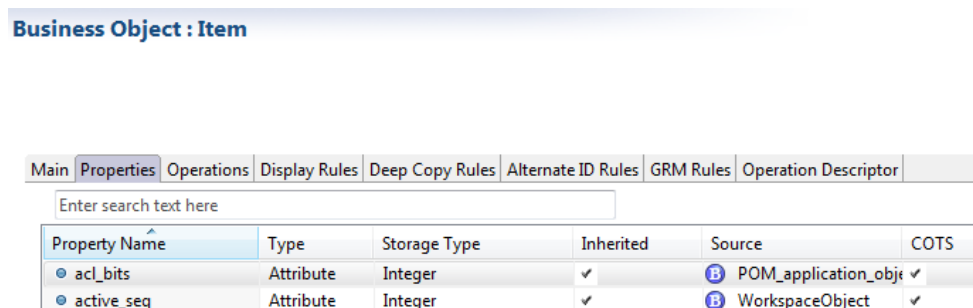
Figure 36. Business Modeler IDE UI

Some system preferences were also changeg. Preference changes can be done by using Teamcenter preference Manager. Figure 37 is illustrating preference manager UI.
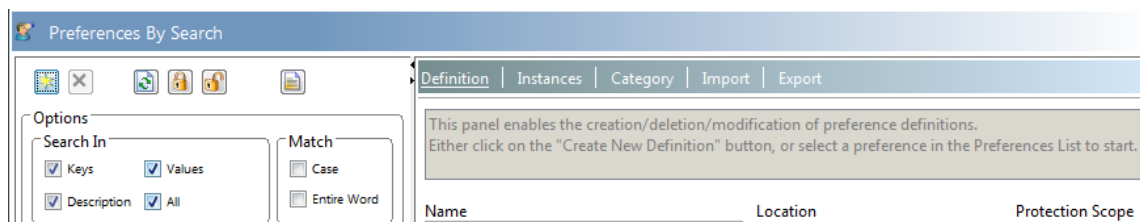
Figure 37. Preference Manager UI

Workflow modifications were also done. Workflow modifications can be done in Workflow designer, which resembles UML modeling like presented in Figure 38.
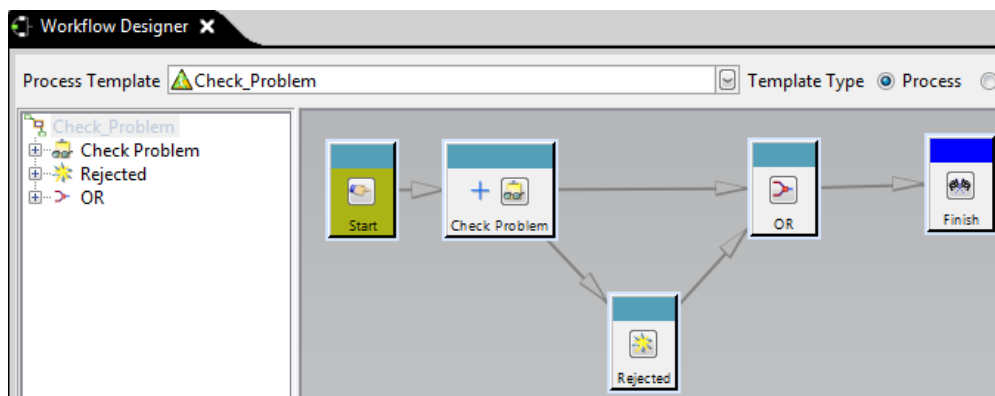
Figure 38. Teamcenter Workflow Designer.

Example projects were created by using Teamcenter Project Administration application. Projects are created by assigning needed attribute information and project Team. Figure 39 illustrates the example project.

Figure 39. Example Project Creation.

Product classification was configured based on VAMK projects. Classification enables effective product classification with certain attribute information. Figure 40 illustrates the created classification hierarchy.
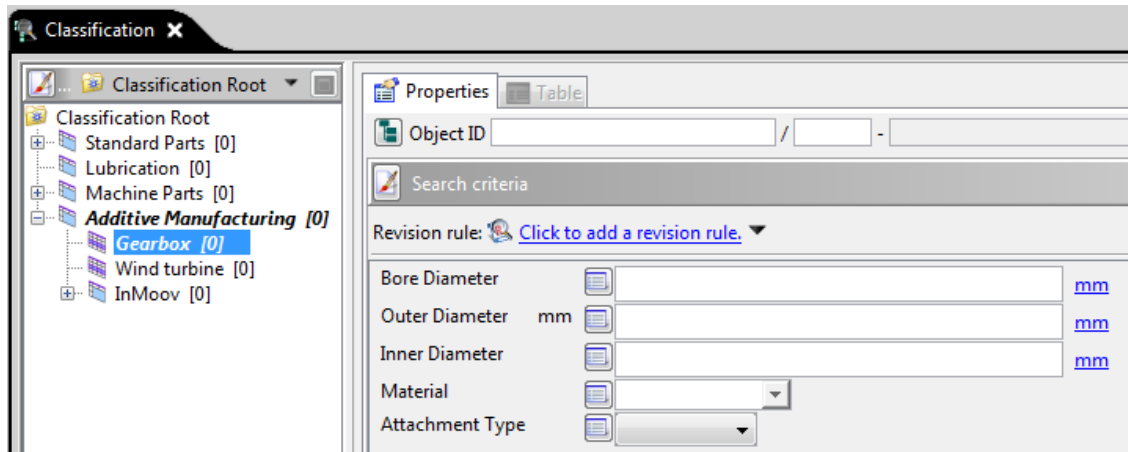
Figure 40. Classification hierarchy.

However, projects and classification hierarchy are not stable in teaching environment because product development projects and products are changing every year. That sets 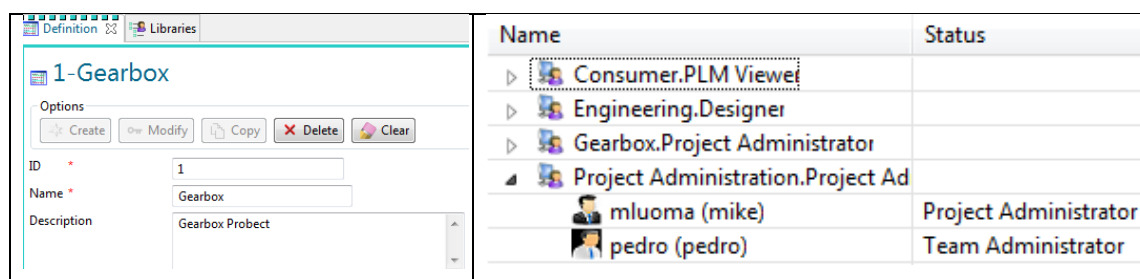challenges to project and classification hierarchy creation. System must be maintained in the future according educational needs.

