LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY LUT
LUT School of Energy Systems
LUT Mechanical Engineering

Tomi Huoso

THE DESIGN AND IMPLEMENTATION OF A REUSABLE PART LIBRARY

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Examiner(s): Professor Harri Eskelinen
D. Sc. (Tech.) Vesa Tuomainen

TIIVISTELMÄ

Lappeenrannan-Lahden teknillinen yliopisto LUT
LUT School of Energy Systems
LUT Kone

Tomi Huoso

Kirjaston kehittäminen ja toteutus uudelleenkäytettäville osille

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D. Sc. (Tech.) Vesa Tuomainen

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Tämän diplomityön aiheena oli selvittää osakirjastolle kohdistuvat vaatimukset ja löytää paras vaihtoehto sen toteutukselle kansainvälisessä teollisuusyrityksessä. Työn teoreettisessa osuudessa tarkastellaan tuotetiedon hallinnan keskeisiä käsitteitä, osien luokittelua ja osien uudelleenkäyttöä. Työssä selvitettiin myös nykyaikaisen tuotteen elinkaaren hallintajärjestelmän (PLM) tarjoamat mahdollisuudet osien luokittelemiseksi ja osien uudelleenkäytön edistämiseksi.

Diplomityön osana toteutetussa tapaustutkimuksessa kuvataan kohdeyrityksen tuotetiedon hallintaa liittyvät nykyiset käytännöt ja ongelmakohdat. Osakirjastoihin kohdistuvat kehitysmahdollisuudet ja tarpeet on kartoitettu haastattelemalla tuotesuunnittelijoita sekä tuotetiedonhallinnan erityisasiantuntijoita kohdeyrityksessä. Tunnistettujen vaatimusten pohjalta kohdeyrityksen PLM-järjestelmän kehitysympäristö päivitettiin vastaamaan kohdeyrityksen tarpeita.

Työn tuloksena syntynyt kirjaston hallintamalli ottaa huomioon kohdeyrityksen organisaatiorakenteen, eri objektityypit ja erityyppisiin osiin kohdistuvat vaatimukset. Osana tutkimusta kohdeyrityksen käyttöön kehitettiin malli osa- sekä suunnittelukirjastoille. Lisäksi työssä ehdotetaan uuden osien luokittelumallin käyttöönottamista kohdeyrityksessä.

Esitetty malli sai positiivisien vastaanoton kohdeyrityksessä. Sen koettiin vastaavan yrityksen tarpeita ja olevan yhdenmukainen tulevan PLM-projektin vaatimusten kanssa. Yrityksen PLM-järjestelmän kautta käyttäjä voi suorittaa avainsanahakuja ja suodattaa tuloksia käyttämällä osan teknisiä ominaisuuksia. Nopea haku yhdessä osien visualisoinnin kanssa nopeuttaa osien hakua ja hakutulosten käsittelyä. Standardiosakirjaston käyttöönottamisen vaatima osaduplikaattien läpikäynti ja luokittelutietojen etsiminen on työlästä, koska nykyisestä tuotetiedon hallintajärjestelmästä saatavat tiedot ovat osittain puutteellisia.

ABSTRACT

Lappeenranta-Lahti University of Technology LUT
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Tomi Huoso

The design and implementation of a reusable part library

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The aim of this thesis was to find out the requirements for a reusable part library and to find the best alternative for its implementation in an international industrial company. The theoretical part of the thesis presents the key concepts of product information management, the classification of parts, and the reuse of parts. The work also explores the possibilities offered by a modern product lifecycle management system (PLM) to classify parts and promote the reuse of parts.

The practical part of the thesis was carried out as a case study. The case study describes the case company's current practices to manage product information and problem areas. The libraries development opportunities and needs for the development have been mapped by interviewing product designers and product information management specialists in the case company. Based on the recognized requirements the development environment of the target company's PLM system was updated to meet the company's needs.

A management model for the library created as a result of the thesis, considers the organizational structure of the target company, different object types and requirements for different types of parts. As part of the research a model was developed for part and knowledge libraries for the use by target company. In addition, the thesis proposes implementing a new parts classification model in the case company.

The proposed model was received positively in the target company. It was perceived to meet the needs of the company and is consistent with the requirements of the upcoming PLM project. The PLM system allows a user to perform keyword searches and filter results using technical characteristics of the part. A quick search in conjunction with the visualization of parts speeds up the search and processing of results. The process of reviewing duplicates of standard parts and searching for classification attributes is cumbersome because the information in the current product information management system is partially incomplete.

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Vantaa, October 18, 2020

Tomi Huoso

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LIST OF SYMBOLS AND ABBREVIATIONS

ATTRIBUTE	Information describing the object
COMMONSPACE	Consists of the sum of folder locations that are accessible to any user in the PDM system
DATA SERVER	PLM application’s data server that manages the metadata, store information and relations between objects
DMS	Document Management System
DUPLICATE	A part that is identical to another part but stored with a different material code
ECAD	Electronic Computer-Aided Design software
ECM	Engineering Change Management
ERP	Enterprise Resource Planning
GENERIC	A base object that is used to generate instances
IDF	Intermediate Data Format
INSTANCE	The child of generic object
MBOM	A manufacturing bill of materials
MCAD	Mechanical Computer-Aided Design software
MODULE	Exchangeable parts or options of a product
MRP	Material Requirements Planning
OBJECT	An article stored in an information management system that usually contains a file
PART	PLM application’s database object (WTPart) that represents a physical component or assembly
PDM	Product Data Management
PIM	Product Information Management
PLM	Product Lifecycle Management
PRODUCT ELEMENT	A part or assembly that may be in more than one separate product
WORKSPACE	Designer's own local workspace in PDM application

1 INTRODUCTION

In virtually every industrial segment, the quantity of products and parts used for building them has been increasing for the past decades. With the development of technology, the hardware solutions of the products have become more generic and instead the software together with the electronics make up most of the variations of the product. Case company's products rely on electronic processors and controls driven by the embedded software to reach remarkable level of precision in motor control. The effective management of product platform and its parts over its lifecycle is essential in order to stay competitive.

One of the key methods for decreasing product's design and maintenance cost is related to reuse of existing parts by standardizing products. To bring the products to market as fast and as mature as possible the number of new parts should be kept as low as possible. Traditionally, the design engineers responsible for new product development must know product offering and their features well in order to find the best existing design solutions and parts to be reused. Virtually in all the cases, the designer needs to pile up the information required for reuse from multiple systems as the parts data is scattered around the information systems, resulting in time consuming detective work and frustration. Poorly performed part selection can compromise product quality or increased manufacturing cost, if designer decides to recreate parts which equivalent was already available through supply channel. However, both challenges can be resolved by making parts easy to search and key information easily available. This can be achieved by creating a library for parts used in existing products.

Product lifecycle management system aim to integrate ECAD and MCAD tools in order to manage all information produced throughout the product's lifecycle. Product lifecycle management (PLM) system can increase design productivity by integrating the disconnected tools and processes. Facilitating collaborative engineering across the enterprise enables decreasing product costs and improving quality. PLM system enables a global design team to share their data easily during the product design phase within the product context. Fundamental of PLM is to have standards-based interchange format for transferring data. In addition, the system provides common platform for communication and information sharing across different products and domains. By implementing the part library to the PLM system, the item managers can manage the attributes in part libraries as well as relationships between the objects. Centralized part management can reduce part duplication, prevent engineers to use unapproved or obsolete parts and help assigning compliance data. By transferring product information management to PLM system from production process centric environments a company creates potential to increase design department’s productivity and unlock cost savings in products.

1.1 Description of the problem

Today, the case company’s design teams from all over the world collaborate to launch new products to competitive market. Manufacturing of the product often happen in different location than where the design was created and, in this situation, it is important to have the design finalized and verified at early stage, to avoid time consuming problem solving during the production ramp-up. The product must be released to market within certain time period and time-consuming design iterations have potential to cause significant additional costs to the company. In the past due to the different competitive environment, the need for product platform management was not recognized and part duplicates were commonly created. Decentralized design environment and loose processes lead to poor part reuse as the development projects were driven by silo mentality. Due to growth in product offering and engineering organization the company’s enterprise resource planning (ERP) and product data management (PDM) systems became saturated with inconsistent data. Designers from different functions have created objects according to their preference and the system has multiple identifiers for the same part, making it difficult to find reliable information about documents and parts in the system.

The lifespan of case company’s products are longer than in many other electronic products categories. It’s expected lifetime can be, depending on the size the unit, from 10 – 30 years. However, at the same time technology is outdating on faster phase, as new innovations are created constantly, and if product development project take long, competitors might be able to do market undercut. When competitors launch new products with more features or cheaper price on the market, the competing company must respond by dropping prices or update their existing product rapidly. Falling behind the competitor in key product category have large negative impact on company’s sale, because many of the industrial customers prefer to purchase their products from one supplier. Similarly, developing an industry product that doesn’t meet customer’s expectations will hurt company and its reputation. Therefore, the product must be right at the time of the market release and there is no time for iterative product development as in past when the company was known as the technology pioneer in its own segment.

The case company makes constant process and tool development to adapt in changing global operation environment. Division has invested heavily on design tools and as a result its designers have the latest CAD design tools, PLM application’s PDM system for mechanical design and separate PLM system for electrical design. The organization has done a lot of internal advancements to develop the ERP application in order to get the system support operational requirements and to get Just-In-Time working. The company has also been investing a lot on production lines to improve production capacity and increase automation level. Despite the changes and investments made, the management of the company has not seen enough improvement in performance, and one of the main drivers of the problems is that the product development projects take too long time, and as a result, products are often late on market or product's maturity is not sufficient when released.

1.2 ABB Motion business

ABB Motion business is the largest supplier of the motors and drive products in the world. ABB Group is based in Switzerland, operate in approximately 100 countries and employs approximately 110,000 people around the world. The ABB Motion business consist of six independent divisions. Motion business employed in 2019 approximately 20,000 people. (ABB 2019a) ABB’s aim products enhance customers' businesses but at the same improved energy efficiency and reduce consumption of natural resources. The aspects of sustainability are built into the operation model through a process called ABB Gate Model. (ABB 2020a) The division responsible for low power drive business, is the leading global manufacturer in the market segment. The division employs approximately 2,500 people worldwide and produce more than a million units annually. Product development activities are focused mainly in 3 countries and most of the engineering organization is in Helsinki campus. In recent years engineering organizations in USA and China have been growing and taking more responsibility in carrying out the implementation of the global product development projects.

1.3 Objectives and research questions

Modern PDM / PLM systems offer engineering organization new ways of working and enable more automated processes, as the part management focus transfer from the ERP system to the PLM system. ABB has identified the digital product data management as one of the enabling components in the company's future strategy to move towards Industry 4.0 and a new organizational structure (ABB 2019a). Management's fourfold vision for the PLM system is that product development would stop re-inventing the wheel and reduce time to market by enabling collaboration across different functions and geographical locations. In company's current design process, designers in different design areas use different computer-aided design systems (CAD) and once the design is completed, the drawing is transferred to ERP manufacturing plant and at same made available to other functions in organization.

To facilitate business initiatives the company is developing product architecture to support increasing demand for platform products, that are easily customizable to meet the demands of specific market segments or application. In order to speed up the design process, and fewer errors in manufacturing, the business have initiated PLM system project to move design from ERP system centric approach to integrated PLM driven system and processes. In the early phase of forming research questions, they were related on launching product to market in faster schedule, and how design system can support this objective. Research hypothesis is, that enterprise-wide part library management in PLM system have a significant role in ensuring that accurate and up to date product data is available across the organization. Objective of the research is to enable efficient part reuse process by developing a library model that support this. The research objectives are formulated into these research questions:

1. Which elements of a part library enable the designer to find existing parts so that they can be used more often in the design of a new product and thus reduce the number of parts to be redesigned?
2. How should the part library be structured and managed so that the information it provides is adequate, reliable and unambiguous?