4.4.4   Applications, Use Cases and Processes

Teamcenter has three different connection modes. Traditional connection modes are 2-Tier Rich Client and 4-Tier Rich client. Both connection modes require installation to client computer. Furthermore, 2-Tier clients are nowadays used mainly in server installations. Because of the performance benefits 4-Tier client is more commonly used in standard laptop and workstation installation. Contemporary connection mode is Active Workspace, which is providing access to Teamcenter PLM system by using web browser. Advantage in this connection mode is that no installations are needed to end users. Furthermore, PLM system can be also accessed from smartphones and tablets. User interface is different in Active Workspace and traditional 4-Tier client because of the

differences in technology. System functionalities remain the same, but active workspace does not have clear borders between applications. **In case of degree level students**, web browser-based solution is relevant because no installations are needed to student computers. Therefore, use cases and processes are documented by using Active Workspace user interface. Application borders are used to structure the headings. Use case steps were found by exploring Teamcenter Active Workspace web client, but also by reading Teamcenter PLM system documentation provided by Siemens PLM software.

4.4.4.1   PLM Foundation

PLM Foundation is not application itself. However, many actions in Teamcenter PLM system are done in My Teamcenter application, which contains many standard PLM system functionalities.

In context of PLM foundation also general topics should be considered. These topics include login into system, user settings, user profile, user interface, navigating in the system and general presentation of the buttons shown in user interface. These general topics are covered in demonstration chapter. Detailed use cases in PLM foundation are presented in table 13. Detailed steps of use cases can be also seen in demonstration videos.

Table 13. Detailed PLM Foundation Use Case Steps.

Use Case 1: Create Item	Use Case 2: Modify Item
Description: How to create new item	**Description:** How to modify items
Purpose: Create product data	**Purpose:** Change product data
Actors: Single user	**Actors:** Single user
Assumptions: Successful	**Assumptions:** Successful
Pre-Conditions: System access	**Pre-Conditions:** System Access
Normal Flow of Events:	**Normal Flow of Events:**
1. Click New Part	1. Select Item Revision
2. Check ID and Revision	2. Click Open
3. Type Name	3. Click Start Edit
4. Type Description	4. Edit Data
5. Type unit of measure	5. Click Save Edits
6. Click Add	**Post Conditions:** Successful
Post Conditions: Successful	**Alternative Flow:** Rich Client

Alternative Flow: Rich Client **Special Conditions:** None **Notes:**	**Special Conditions:** None **Notes:**

Use Case 3: View Items
Description: How to view items
Purpose: View product data
Actors: Single user
Assumptions: Successful
Pre-Conditions: System Access
Normal Flow of Events:
   1. Select Item Revision
   2. Click Open
   3. Navigate between overview, 3D, Where used, Attachments, History, Relations and Participants Tabs
Post Conditions: Successful
Alternative Flow: Rich Client
Special Conditions: None
Notes:
	Use Case 4: Start Workflow
	Description: Send Item to Workflow
	Purpose: Approve, Sent to ERP
	Actors: Single user
	Assumptions: Successful
	Pre-Conditions: System access
	Normal Flow of Events:
	   1. Select Item Revision
	   2. Click Open
	   3. Select Submit to Workflow
	   4. Select Quick Approve
	   5. Select Submit
	Post Conditions: Successful
	Alternative Flow: Rich Client
	Special Conditions: None
	Notes:

Use Case 5: Approve workflow
Description: How to Approve Items
Purpose: Approve Product Design
Actors: Single user
Assumptions: Successful
Pre-Conditions: System Access
Normal Flow of Events:
   1. Click Home Button
   2. Click Inbox
   3. Select Perform Approval Task
   4. Add Comment
   5. Click Approve
Post Conditions: Successful
Alternative Flow: Rich Client
Special Conditions: None
Notes:
	Use Case 6: Search
	Description: How to Search Items
	Purpose: Find Product and Information
	Actors: Single user
	Assumptions: Successful
	Pre-Conditions: System Access
	Normal Flow of Events:
	   1. Locate Search Tab
	   2. Type Key Word
	   3. Click Magnifier
	Post Conditions: Successful
	Alternative Flow: Advanced Search
	Special Conditions: None
	Notes: Search is Indexed

Use Case 7: Classify Data
Description: How to classify data
Purpose: Classification of data
Actors: Single user
Assumptions: Successful
Pre-Conditions: System access
Normal Flow of Events:
   1. Select Item
   2. Click Open
   3. Select Classify
   4. Select product class
	Use Case 8: Attach Data to Items
	Description: How to attach data to items
	Purpose: Adding product data
	Actors: Single user
	Assumptions: Successful
	Pre-Conditions: System access
	Normal Flow of Events:
	   1. Select Item
	   2. Click Open
	   3. Navigate to Attachments Tab
	   4. Click Add To

5. Fill attributes 6. Click classify **Post Conditions:** Successful **Alternative Flow:** Rich Client **Special Conditions:** None **Notes:**	5. Select File 6. Type Name 7. Check Dataset Type & Relation 8. Click Add **Post Conditions:** Successful **Alternative Flow:** Rich Client **Special Conditions:** None **Notes:**

Use Case 9: Download Data
Description: How to export files from TC
Purpose: Exporting Product Data
Actors: Single user
Assumptions: Successful
Pre-Conditions: System access
Normal Flow of Events:
  1. Select Item
  2. Click Open
  3. Navigate to Attachment Tab
  4. Select Download File
Post Conditions: Successful
Alternative Flow: Rich Client
Special Conditions: None
Notes:
	Use Case 10: Check In/Out
	Description: How to Check In/Out Items
	Purpose: Reserve product data
	Actors: Single user
	Assumptions: Successful
	Pre-Conditions: System access
	Normal Flow of Events:
	  1. Select Item
	  2. Click Open
	  3. Click Check-Out
	  4. Click Check-In
	Post Conditions: Successful
	Alternative Flow: Rich Client
	Special Conditions: None
	Notes:

Use case documentation in standardized way is not enough for degree level teaching. Video material created in demonstration can be used in PLM teaching. Furthermore, also training material should be created based on the presented use case steps.

4.4.4.2   Bill of Material Management

Most commonly used Bill of Materials Management application is Structure Manager. Structure manager is used to create, modify and view product structures. Furthermore, generic product structures can be used to create certain customer variants.   Product Structure is presented in multi-level presentation mode. Detailed structure manger use case steps are presented in table 14. Detailed steps of use cases can be also seen in demonstration videos.

Table 14. Detailed Use Case Steps in structure manager.

Use Case 1: Create Structure
Description: How to create BOM
Purpose: Bill of Material Creation
Actors: Single user
Assumptions: Successful
Pre-Conditions: System access
Normal Flow of Events:
  1. Select Item
  2. Click Open
  3. Select Content Tab
  4. Select Add
  5. Select Search
  6. Type Component you want to add into structure
  7. Click add
Post Conditions: Successful
Alternative Flow: Rich Client
Special Conditions: None
Notes:
	Use Case 2: Modify BOMLine Notes
	Description: How to Modity BOM
	Purpose: Bill of Material Modification
	Actors: Single user
	Assumptions: Successful
	Pre-Conditions: System access
	Normal Flow of Events:
	  1. Select Item
	  2. Click Open
	  3. Select Tree View
	  4. Click Start Edit
	  5. Modify BOM Notes
	  6. Click Save Edits
	Post Conditions: Successful
	Alternative Flow: Rich Client
	Special Conditions: None

Use Case 3: Add items to BOM
Description: How to Add items to BOM
Purpose: Bill of Material adding
Actors: Single user
Assumptions: Successful
Pre-Conditions: System access
Normal Flow of Events:
  1. Select Item
  2. Click Open
  3. Select Tree View
  4. Select Add
  5. Click Search
  6. Select Component
  7. Click Add
Post Conditions: Successful
Alternative Flow: Rich Client
Special Conditions: None
	Use Case 4: Modify BOMLine Notes
	Description: How to Modity BOM
	Purpose: Bill of Material Modification
	Actors: Single user
	Assumptions: Successful
	Pre-Conditions: System access
	Normal Flow of Events:
	  1. Select Item
	  2. Click Open
	  3. Select Tree View
	  4. Click Start Edit
	  5. Modify Quantity
	  6. Click Save Edits
	Post Conditions: Successful
	Alternative Flow: Rich Client
	Special Conditions: None

Use Case 5: Remove Items from BOM **Description:** How to Add items to BOM **Purpose:** Bill of Material adding **Actors:** Single user **Assumptions:** Successful **Pre-Conditions:** System access **Normal Flow of Events:**	**Use Case 6**: Modify BOMLine Notes **Description:** How to Modity BOM **Purpose:** Bill of Material Modification **Actors:** Single user **Assumptions:** Successful **Pre-Conditions:** System access **Normal Flow of Events:**

1. Select Item 2. Click Open 3. Select Tree View 4. Select Line to be removed 5. Click Remove 6. Confirm Remove **Post Conditions:** Successful **Alternative Flow:** Rich Client **Special Conditions:** None	1. Select Item 2. Click Open 3. Select Tree View 4. Click Start Edit 5. Modify Sequence Numbers 6. Click Save Edits 7. Click Configuration 8. Select Pack/Unpack Similar lines **Post Conditions:** Successful **Alternative Flow:** Rich Client

Use case documentation in standardized way is not enough for degree level teaching. Video material created in demonstration can be used in PLM teaching. Furthermore, also training material should be created based on the presented use case steps.

4.4.4.3 Mechanical Design Management

Mechanical Design Management contains various CAD integrations between Teamcenter PLM system and CAD software. Many CAD applications are supported. Most common CAD applications are NX, Solid Edge, SolidWorks, Autodesk Inventor, Catia and Creo. Even though CAD software provides have different functionalities, from integration point of view most common use cases remain the same. Common use cases are presented in table 15. Detailed steps of use cases can be also seen in demonstration videos.

Table 15. Detailed Use Case Steps in Mechanical CAD integration.

Use Case 1: Create 3D Part
Description: How to Create 3D Part
Purpose: Data Creation in MCAD
Actors: Single user
Assumptions: Successful
Pre-Conditions: System access
Normal Flow of Events:
  1. Open MCAD
  2. Click File – New - Item
  3. Select Model Template
  4. Assign ID and Name for Part
  5. Select Folder
  6. Click ok
	Use Case 2: Create 3D Assembly
	Description: How to Create 3D Assembly
	Purpose: Data Creation in MCAD
	Actors: Single user
	Assumptions: Successful
	Pre-Conditions: System access
	Normal Flow of Events:
	  1. Open MCAD
	  2. Click File – New - Item
	  3. Select Assembly Template
	  4. Assign ID and Name for Part
	  5. Select Folder
	  6. Click ok

Post Conditions: Successful **Alternative Flow:** None **Special Conditions:** None	**Post Conditions:** Successful **Alternative Flow:** None **Special Conditions:** None

Use Case 3: Create 2D Drawing
Description: How to Create 2D Drawing
Purpose: Data Creation in MCAD
Actors: Single user
Assumptions: Successful
Pre-Conditions: System access
Normal Flow of Events:
  1. Open MCAD
  2. Click File – New - Item
  3. Select Drawing Template
  4. Assign ID and Name for Part
  5. Select Reference 3D Part
  6. Click ok
Post Conditions: Successful
Alternative Flow: None
Special Conditions: None
	Use Case 4: Create PDF/JT/DXF
	Description: How to Create PDF/DXF/JT
	Purpose: Data Creation in MCAD
	Actors: Single user
	Assumptions: Successful
	Pre-Conditions: System access
	Normal Flow of Events:
	  1. Open MCAD
	  2. Click – File - Open
	  3. Select design and click ok
	  4. Select File – Export–PDF/DXF/JT
	  5. Type Name
	  6. Click ok
	Post Conditions: Successful
	Alternative Flow: None
	Special Conditions: None

Use Case 5: Modify 3D Part Design
Description: How to Modify 3D Part
Purpose: Data Modification in MCAD
Actors: Single user
Assumptions: Successful
Pre-Conditions: System access
Normal Flow of Events:
  1. Open MCAD
  2. Click Open
  3. Select Existing design
  4. Click ok
  5. Modify Design
Post Conditions: Successful
Alternative Flow: None
Special Conditions: None
	Use Case 6: Modify 3D Assembly
	Description: How to Modify Assembly
	Purpose: Data Modification in MCAD
	Actors: Single user
	Assumptions: Successful
	Pre-Conditions: System access
	Normal Flow of Events:
	  1. Open MCAD
	  2. Click Open
	  3. Select Existing Assembly
	  4. Click ok
	  5. Modify Assembly
	Post Conditions: Successful
	Alternative Flow: None
	Special Conditions: None

Use Case 7: Modify 2D Drawing
Description: How to modify drawing
Purpose: Data Creation in MCAD
Actors: Single user
Assumptions: Successful
Pre-Conditions: System access
Normal Flow of Events:
  1. Open MCAD
  2. Click Open
  3. Select Existing Drawing
  4. Click ok
  5. Modify Drawing
Post Conditions: Successful
	Use Case 8: Fill Drawing Attributes
	Description: How to fill attributes
	Purpose: Data Creation in MCAD
	Actors: Single user
	Assumptions: Successful
	Pre-Conditions: System access
	Normal Flow of Events:
	  1. Open MCAD
	  2. Open Drawing
	  3. Select File - Properties
	  4. Select Attribute - Modify
	  5. Click ok
	Post Conditions: Successful

Alternative Flow: None	Alternative Flow: None
Special Conditions: None	Special Conditions: None
Use Case 9: Save Design	Use Case 10: Clone Design
Description: How to Save Design	Description: How to clone design
Purpose: Data Creation in MCAD	Purpose: Data Creation in MCAD
Actors: Single user	Actors: Single user
Assumptions: Successful	Assumptions: Successful
Pre-Conditions: System access	Pre-Conditions: System access
Normal Flow of Events: 1. Open MCAD 2. Open existing Design 3. Select File - Save	Normal Flow of Events: 1. Open MCAD 2. Click Menu – Assemblies – Cloning – Create Clone 3. Click Add Assembly 4. Select Assembly to be cloned 5. Adjust options 6. Click Execute
Post Conditions: Successful	Post Conditions: Successful
Alternative Flow: None	Alternative Flow: None
Special Conditions: None	Special Conditions: None

Use case documentation in standardized way is not enough for degree level teaching. Video material created in demonstration can be used in PLM teaching. Furthermore, also training material should be created based on the presented use case steps.