First of the research questions is needed to recognize the elements that the part library needs to include in order to improve product development efficiency. The second research question focus on technical implementation and governance model of the part library. The question also relates to the roles in organization, how to take environment and sustainability requirements into consideration, and furthermore how to support product platform element management.

1.4 Research scope and constrains

One of the tasks is to study how PLM systems part libraries are commonly implemented to design environment and how different type of implementations impact on usability. Another essential task is familiarization of part data model and classification model, since it is applied to for part categorization and may have future potential for further applications in areas such as supplier data management, compliance and safety data management, environmental compliance data management and service catalogue management. Naturally, another practical task is to evaluate the design process performance improvements of classification model implemented and estimate effect on reducing part duplicates and show how process prevent engineers to use unapproved, obsolete or end-of-life parts.

In addition to the practical implementation, the aspects related to the part library governance and workflow process are studied. One of the key questions is, how the upkeep of the library should be arranged to ensure that information stay consistent and reliable as new parts are added.

At the beginning of the research, there was no unified policy for managing part libraries for different type of parts. Some of the parts, example fasteners, implemented loosely defined process and were listed in excels, but equally all, the practices were variegated from the efficient part reuse point of view. The aim of the research data collection process is to collect library management models from many different actors for the benefit of all, as illustrated in Figure 1.

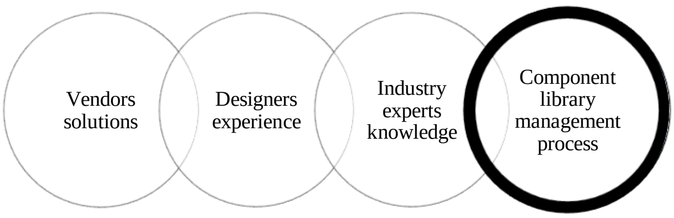

Figure 1. Part library management process objectives from a data collection perspective.

The reusable part library study is limited to parts owned by the case company's division. The set of product parts does not include part types managed completely outside division's MCAD application, such as the PCBA part library, nor the raw materials library.

1.5 Structure of the thesis

The thesis is composed of two parts, the literature review and the case study. The introduction presents the motivation and the objectives of the research, which were determined by the case company. Chapter 2 describes the research approach and methodology for exploring the benefits of a library structure to be implemented. Chapter 3 gives a short introduction to the topic presenting the theories and models behind part classification, product data management and part library management methods used in this thesis. Chapter 4 describes the target company's current information management system to the extent applicable to the study. In addition, the reader gets understanding of the part libraries the company currently have, how they are maintained and what kind of problems occur with their use. The number of part types to be included to the library and the classifications to be attached to them are charted by observing at the company's naming convention for mechanic and electronic parts. The naming convention of parts together with the classification model is the basis for naming library folders and part categorizing.

The practical part of the work is conducted as a case study. Chapter 5 presents the requirements definition of the library created as a result of the interviews and the analysis of the current situation. Chapter 6 describes the structure and functions of the reusable part library developed as a result of the research. The case study solution is developed based on the problems identified in the target company and the proposed model seeks to provide improvement to current situation by offering new approach. The model is developed by examining the design and product engineering functions of the target company and the deviations related to part reuse. Chapter 7 evaluates the results of the case study, discuss about the validity, reliability and limitations of the study, answers the research questions posed and assesses the need for further development. Finally, Chapter 8 summarizes the thesis and evaluates the success of the work.

2 RESEARCH METHODS

Research methods chapter introduces methodology utilized in the research. Both quantitative and qualitative research could be used for conducting this research. Quantitative research approach focusses on acquiring measurable numerical information where qualitative research method collects information that is used for understanding a phenomenon or circumstance. Next chapters will present more detailed comparison between two methods and their suitability for this study conducting to selection of method.

2.1 Quantitative and Qualitative Research

Quantitative method suits as a research method the best when information can be described in numerical ways or for comparing how something change in relation to something. In other words, its purpose is to explain functions though technical or numerical parameters when the studied subject can be measured. Various information collection methods can be used, and it is common for researcher to develop new metrics or methods of analysis to assess the phenomenon. When quantitative research collects information, for example by utilizing a questionnaire, the results must be able to be converted to measurable form. The qualitative uses language rather than numbers for presenting data. (Welman et al. 2005, p. 187 – 205)

The qualitative research method utilizes structured, focused and unstructured interview methods. The objective is to understand the definitions, characteristics, meanings and concepts around the research topic by discussing with the subjects. The structured interview, where the questions are typically pre-formed, suits the best when research problem is precisely specified, there is large group of participants and which aim to quantify the data. In focused interview the questions focus on the selected theme, but do not have an exact format or order of presentation. The unstructured interview is not built upon questions but resembles more like a conversation. This method is best suited when the experience of the interviewees varies or when interviewer want to bring up the quiet information visible. (Welman et al. 2005, p.187 – 205)

2.2 Case study

As a qualitative research method, a case study focuses on researching one or more selected sample cases in detail and help researcher to understand complex relations around the case. The research sample can be process, organization, group of people or one individual. Case studies do not limit the research methods to be quantitative or qualitative, but its purpose is to put together understanding about the research sample. Case studies usually do not pursue to gain information that can be generalized. (Eskelinen 2014, p.76 – 77)

To conduct case study the boundaries of the studied case should be determined, however they may change during the research if required. Qualitative research can be conducted by observing and participating, interviewing and collecting secondary data. The researcher should attempt to understand the topic and context on detail level using several approaches because he is the research instrument. The researcher and the subject are on interaction with each other in the case study and the study proceeds as a process. (Welman et al. 2005, p.187 – 205) A triangular methodology, in which the new theory developed is get support from experiments, groups under investigation and other experts, increase the reliability of the research (Eskelinen 2014, p.70 – 71). The case study does not directly define the research method. Case studies are often utilizing participant observation and Delphi method. Case analyses are facilitated by background theory and its clear structuring as a basis for research questions.

2.3 Interviews

Interviews methods used in qualitative research can be structured, semi-structured or unstructured. Before choosing the method, the researcher needs to define the style and purpose of study. The research can be about finding new information, research aiming to verify a model or theory, or research testing hypothesis. The structured interview, as the name suggest have predefined structure, where unstructured resembles a conversation. But these interview methods can overlap and adapt aspects from each other. (Eskelinen 2014, p. 84 – 87)

Structured interviews are commonly used when many people need to be interviewed. The questions are predefined, and all participants answer them in same order. Survey can be conducted by telephone, form or online form. Structured interview aims to keep received answers as countable as possible so that they can be quantified. To achieve this the possible answers are often predefined, or interviewee can select the most corresponding from a scale of answers. In order to maintain the reliability of the structural interview, only the original answers are compiled, no combined. (Eskelinen 2014, p. 84 – 87)

Unstructured interviews are most suitable when the experience of the people being interviewed is in different areas or when interview want to highlight poorly recognized topics. This type of interviews helps the researcher to collect exploratory information and identify topics for further research. The free structure of the interview also allows interviewer to ask more focusing questions during the interview, which allows the researcher to gather detailed information about topics of interest. Since unstructured interviews are not predefined, the researcher should have a clear understanding around the topics are to be discussed in order to keep the focus within the research framework. (Eskelinen 2014, p. 84 – 87)

When the interview is used as a research method, the information obtained from the interviewees can be distorted in many ways. In particular, the unstructured interview is sensitive to this because interaction between the researcher and the interviewee affects the answers and on the other hand poorly formed questions lead to subjective answers. (Eskelinen 2014, p. 87 – 88)

2.4 Selected research approach

The research methodology applied in this study is essentially based on a qualitative approach employing triangulation method to study the real-life problem that need to be solved. From a general viewing point, this research has the theme of PLM with a specific focus on managing the elements of mechatronic product in part library. Triangulation consist of three independent sources of knowledge:

- Literature research
- Engineer and PLM specialist interviews using Delphi method
- Comparing the solution against previous studies and known implementations.

The main research questions of this study are “Which elements of a part library enable the designer to find existing parts so that they can be used more often in the design of a new product and thus reduce the number of parts to be redesigned?" and "How should the part library be structured and managed so that the information it provides is adequate, reliable and unambiguous?". The research was concluded in three-part case study. Objectives of the parts were to:

1. Understand the starting point and to map the requirements that the company has for the part library.
2. Find a suitable solution based on the requirements utilizing the results of the interviews and PLM project's work on the topic.
3. Create an example implementation of the solution and evaluate the suitability based on the gathered requirements.

To complete the first part of the study it was important to understand, "what is required of the part solution?" and "what kind of solution would help designers in their daily work?". To answer these questions, unstructured interviews of the industry experts was concluded, including process owners, tool owners, PLM consultants and designers. The first interviews were concluded in the beginning of the research and further interviews were done to understand the topics on more deep level. Utilizing the unstructured interviews as an information collection method was chosen because the sample size of interviewees was small, purpose was to find core requirements and to understand other important aspects to the topic. This interview method made it possible to first gather general understanding and then make more detailed questions during interview.

Regarding to the product information management process it's important to note that it has not been found but has evolved from the requirements set by the of operations and product design domains. Based on the analyze performed in the study, the set development targets in order to enable efficient reuse of parts. Based on the findings, the research develops part library model which is tailored to the target company's needs.

2.5 Reliability, Validity and Sensitivity Analysis

The reliability and objectivity of the research results are ensured by interviewing the target company's engineers as widely as possible and by examining and analyzing the quality of the data obtained from the design system and by benchmarking the developed system towards common industrial design practices. The research methods mentioned above aim to identify the areas where the target company of the research need to improve in terms of part libraries and operating methods to enable efficient part reuse.

3 PRODUCT DATA MANAGEMENT AND CLASSIFICATION OF OBJECTS

This chapter introduce main technologies and principles of product data management that could beneficial for implementation of the solution. After this chapter the reader has an idea of how items are created and how items are classified in PLM system.

Industry 4.0 is a commonly term used to refer to the industrial transformation that drive towards digitalization of flow of information. Most of the technologies for digital product information management and data sharing have been available for some time and are not new in the manufacturing industry, but companies wanted to wait the systems and market to mature before implementing the solutions. More extensive support for different processes, improvements in stability, and reduced operative costs have made these industrial applications commercially viable. Previously isolated manufacturing and design activities have more potential than ever to be integrated with fully automated information flows within global value chains between different departments of company but also from company to company. Having more accurate information available helps company making better business decisions and streamline processes as the communication between production lines, suppliers and design functions improve with the real-time data visibility. (Strange 2017)

3.1 Enterprise Resource Planning

Enterprise Resource Planning (ERP) system’s purpose is to manage enterprises’ core business processes such as production, accounting, sales, procurement. The evolvement of the modern ERP systems started in the 1980s from Material Requirements Planning (MRP) systems. Their objective was to control production’s raw materials, keep stock levels as low as possible and plan activities around manufacturing. MRP systems alone didn’t offer companies management to react of changing markets which often caused overproduction of certain products or high buffer stock values. (Monk & Wagner 2009, p. 20 – 25)

ERP systems brought significant benefits to manufacturing industry as the different departments inside one location and sister factories were able to share information instantly. Operation processes often depend on information arriving from many departments and to make well informed decisions it is crucial that real time information is available. (Monk &

Wagner 2009, p. 36) To make practical example, marketing department can use the information about the product development project's schedule when planning sales release for new product family. Information about materials design status and inventory levels globally can then be used on estimating how product should be ramped up and which market areas product is launched first to ensure feasible delivery times to customers. Combining information from multiple sources help management to build bigger picture for enterprise in planning future actions and reacting on changing demands in operational field.