4.4.4.4 Visualization and Digital Mockup

Visualization enables system user to work with managed visualization data by using viewer in Teamcenter PLM software. Viewer provides many visualization tools which can be used in web browser. Advantage is that user does not need to have CAD software in able to view and investigate visual data. Common use Cases are presented in table 16. Detailed steps of use cases can be also seen in demonstration videos.

Table 16. Detailed Use Case Steps in Teamcenter Visualization.

Use Case 1: Screen Capture and Markup	Use Case 2: Measure
Description: How to capture images	Description: How to Measure 3D
Purpose: Report product	Purpose: Report product
Actors: Single user	Actors: Single user

Assumptions: Successful
Pre-Conditions: System access
Normal Flow of Events:
  1. Select Item
  2. Click Open
  3. Navigate to 3D Tab
  4. Click Capture
Post Conditions: Successful
Alternative Flow: Rich Client
Special Conditions: None
	Assumptions: Successful
	Pre-Conditions: System access
	Normal Flow of Events:
	  1. Select Item
	  2. Click Open
	  3. Navigate to 3D Tab
	  4. Click Geometric Analysis
	  5. Click Measure
	  6. Pick Filters
	  7. Pick objects to measure
	Post Conditions: Successful
	Alternative Flow: Rich Client
	Special Conditions: None

Use Case 3: View Commands
Description: How to View 3D
Purpose: Report product
Actors: Single user
Assumptions: Successful
Pre-Conditions: System access
Normal Flow of Events:
  1. Select Item
  2. Click Open
  3. Navigate to 3D Tab
  4. Click Standard Views
  5. Select View from List
Post Conditions: Successful
Alternative Flow: Rich Client
Special Conditions: None
	Use Case 4: Hide Components
	Description: How to Hide 3D
	Purpose: Report product
	Actors: Single user
	Assumptions: Successful
	Pre-Conditions: System access
	Normal Flow of Events:
	  1. Select Item
	  2. Click Open
	  3. Navigate to 3D Tab
	  4. Visibility Control
	  5. Click Hide/Show
	Post Conditions: Successful
	Alternative Flow: Rich Client
	Special Conditions: None

Use Case 5: Query
Description: How to Query 3D
Purpose: Report product
Actors: Single user
Assumptions: Successful
Pre-Conditions: System access
Normal Flow of Events:
  1. Select Item
  8. Click Open
  9. Navigate to 3D Tab
  10. Click Geometric Analysis
  11. Click Query
  12. Pick Filters
  13. Pick objects to Query
Post Conditions: Successful
Alternative Flow: Rich Client
Special Conditions: None
	Use Case 6: Section
	Description: How to Section 3D
	Purpose: Report product
	Actors: Single user
	Assumptions: Successful
	Pre-Conditions: System access
	Normal Flow of Events:
	  1. Select Item
	  2. Click Open
	  3. Navigate to 3D Tab
	  4. Click Geometric Analysis
	  5. Click Section
	  6. Select Create Section
	  7. Select Plane
	  8. Select Coordinates
	Post Conditions: Successful
	Alternative Flow: Rich Client
	Special Conditions: None

Use Case 7: Volume	Use Case 8: Proximity
Description: How to Measure 3D	**Description:** How to Measure 3D
Purpose: Report product	**Purpose:** Report product
Actors: Single user	**Actors:** Single user
Assumptions: Successful	**Assumptions:** Successful
Pre-Conditions: System access	**Pre-Conditions:** System access
Normal Flow of Events:	**Normal Flow of Events:**
1. Select Item 2. Click Open 3. Navigate to 3D Tab 4. Click Geometric Analysis 5. Click Volume 6. Pick Component 7. Click Filter	1. Select Item 2. Click Open 3. Navigate to 3D Tab 4. Click Geometric Analysis 5. Click Proximity 6. Pick Component 7. Set Visibility distance 8. Click Filter
Post Conditions: Successful	**Post Conditions:** Successful
Alternative Flow: Rich Client	**Alternative Flow:** Rich Client
Special Conditions: None	**Special Conditions:** None

Use case documentation in standardized way is not enough for degree level teaching. Video material created in demonstration can be used in PLM teaching. Furthermore, also training material should be created based on the presented use case steps.

4.4.4.5   Change Management

Change manager supports to track product changes during lifecycle. Change management covers the whole process from Reporting the problem to change implementation. Typical Change Management in Teamcenter PLM system are called Problem Report (PR), Engineering Change Request (ECR) and Engineering Change Notice (ECN). Common use cases are presented in table 17. Detailed steps of use cases can be also seen in demonstration videos.

Table 17. Detailed Use Case Steps in Teamcenter Change Management.

Use Case 1: Create Problem report	Use Case 2: Create Change Request
Description: How to create PR:s	**Description:** How to create ECR:s
Purpose: Report Changes	**Purpose:** Report Changes
Actors: Single user	**Actors:** Single user
Assumptions: Successful	**Assumptions:** Successful

Pre-Conditions: System access
Normal Flow of Events:
   1. Select Item and Open
   2. Click Create Change
   3. Select Problem Report
   4. Type synopsis and description
   5. Click Submit
Post Conditions: Successful
Alternative Flow: Rich Client
Special Conditions: None
	Pre-Conditions: System access
	Normal Flow of Events:
	   1. Select Item and Open
	   2. Click Create Change
	   3. Select Change Request
	   4. Type synopsis and description
	   5. Click Submit
	Post Conditions: Successful
	Alternative Flow: Rich Client
	Special Conditions: None

Use Case 3: Create Change Notice
Description: How to create ECN:s
Purpose: Report Changes
Actors: Single user
Assumptions: Successful
Pre-Conditions: System access
Normal Flow of Events:
   1. Select Item and Open
   2. Click Create Change
   3. Select Change Notice
   4. Type synopsis and description
   5. Click Submit
Post Conditions: Successful
Alternative Flow: Rich Client
Special Conditions: None
	Use Case 4: Assign Participants
	Description: How to assign participants
	Purpose: Report Changes
	Actors: Single user
	Assumptions: Successful
	Pre-Conditions: System access
	Normal Flow of Events:
	   1. Select PR/ECR/ECN
	   2. Open PR/ECR/ECN
	   3. Select Assign Participants
	   4. Select Relevant Person from List
	   5. Click ok
	Post Conditions: Successful
	Alternative Flow: Rich Client
	Special Conditions: None

Use Case 5: Attach Reference/Impacted Solution Items
Description: How to attach items to change
Purpose: Report Changes
Actors: Single user
Assumptions: Successful
Pre-Conditions: System access
Normal Flow of Events:
   1. Select PR/ECR/ECN
   2. Open PR/ECR/ECN
   3. Take Copy of the Item
   4. Paste item to Attach Reference/Impacted/Solution Items Pseudofolder
   5. Click ok
Post Conditions: Successful
Alternative Flow: Rich Client
Special Conditions: None
	Use Case 6: Start PR/ECR/ECN Process
	Description: How to start change process
	Purpose: Report Changes
	Actors: Single user
	Assumptions: Successful
	Pre-Conditions: System access
	Normal Flow of Events:
	   1. Select PR/ECR/ECN
	   2. Open PR/ECR/ECN
	   3. Click submit to Workflow
	   4. Select PR/ECR/ECN process
	   5. Click Submit
	Post Conditions: Successful
	Alternative Flow: Rich Client
	Special Conditions: None

Use case documentation in standardized way is not enough for degree level teaching. Video material created in demonstration can be used in PLM teaching. Furthermore, also training material should be created based on the presented use case steps.

4.5   Demonstration

Demonstration covers most of the selected Teamcenter PLM system functionalities. Demonstration took place in configured Teamcenter PLM system with NX CAD Integration. Gearbox assembly served as main data in the demonstration. Demonstration was recorded by using screen capture technology. Teamcenter PLM system with NX CAD software was shown in in the screen while explaining the system functionality. Demonstration was divided into four different videos. First video was introduction video where general information about Product Lifecycle Management and Teamcenter PLM software was presented. Demo Setup is presented in Figure 41.
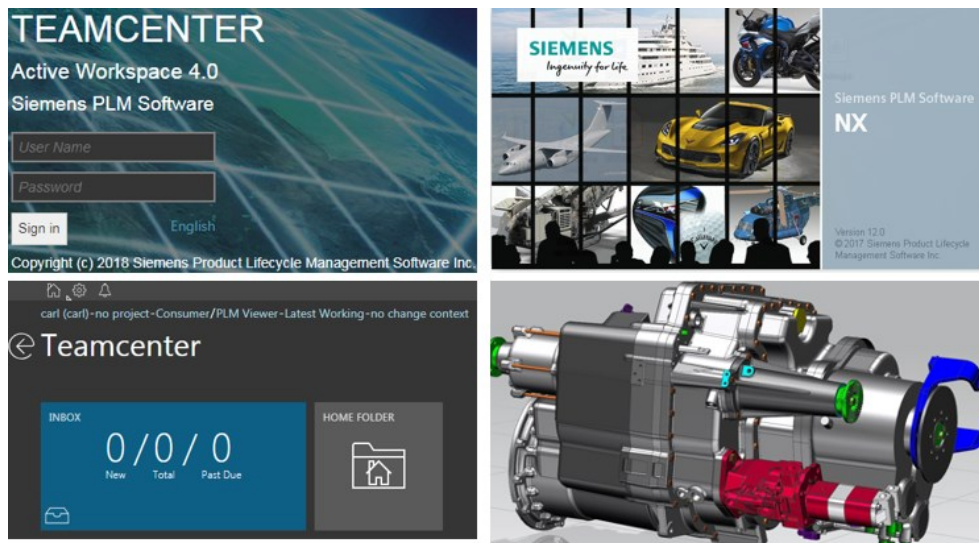
Figure 41. Demo Setup.

The actual demonstration flow was based on different roles in the system. Flow started by presenting User interface and some basic commands by using consumer level user. After that engineering role was used to demonstrate engineering activities. Finally,

Product Manager role was used to validate modified design and approve the revisions. Main steps of each role in demonstration are presented in following chapters.

4.5.1 Data Viewer or Consumer User

Consumer users can be categorized to Data viewers. Their main purpose is not to produce new product data into system. Viewing data and reporting are most important tasks in this role. Even though user is not producing new data, basic knowledge about PLM and also many PLM systems skills are needed. These needed skills are demonstrated by using configured PLM system. Main process for consumer user is presented in Figure 42.

Figure 42. Consumer User Demo Script.

Consumer user process was presented in demonstration Part 1 video. Demonstration video part 1 is 43 minutes presentation about consumer user functionalities.

4.5.2 Engineering User

Engineering user is both data viewer and data producer. Same use cases which were demonstrated in Consumer User Role are also valid for Engineering User. However, engineering user has many other possibilities in Teamcenter PLM system since engineering user is also producing product data in the system. Engineering user is traditionally using some CAD systems which is integrated to Teamcenter PLM system. In this demonstration NX cad system is used because Vaasa University of Applied sciences is using NX CAD software in teaching. Even though process and use cases for Engineering user are same as for data viewer user, process and demonstration describes only the additions to the process what Engineering group member is capable to accomplish. Main process for Engineering user is presented in Figure 43. Process and demonstration is excluding the steps which were already presented in consumer user section.

Figure 43. Engineering User Process.

Engineering user process was presented in demonstration Part 2 video. Demonstration video part 2 is 30 minutes presentation about Engineering user functionalities. Consumer user process and functionalities are also valid for engineers, but these are excluded from process and demonstration.

4.5.3   Product manager User

Product manager user validates the product information changes. He is also responsible about the whole design and about communication between subcontractors and manufacturers. Product manager can execute same activities like Consumer user and Engineering user. However, product manager user can also validate and approve new designs. Main process for Product Manager user is presented in Figure 44. Process and demonstration is excluding the steps which were already presented in consumer user and engineering user sections.

Figure 44. Product Manager User Process.

Product Manager user process was presented in demonstration Part 3 video. Demonstration video part 3 is 15 minutes presentation about Engineering user functionalities. Engineering and Consumer user process are also valid for Product Managers, but these are excluded from process and demonstration.

4.6 Evaluation

Four different videos demonstrated the most common Teamcenter PLM system applications, use cases and processes. Video demonstration indicates that Teamcenter PLM system can be used for determined use cases. Therefore, evaluation of the environment based on system demonstration is successful.

4.7 Communication

Master thesis serves as main communication channel. However, also additional documentation was created, but access to that documentation is restricted to certain group of people. Video demonstrations serve as secondary communication channel. Video demonstrations can be used to support degree level PLM teaching in Vaasa University of Applied Science, but also in University of Vaasa.

5. DISCUSSION

Product Lifecycle Management as concept and research topic is rather new. Some research about Product Lifecycle Management already exists, but the amount of research and literature is rather limited if compared for example to quality management research. In past years many Finnish Manufacturing companies have implemented Product Lifecycle Management system, but there are still many companies which do not have any PLM system. Even though many companies have already implemented Product Lifecycle Management system, this research indicates that Teamcenter PLM system usage will be increasing in the future. Furthermore, this research indicates that functionalities that are traditionally understood as ERP system functionalities are most probably moving towards PLM system. Main objective of this research was to clarify most commonly used Teamcenter PLM system functionalities in Finnish Manufacturing industry and implement the functionalities to support degree level PLM teaching. In addition to installed and configured PLM system also detailed use cases were documented in text and video formats. Achieved outcomes support the education in degree level teaching and therefore also serves Finnish manufacturing industry by providing skilled workforce to companies.

5.1 Learning outcomes

The research was based on Design Science Research Methodology introduced by Peffers et al. Objective of this research was not to test the selected research methodology. However, based on the experiences of this research, design science research methodology seems to be very good methodology for information system research, where information system is built to serve specific business needs.