A utilization of ERP system can bring massive benefits to globally operating enterprise in form of increased revenue and improved customer satisfaction, if different departments can be successfully integrated and processes between them unified. An ERP system is an immense investment for global enterprise as the widely heterogenous processes need to be unified between different locations and departments. In addition, ERP system's out of the box functionalities don't always support company's operational model and company need to do customization on the ERP system itself in order to add functionalities. Customizations to ERP system become particularly expensive after the ERP system is in place due to difficulty of trying to manage data integrity and rigidity of ERP systems themselves. (Monk & Wagner 2009, p. 36 – 39)

3.2 Product Information Management

Development of the modern product information management has begun to in the 1970s from the United States military industry, from where it spread rapidly to industrial companies because of similar needs to decentralize and parallel product development. In order to make this possible different kind of information systems needed exchange information between each other and integration platform between systems was established. (Stark 2020) In a manufacturing company, improving the product information management is typical process development effort. Process and tool improvements can be supported by introducing the PLM system or, alternatively, by expanding the functionality of the systems used by the company to support product information management needs. For now, a company needs a separate ERP and PLM system because neither of these has yet grown to replace the other entirely. Company's product related information is often processed in dozens of different information systems, and the PLM system is a natural platform for integrating separate systems and transferring data from one system to another. Item management is cornerstone of all PLM systems, however if a clear item management strategy is deficient, information systems are unable to help the company integrate and improve communication between functions. (Monk & Wagner 2009; Sääksvuori & Immonen 2005)

The main task of PLM system is to make information processes as transparent and manageable as possible throughout products whole lifecycle span. The main method used for this purpose is to increase data availability for all participants of the product lifecycle, which requires the integration of all data on the product into a logically unified information model. Use of PLM technology provides increase of efficiency of management of the information. The product data consist of identification data, defining data (e.g. product configuration data) or documents which are used to describe the product or the processes of its design, manufacture or operation. (Sääksvuori & Immonen 2005)

According to Stark (2020) PDM system's primary purpose is to manage product and design information that define company's products and describes them. Product Information Management (PIM) is another common term that used for describing management of product data. PDM system a subset of PLM and one of the most important parts of it as it manages nearly all of the product data created through the product lifecycle and is the source for the right information. ABB division's internal definition for the PDM is specified in company's PIM standard (2018b) which states that product information management is a part of product lifecycle management. The idea is to have a predefined way how to create items, i.e. materials and documents, product structures and related technical data, how to store data in the system and how to maintain it.

Conventionally, the PLM system is for managing part and structure related data that is produced in product development process. PLM system connects discrete information structures, processes and different CAD systems under one umbrella. The confusion of terminology related to product information management has arisen when different commercial operators have developed their own terminology to promote commercial differentiation. Other terms that are approximately the same meaning in addition to those mentioned above include: Engineering Data Management (EDM), Collaborative Product

Definition Management (cPDm), and Collaborative Product Commerce (CPC). Product information management is typically divided into the following topics:

- Item management. Any individual identified article that is included in scope of the product information management, for example, a part or document. Item management has multiple sub-areas including identifier, type, version, attribute, and classification management.
- Document management. Documents can be understood as one type of item with specific features. In addition to the identifier, type, attributes, and classification, the document includes the actual content of the document that is processed outside of the PLM system.
- Product structure management. Almost all physical products have a hierarchical multi-level structure. The problem with handling BOMs is the different versions of parts, different manufacturing localizations, and variants that require parallel structures to describe different cases.
- Configuration knowledge management. The configuration information instructs configurations to tailor products to variants that meet the required feature.
- Engineering change management. Managing changes in the PLM system is usually implemented through workflow management. There are a lot of inter-product dependencies that can be difficult to understand, and on the other hand changes need to be implemented quickly.
- User authentication and authorization management. The management of know-how and intellectual property rights is important in a decentralized environment in order to protect the company's business.
- Interface design and integration management. The most important integrations for business flow are the interface to the ERP and CAD systems. Good integration and usability improve company's productivity and error rate. (Martio 2015, 47 – 50; Sääksvuori & Immonen 2005, 13 – 18)

The concept of the PLM is based on the idea of creating a single source for product related information where all product relevant information can be accessed throughout product’s lifecycle (Sääksvuori & Immonen 2005). The unity of the information space does not imply to physical location of server or specific system that store all the data. On the contrary, PLM systems support the efficient sharing of information between multiple information systems and collect the relevant data. Two basic ways of data storage are applied in PLM system: in the form of the objects possessing a certain set of properties, or as the complete documents containing the necessary data. At the same time, a document in the system is an object with certain properties of its own. Storage of all objects and documents can be organized through directories or folders similarly to the file system of personal computer. In this case the documents can be stored either independently or be bound to another system object.

Information from different design and manufacturing locations around the world becomes available to any user at the right time and in a convenient way as the users of the PLM system can have role specific views. The challenge with the efficient management of product information in ERP system is the huge amount of information that is stored behind numerous transactions and some of them are restricted for designers. Fragmentation and outright lack of information create barriers between the stakeholders of the product data management process. In principle, the PLM system should manage all product-related information, but in practice this is realized rarely due to ERP systems fragmentation. Corporate business-driven ERP systems support product development poorly but often information needed by the commercial operations such as stock size, prices and customer data has been left in the ERP systems and duplicated to PLM system.

A complex product may consist of thousands of parts that need to be designed. For each item, the data must be created, modified, reviewed and approved by many people and probably more than once until the product reach production. In addition, development methods and accompanying data required for different types of parts variate as are mechanical items requiring a 3D model and some may be printed circuit boards requiring their specific documentation. Modification of item will have an impact on all associated data and, therefore, constant need for new modifications, verification and recheck arises. From the product development project’s point of view, it can be very challenging to determinate what should be done in the future and what actions are require. In such situation PLM system regulate the entire workflow in the project according to predeterminate rules for each item type and notify people that they been assigned jobs. To transfer work and data between employees the PLM system involves use of appropriate folders known as contexts. Product development project may contain thousands of tasks and it is often necessary to track the relationship between tasks. Also, business rules can be attached to workflows, for example, PLM system may have limitation that approver cannot approve bill of material before all parts are approved. Flexibility of actions provided to project participants depend how task management is implemented in the PLM system. The result of regulating the workflow in the project is increased transparency and manageability as tasks can be traced in order to recognize presence of bottlenecks in the project.