This research provides information about the importance of product lifecycle management theoretical topics, but also practical information what are the most important Teamcenter PLM system solutions are the moment. Results are based on PLM vendor secondary data, but also on opinions of PLM professionals who work in Finnish

Manufacturing industry. However, the research is only snapshot of certain point of time. Currently information system technology is changing heavily because of the ongoing digitalization. Therefore, this research will be soon outdated.

Research provides also information what PLM professionals think about the current PLM skills of graduated students. Results indicate that skills are poor and more education is needed in order to provide skilled workforce to Finnish Manufacturing industry.

Further investigation about the most commonly used Teamcenter PLM solution areas revealed also applications, use cases and processes. Detailed instructions were created by exploring the Teamcenter PLM system functionalities but also by reading the documentation provided by Siemens PLM software. Instructions in text and video format can be further used to support degree level PLM teaching.

Installation and configuration of Teamcenter PLM system was also done during the research. Successful system implementation was achieved by exploring the software, but also by reading the documentation provided by Siemens PLM software.

Amount of new information and skills were rather extensive. Design science research method is suggesting additions to knowledge base that others can also use the gained information and skills. Results and process was documented in detailed level. However, installation and configuration of Teamcenter PLM system is difficult in detailed level, since amount of configuration and customization possibilities is rather extensive. If detailed information about Teamcenter PLM system installation and configuration is needed, it is recommended to refer to the extensive documentation provided by Siemens PLM software.

5.2   Theoretical and practical significance

Research provides both theoretical and practical outcomes, which can be used in degree level PLM teaching. Opinions from Finnish Manufacturing industry PLM professionals

can be considered when creating study plans. Results indicate that more education is needed and Teamcenter PLM system usage is increasing in the future. Furthermore, both theoretical and practical teaching should be included in degree level studies.

Literature review of the research summarizes the current research and other available literature. Literature review of this research can be used as source when planning degree level theoretical training material.

Practical software implementation and configuration serves mainly PLM teaching in Vaasa University of Applied Sciences. However, documented information can be used also in other Teamcenter PLM software implementation projects. Documented use cases and processes can be used also in other academic institutions. Created video material can be used as electrical training material in degree level teaching.

5.3   Limitations

This research main focus is the most commonly used Teamcenter PLM system solutions. However, the amount of Teamcenter PLM system functionalities is extensive. Furthermore, several integrations exist e.g. to digital manufacturing features, which were not considered in this research. Theoretical part of the research summarizes wide range of topics in Product Lifecycle Management, but practical part with Teamcenter PLM system is only focusing to most common functionalities.

The data of this research is limited to concern Teamcenter PLM software provided by Siemens PLM software. Referred PLM professionals are working mainly with Teamcenter PLM system. However, Product Lifecycle Management as concept is not tied into single software. Many other software providers and users exist in Finnish Manufacturing Industry, but those were excluded from this research.

5.4 Future Research

This research provides snapshot of certain point in time. Current digitalization era is driving software providers to implement new functionalities very quickly. Furthermore, companies are implementing new features continuously. Effect is that this research will be soon outdated. Similar research should be repeated in certain time period in order to keep results updated. Some indications about the future trends was also studied in this research. However, future estimate is not necessarily meaning that those functionalities will be really implemented.

Only selected Teamcenter PLM system functionalities were implemented and configured in this research. The amount of available functionalities is considerable. Future research can concentrate to implement more functionalities in Teamcenter PLM system.

6. CONCLUSION

Driver for this research was the wish to enhance PLM teaching in Vaasa University of Applied Sciences. Teamcenter PLM system is heavily used in Finland and specially in Pohjanmaa were Vaasa University of Applied Sciences is located. Therefore, degree level studies must include PLM teaching in order to serve Finnish Manufacturing Industry. Aim of this research was to enhance the degree level PLM teaching by clarifying the current status, needs and opinions about PLM teaching.

According PLM professionals from Finnish manufacturing industry, PLM skills and knowledge of graduated students is not in the level it could be. Only one respondent stated that skills are good, 36 stated that skills are poor, 30 stated that skills are reasonable. Furthermore, according the results Teamcenter PLM system will be more heavily used in the future so more skills are needed. This indicator is important since it states the opinion of Finnish Manufacturing industry experts.

Another statement is that both theoretical and practical PLM education is needed. Furthermore, education should be arranged in specified PLM course, but teaching should also be integrated to other product development and digital manufacturing courses. These finding should be considered when creating study plans for degree level teaching.

Importance of PLM theoretical topics are sorted by order of importance. In degree level studies resources and time reserved for teaching are not unlimited. Therefore, focus of the studies must be carefully considered in order to meet time limitations. When planning the focus of PLM theoretical topics, sorted order of importance table should be considered. Three most important focus points should be Characteristics of PLM system, Product Lifecycle Phases and PLM Benefits in companies. Detailed information about these topics can be found from literature review section of this study. Order of importance was generated based on the opinions of Finnish manufacturing industry PLM professionals.

Because of the time and resource limitation of the degree level studies, focus areas must also considered in practical PLM teaching. In this research Teamcenter PLM software most common high-level solution areas were clarified by using PLM vendor secondary data, but also by asking the same question from Finnish Manufacturing industry PLM professionals. Results from Secondary data and answers of PLM professionals indicate same high-level solution areas. Both results indicate that most important high-level solution areas are PLM Foundation, Bill of Material Management, Mechanical Cad Integration, Visualization and Change Management. Focus of degree level PLM teaching should cover at least these solution areas.

In order to teach these high-level solution areas, those must be investigated in more detailed level. Focus group interview with PLM implementation specialists revealed the content of these solution areas. Output of the focus group interview was list of most common Teamcenter PLM system applications, use cases and processes in selected high-level solution areas. The list itself is useful, but also installed and configured Teamcenter PLM system is needed to teach these functionalities. Teamcenter PLM system was installed and configured to meet these needs. Furthermore, detailed steps in each use case and process was documented in text and video formats.

Teamcenter system Installation and configuration is needed that practical education is possible. Furthermore, detailed use case documentation in text and video format is also important since practical education should contain these steps.

Plans for degree level teaching are usually done for keeping mind certain time period in the future. Even though digitalization is rewriting software functionalities very quickly, some future trends were also clarified. Results indicate that Product configurator will be important area in near future. Companies are either implementing new configurator or moving the configurator from some other system into PLM system. Product cost management was mentioned in several survey papers. Many functionalities which are traditionally considered as ERP functionalities seems to be moving towards PLM system. Manufacturing planning and simulation solutions were also mentioned in many survey

papers. These findings describe the current trends. However, future prediction is not necessarily meaning that these functionalities will be really implemented.

This study serves ad backbone for degree level PLM teaching. It provides general recommendations about PLM education, but also practical and theoretical guidelines how to plan and teach PLM studies in degree level teaching.