3.3 Items

From the point of view of product information management, item may be any individual element, that can be identified in organized and standard way. The operational activities of the company determine what kind of items are needed in the business. Examples of such elements include products, materials, documents, services, and resources, however, setting up an item is an investment which requires work and maintenance. Therefore, it is the responsibility of the company's operational management to determine which data is managed as elements of product information management and which are excluded. These decisions also reflect on the development of product lifecycle management because decisions about what kind of information is treated as items, determinate what information can be processed by the PDM system. (Sääksvuori & Immonen 2005, 12)

The product may be associated with items that are included in the delivered product but shouldn’t be referred as components in the context product data management e.g. product test report is not a component in a product as it’s not a physical piece inside the product, however, product test report can be part of product documentation. Whether an item is seen as a part depends on the perspective and it is vague to try to unequivocally distinguish these two. Later in this study, item is considered as a physical part of a larger entity i.e. part is an item that is used as a building block inside a product or sub-assemblies. It is understandable that practices around item definition and conventions vary greatly from one company to another. For example, in streamlined production, there is usually no need to maintain accounts for casting molds or raw materials because the ordering company does not handle such process. On the other hand, standard parts ordered from outside the company often have many manufacturers that can be perceived as interchangeable. In this case, the ERP system typically control material flow through a generic part that is common for all vendors. Same kind of situation can be seen with catalog parts having multiple sources.

The use of interchangeable parts is typical in electronic manufacturing, and although the parts from different manufacturers are similar, they are rarely identical, but instead they just meet the limit values needed in the application. In this situation, it is particularly important that each manufacturer part is tested in application and receive approval before they are used in production. Thus, manufacturing company is adding an indication of the test status of the manufacturer-specific part in the generic part’s data. Well-implemented part management systems can be used to search for parts simultaneously in the company’s own, part manufacturers and suppliers’ databases using classification and item attributes. Standards have been developed for the construction of part databases, such as the ISO 13584 standard, which determines the general way of presenting part data and thus enable combining the supplier's (supplier library) and the company's own (user library) database. However, this standard does not distinguish between the manufacturer and the supplier of a part even though this definition can have significant impact on specific company’s operation.

3.3.1 Item data model

The product information data model describes the connections between pieces of information on conceptual level, so that forms of information can be examined on general level. Its most important function is to define information objects and their meaning for product. (Sääksvuori & Immonen 2005, 23) Each item has its own unique identifier, also known as Article ID, and description. Dissimilar types have their own definitions, because they can behave in different ways. For example, whereas document version represents both evolution and variants of a document, the evolution of parts is represented by revisions and new part version creates a new alternative. Some of the entities and related operations inside the data models, for example basic object types, are very fixed. On the other hand, defining new object types give flexibility to add different kinds of attributes.

The product information data model defines item types, their attributes and definition for attributes. Each item managed in a PLM system must have an unambiguous identifier, called item or part ID. The item ID can categorize item properties, in which case the content of the character set is significant, or the code can consist of random character sequence. When using a non-categorized identifier, the user can search for items, for example, using a description. When companies merge, the information systems merge as well, and information system may contain duplicate parts. Deleting duplicate parts is difficult because they appear in parts lists and maintenance instructions. A description is commonly used as a pair of item ID to explain what kind of item it is. The description is clear generic name of the item and comply with the terminology used in the company or standard. In addition to the generic description, more detailed technical description is usually required in order to identify the part and the item data model should include the identifier of the drawing or other specifying document with the revision information. (Martio 2015, 51 – 60)

3.3.2 Item types and attributes

PLM systems allow system administrator to create subtypes for parts and documents, which can also inheritance attributes from the parent type. Different item types can be organized into a type hierarchy that is responsible for grouping the type so that similar types can be associated with common attributes. The sorting of objects to type hierarchy is called taxonomy. This allows, for example, a fan to have specific attributes, such as operating voltage and flow rate, in addition to attributes common to all items. In a type hierarchy of Figure 2, a type such as mechanical part can be a subtype of another type part, if the type defines the attribute hereditary is this attribute expressed for all instances of the parent type and subtype.

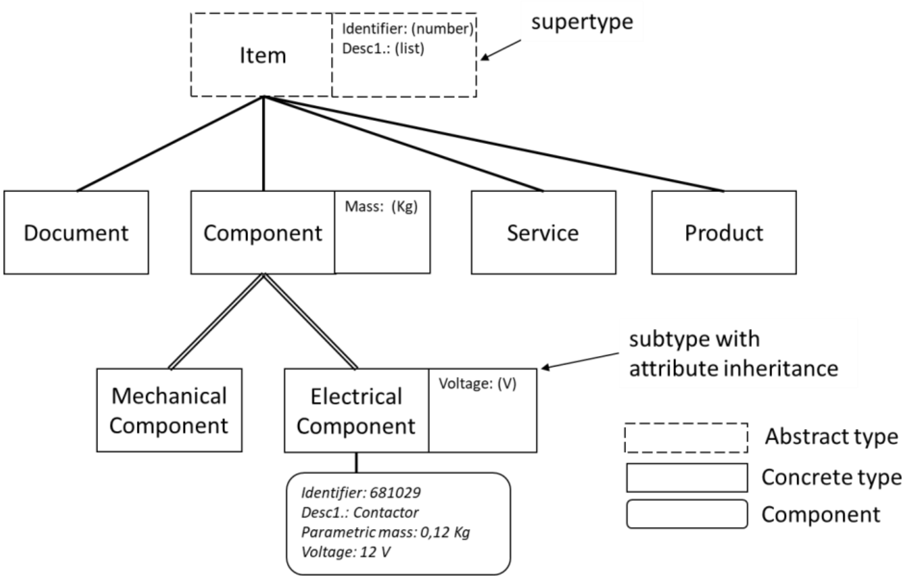

Figure 2. All part attributes are hereditary.

As the item, attribute also have some basic information associated with them. In addition to the identifier, the parts are associated with a short and long description, which can be a free-form text or list selection. A selection list makes it easy to translate descriptions into multiple languages. The attribute has a value type that indicates the values that can be assigned to the specific attribute and thus also determine how that attribute can be used. The value types generally used in a PLM application are:

- Real number values with and without units, for which it is possible to assign the maximum and minimum limits
- String type values, that contain free text
- Selection list type values, for which allowed values defined by predefined list
- Boolean type values, which let select *Yes*, *No*, or *blank*
- Time and date type values
- Hyperlink type values
- Object type values, for example parameters imported from the CAD system.

Using selection list type values improves the quality of item data because, without a list, the user can enter uninformed values, making it difficult to retrieve and sort items. A distributed design organization has people of different backgrounds, and information that means the same can be written in several ways according to the local preference. All the value types described also apply to item attributes, which can also be managed by using global selection lists. A specific value in a list can be mapped directly through an item type to an item that is opened, so that the selection list values can be sorted, or the selection of a specific value can be automated regardless of the user.

3.3.3 Categorization of items

In order to distinguish items from each other, classification can be used for creating groups of items according to their features. The item classification is a key factor enabling characteristic based item search and grouping. Finding items from the information system can be further helped by grouping similar items into their own groups, in which case different attributes can be established for the item group that describe the properties of the group.

As noted earlier, PDM systems typically support different item types that can be defined on a company-by-company basis, and the resulting type hierarchy can be used to classify items so that the item type forms a class. However, classification does not have to be based on its type hierarchies, as modern PDM systems support a wide range of ways of classifying items and there may also be several different classification models attached to a single item. However, it should be noted that the data maintenance increase as new item classifications are added and because of this the number of different item classifications should be kept small and rather try to create a compromise of different classification requirements. (Martio 2015, p. 70 – 78; Sääksvuori & Immonen 2005, p. 12 – 13)

Classification method is the foundation for viewing, handling and retrieving parts in the PLM system. Main classification methods are keyword classification, enumeration classification, facet classification and attribute classification. There is no one correct way to classify items, because use cases need different classification criteria, and within the company it may be needs to classify the same item in several categories. Categorization reduces the unnecessary creation of similar parts. If a designer needs a screw in his product, he checks at the group of fasteners if there is already a suitable screw for him. Items can also be categorized according to their importance, quality or price.

If items are grouped by description, the group can be assigned with attributes that are inherited from items in the group. Items can also be categorized by adding an attribute to them that indicates their position in the classification hierarchy. To make the difference in classification methods easier to understand, attribute and hierarchical classification they are explained using a simple example. Figure 3 shows an ungrouped set of items with differences in shape, color and size.

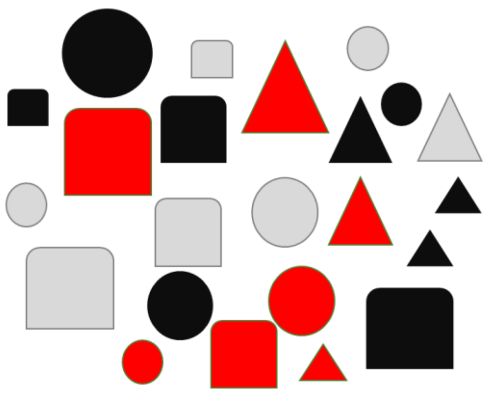

Figure 3. A group of items without classification.

If goal is to group the items shown in Figure 3 using a classification method, it is easy to do so by using the properties that describe the item. The purpose determines what kind of classification should be established for this set. If a classification based on one attribute, three groups can be created based on each property e.g. items can be divided in three different groups based on the color. Figure 4 shows the same set using three classifications, color, shape, and size.

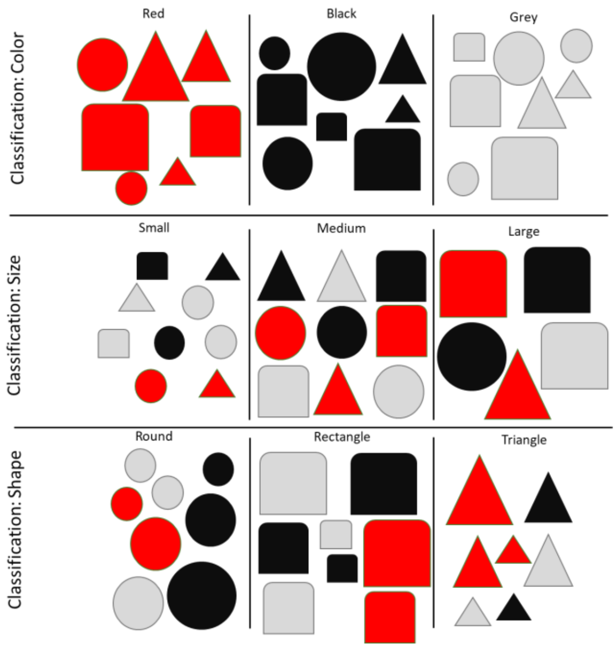

Figure 4. Groups created using three types classification.

As shown in the Figure 4, this makes it easy to set up six different item views based on the properties of presented items. Modern PDM systems also allow to group items using a hierarchical classification structure and allows multiple inheritance meaning that item can have multiple immediate supertypes. If the set of items shown in Figure 4 is presented using a hierarchical classification, the selection of the higher level is inherited to the lower levels. Figure 5 shows the hierarchical classification using the color-shape-size hierarchy model.