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APPENDICES

Annex 1

General Questions Concerning PLM

Describe the PLM skills and knowledge of graduated students

Poor ☐   Reasonable ☐   Good ☐

PLM should be taught

In theory ☐   Only by using PLM software ☐   Both ☐

PLM should be part of teaching

In specified PLM course ☐   Integrated to other courses ☐   Both ☐

Describe the importance of following topics by using scale 1-5 (5=very important)

Product Lifecycle Phases	From the first idea of the product until its disposed	
Closed-Loop PLM	Information flow from product to system	
Characteristics of PLM system	Single information source, items, traceability	
Big Data & PLM connection	Gathering information from product	
Product information	What information product can contain	
Classification of product information	Teamcenter Classification	
PLM in organizational context	Sales, design, manufacturing (author/consumer)	
PLM benefits in companies	Motivation to use PLM, purpose	
PLM actions and use cases	Most common use cases. E.g. approval, item create	
PLM processes	Engineering process and manufacturing process	
Most common PLM applications	E.g. Structure Manager, Change Manager	
Future of PLM	PLM future Roadmap	
PLM system implementation	PLM project most common phases	
PLM Integrations	Integrations to other systems	

Other important topics:

_____

_____

Questions Concerning Teamcenter PLM Software

Give an estimate about Teamcenter PLM system usage in the future

Decrease ☐   Same   ☐   Increase ☐

Describe the importance of Teamcenter Solutions areas by using scale 1-5 (5=very important)

PLM Foundation (My Teamcenter)		Product configuration	
Bill of Materials Management (structure man)		Product Cost Management	
Change Management		Requirements Engineering	
Document Management & Publishing		Program Planning & Project Execution	
Electrical Design Management		Search & Analytics	
Environ Compliance & Product sustainability		Simulation Management	
Manufacturing Data & Process Management		Software Design & Asset Management	
Materials Data & Lifecycle Management		Sourcing & Supplier Integration	
Mechanical Design Manag. (CAD integration)		Streamline Service Operations	
Systems Engineering		Visualization, & Virtual reality	

What new TEAMCENTER PLM SYSTEM features you think that your company is going to implement or pilot in next 5 years (what are the most interesting areas)

_____

What new DIGITAL MANUFACTURING features you think that your company is going to implement or pilot in next 5 years (what are the most interesting areas)

_____

What functionalities you think will move from other systems to TEAMCENTER PLM system in next five years (functionality transform OR integration)

_____

What practical TEAMCENTER PLM skills graduated student should have?

_____

Annex 2

Structured interview about Teamcenter PLM most common applications, use cases and processes

Define the most common applications in **PLM Foundation**

- Define the typical use-cases in that application

Define the most common applications in **Bill of Materials Management**

- Define the typical use-case in that application

Define the most common applications in **Mechanical Design Management**

- Define the typical use-case in that application

Define the most common applications in **Visualization, Digital Mockup, VR**

- Define the typical use-case in that application

Define the most common applications in **Change Management**

- Define the typical use-case in that application

Define the most common Processes used in Teamcenter PLM System

Annex 3
Questionnaire open questions full answers.

Other important topics
Most Common Practises and use Cases, Basics, Concepts, Wocabulay x 7
More PLM Education needed
Different Roles (Electrical, Mechanical)
Software Development Aspect
Affects in Organization + Benefits
Real Life Examples from industry
Ways of Working
Master Data and its quality

What new TEAMCENTER PLM SYSTEM features you think that your company is going to implement or pilot in next 5 years	
Product Configurator x 12 (+Rulestream)	Search & Analytics, Suplier Integration
Product Cost x 4	Industrial Design
Visualization x 3	Large assembly management
Change Mangement x 3	EDA (ECAD) integration
Active Workspace x 3	As Maintained Structure
Teamcenter Foundation 3	Bill of Process
Classification x 2	Service Operations
Simulation Data Management	Environmental Compliance
Asset Management	Requirements management
Virtual Reality / Optimization	Document Management
Datamanagement	Multi Structure Manager
Desing - Manufacturing Data Mangement	Systems Engineering
PMI	Sourcing and Suplier

What new DIGITAL MANUFACTURING features you think that your company is going to implement or pilot in next 5 years
Tecnomatix products (Manufacturing Simulation) x 9
Virtual Reality x 7
Additive Manufacturing x 4
Digital Twin x 2
Layout design
MES
Bill of Process Management
Machinery Control
Information Transfer from Sourcing to Design
NX CAM
Simulation Tools

MBOM
Optimization

What functionalities you think will move from other systems to TEAMCENTER PLM system in next five years	
Product Configurator x 6	Vendor Management
ERP functionalities x 3	Material Planning and Procurrement
Project Management x 2	As Maintained
Manufacturing Management x 2	Cost management
Requirements Management x 2	Service Planning
Document Management x 2	Learning Materian Management
ECAD + ERP functionalities	Supply Chain Management
Service Lifecycle Management	Digital Twin
Data Transfering Process	Environmental Compliance

What practical TEAMCENTER PLM skills graduated student should have
Most Common Practises and use Cases x 12
Basics x 11
MCAD integration x 6
Undestanding why it is used x 2
Systems Engineering
Structure Manager
Insight to PLM
More than just MCAD
BOM
Workflow
Change Manager
Foundation
BOM management
Change Management
Create, Import, Export
Product information Meaning and benefits to company

Annex 4
Detailed steps of Teamcenter PLM System Installation

Installation Step	Selected Variables
Configuration Name and ID	TC12 / TC12
Solutions	Corporate Server, Active Workspace server Extensions, Active Workspace Client, Rich Client 2-Tier
Features	
Base Install	Teamcenter Foundation, Teamcenter Rich Client 2-Tier,
Client	Active workspace Client (Java EE), Document Management Client, Relationship Browser, Visualizations Server Pool Assigner (Java EE), Workflow, Active content, NX integration, MCAD, Change Management, Markup, Classification
Indexing Server	Active Workspace Indexing Engine, Active Workspace Indexer,
Server Extension	Active Workspace, Active Content Structure, Active Workspace Document Management, NX for Active Workspace, workflow, visualization extension
Server Enhance.	Java EE Based Server Manager, Teamcenter Management Console
Integrat. for NX	NX Part Family Classification Integration
	NX foundation
Install Directory	D:\Siemens\TC12\
Key Manager Configuration	Do not Enable
Prequirisite Checks	-Passed-
File system Cache Service	FSC ID = FSC_WINVHH8991SCJ8_TCTEST
	Port = 4544
Operating System User	User = AD*******
	Password= *******

| Foundation	Selection = Create and Populate database, create new data directory
Foundation Database	Database Server = MS SQL Server Host = tc12 Port = 1433 Login Name = ****** Password = ****** Database Name = TCTEST Sytem User = ***** Pasword = ****** Database Path = C:\Program Files\Microsoft SQL Server\ Collation = Lation1_General_BIN Data Directory = D:\Siemens\tcdata12\
Volume information	Name = infodba_volume Directory = D:\volume\infodba_volume\
Foundation Settings	Windows Clients = D:\Temp\transientVolume_TCTEST UNIX clients = /tmp/transientVolume_TCTEST Generate server cache = yes Generate client cache = yes Environment = Production Environment
FLEX Licence Client	Port = 28000 Host = FIWS069
Teamcenter Administrative User	User = ******* Password = *****
Password Security	%TC_ROOT%\security
TcServer Character Encoding Settings	Canonical Name = ISO8859_1 Description = ISO8859-1, Latin alphabet No. 1

Multiplaxing Proxy	Port = 8087 TECS Admin Port = 8084
Indexing Engine Configuration	SOLR Files location = D:\Simens\tcdata12\ftsi\solr_schema_files JRE Location = C:\Java\jre8\
Communication Configuration	Pool ID = Pool A JMX RMI Port = 8088 Assignment Service Port = 8086 Server Host WIN-VHH8891SCJ8 Max Serversin Sub-pool = 30 Min Warm Servers = 1 Server Target = 0700 9, 1700 5 Logins Per minute = 0 Startup Mode = Service Daemon
Server Manager TreeCache Configuration	TreeCache Cluster Name = Cluster TCP Mode : Local Service Port = 17800 Connection Timeout = 15000 TreeCache Peers : Host = WIN-VHH8891SCJ8 Port = 17810
Active Workspace Indexer Settings	Standalone indexing environment Teamceter 4-tier URL = http://WIN-VHH8891SCJ8:8080/tc Maximum Teamcenter Connections = 5 Teamcenter retry Count = 5
Active Worksapce Indexer Type Selection	Active Workspace Object Data indexer Active Content Structure Indexer
Active Workspace Object Data Indexer Settings	Start Time Year=2019, Month 01, Day 5, Time 00:00 No End Time

Management Console LDAP Configurations	Protocol = idap Port = 15389
JMX Configuration Panel	Type = Server Manager ID = PoolA Host = WIN-VHH8891SCJ8 JMX RMI Port = 8088
Communication Configuration	Http Port = 8083 Do not Enable SSL
File Client Cache	Use New FCC = D:\Siemens\TC12\tccs
FCC Parents	FCS Assignment mode = clientmap Protocol = http Host = WIN-VHH8891SCJ8 Port = 4544
2-Tier Server Settings	Connection Port = 1572 TC_DATA = D:\Siemens\tcdata12 Connection Name = WIN-VHH8891SCJ8
Rich Client Settings	Do Not enable Online Help
Active Workspace Client Settings	Teamcenter 4-Tier URL = http://WIN-VHH8891SCJ8:8080/tc JDK Home C:\Java\jdk1.8.0_191 Use Bootstrap URLS = http://WIN-VHH8891SCJ8:4544
Teamcenter Visualization	Visualization Location = D:\Siemens\Teamcenter12\Visualization Install Teamcenter Visualization to above location = yes
License Level for Visualization	Mockup
Indexing Engine User	User = ******** Password = ******
Active Workspace Server Extension Settings	Search Engine URL = http://WIN-VHH8891SCJ8:8983/solr

Product Excellence Program	Do not Enable
Visualization Server Pool	Host = WIN-VHH8891SCJ8 Port = 55566 Server Side 4-Tier URL http://WIN-VHH8891SCJ8:8080/tc
Database Template Summary	
Confirmation	START
Installation Status	Installation Successful!

Annex 5
Apache Tomcat Installation Steps
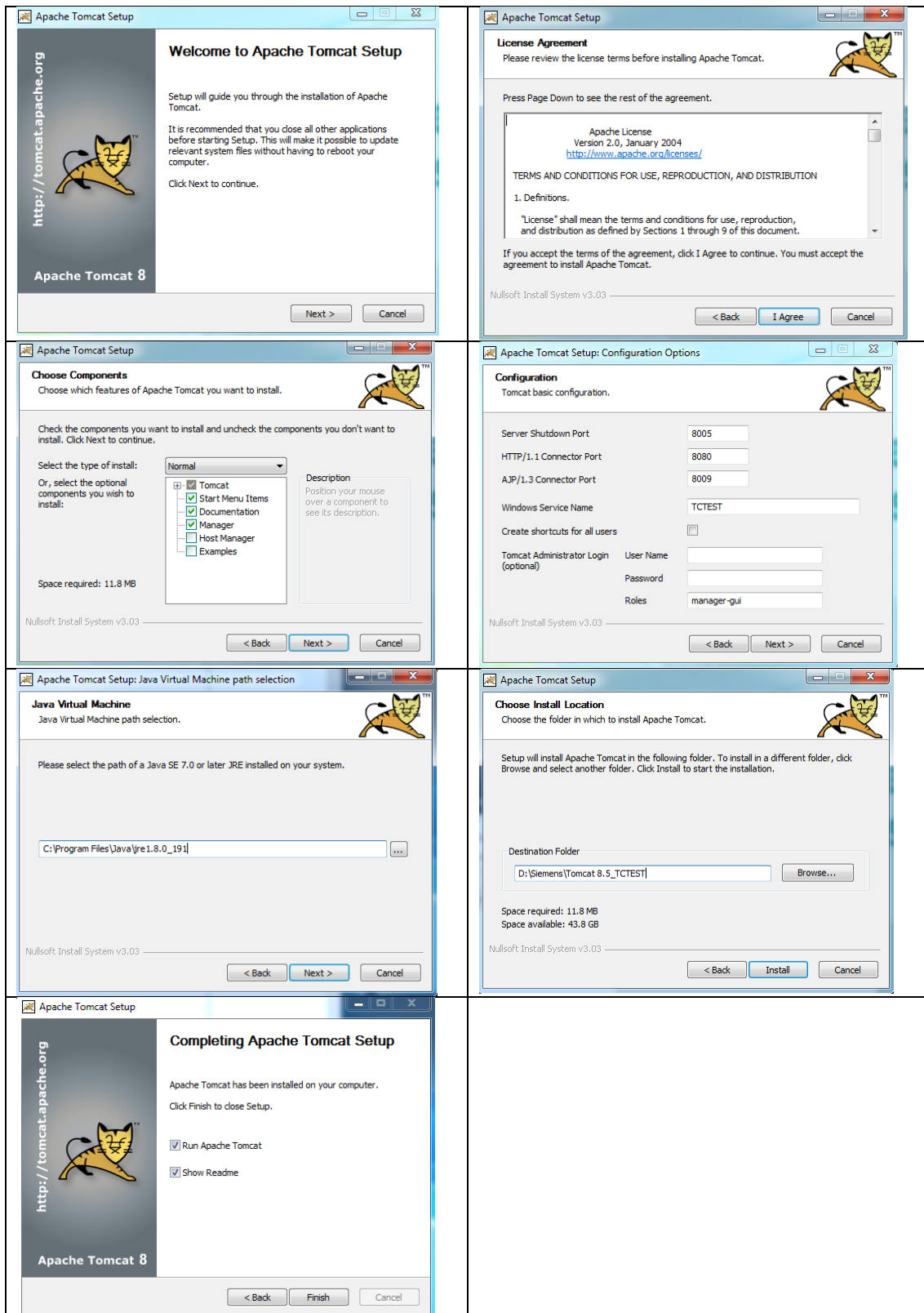
Annex 6
Teamcenter Web Tier Installation