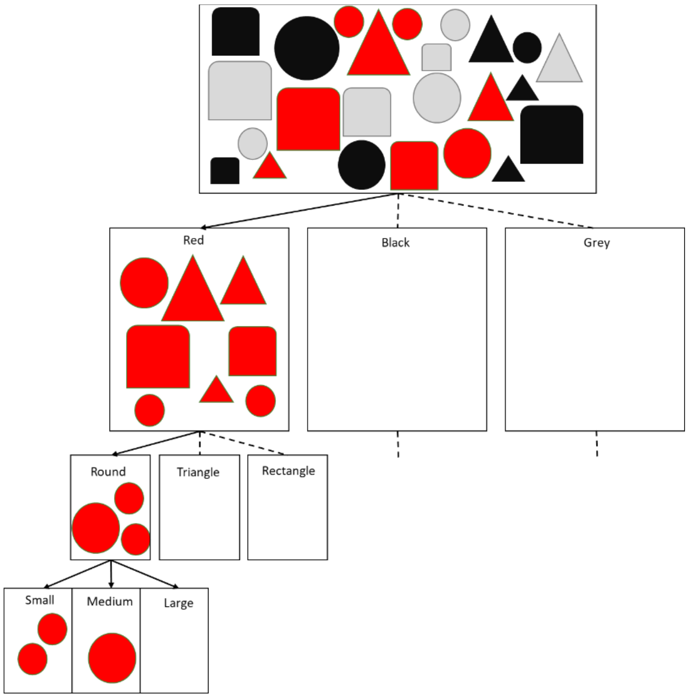

Figure 5. Hierarchical classification model.

Similarly, a screw could have three level classification hierarchy where the first level group all fasteners and sort them using attributes like length and diameter. Second classification level could describe all kind of screws and add thread length attribute. The third level could present certain type of screws, e.g. Philips head screws and introduce more attributes like head diameter and standard number. A type hierarchy is a more advanced way of handling items and there are many standardized models of such a technical classification available, such as IEC 61360, that define classification hierarchy for electrical components.

Implementing standard based classification to PDM system, such as IEC 61360, UNSPSC, or eCl@ss, can benefit large-scale item classification as the machine learning reduce the human effort to reasonable levels (CIMdata 2017). There is no universal classification standard for parts but eCl@ss and UNSPSC are most prominently used among industrial manufacturers. Complexity limit the use of these systems, for example in eCl@ss there is 4 classification levels and 30 main classes on top level following multiple successive choices on lower levels. It is easy to see that the number of different categories can get easily out of the control with complex products and causes confusion in designers. Modern item classification tools provide also textual and geometric clustering which can further improve efficiency of classification process.

As previously noted, items can be divided into groups using classification and attributes. On the other hand, the division can also be made according to the manufacturing process or depending on other local conditions. Several basic materials and parts needed for production are purchased in different configurations compared to how product development has defined the item. The identifiers of these configurations depend on the conditions of the production units, and although in item management parts are treated usually as separate units, this is not always the case when placing the orders. Instead, part may consist of sets or have a minimum order size. Examples of such materials are:

- Screws and other universal accessories, which can be sourced in boxes of different sizes,
- Sheet metal parts, which can be made of raw sheets or pre-cut sheets of different sizes,
- Extrusion profiles and pipes, which can be supplied in a specified length according to the manufacturer's or local standards,
- Electrical cables and wires, which can be sourced in coils or skeins of different lengths,
- Components for circuit boards, which can be supplied in the form of strips defined by the installation machines,
- Chemicals, which can be supplied in containers of different sizes.

Various functions need to be able to groups items from the company's large number of items according to their own criteria. Functions like product development, production, sourcing, financial management and service need view part lists from different aspects. Some PLM systems support use of polyhierarchies, where item can me member of multiple supertypes, so-called multiple inheritance. In this case, additional subtypes can be created to describe the specific item attached to them. However, the PLM system will not be able to answer these functions specific questions unless the data model support this and data has been transferred from the ERP system and, therefore, the item data model created for the PLM system plays an important role in classification as well. Having classification system that is unintuitive for designers can make things confusing to learn and make finding parts even more difficult.

3.4 Part and design reuse in product development

The product development and maintenance functions accumulate a large quantity of knowledge about the product design they are working on. Pieces of information, such as design specifications, CAD drawings, simulation models and technical documents are stored, managed and transferred between different people and applications at every stage of the product lifecycle. Earlier studies indicate that cost savings and faster time to market are main benefits of having formalized reuse policy. The core of knowledge transfer is knowledge reuse, but enterprises often struggle to spread the collected design information efficiently between different department and locations. Many companies do not have official design reuse policy even though it has ultimate effect on the success of the reuse efforts. Nowadays, many manufacturing companies are trying to use increasing number of reusable parts in their products and try to make enterprise full resources available for designers to reduce the time spent on product development. (Ettlie & Kubarek, 2008)

Use of standard parts and existing product elements should be as wide as possible during the mechanical and electrical design process. Design solutions should be standardized between products. However, it was already acknowledged before this research that the information flow is not well supported through the case company’s current design tools and information systems. If a designer doesn’t have an easy way to locate, use and share knowledge for reuse the decision-making process may become inaccurate in the product lifecycle. In addition, this will show in form of duplicating already existing parts and documents. Eventually this inefficiency reduces designers' ability to create new innovations and increase product development costs due to unnecessary work. In order to reduce part duplication and advance design process efficiency, a company can establish part reuse strategy to realize the higher product quality, reduce BOM cost and shorten product development lead-time.

Due to repeated need the mechanical design process often establishing standard part libraries in order to retrieve frequently need parts effectively. Designers must have easy access to the parameters relevant to the application so that they can easily compare the properties of the parts and choose the most suitable one. Without clear rules for the presentation and naming practice, designers fill in the data in different formats. This makes comparing and offering lists of reusable parts difficult. As a result, designers can’t find the part they need from a large mass, or at least it takes a lot of time. According to studies around 20 % of designers’ time go to searching and absorbing product related information and nearly 40 % of information is stored in personal stores where it is not accessible for others. The standard part libraries are a practical Knowledge Based Engineering (KBE) technique which can reduce repeated work tasks, reduce design lead time, develop products that share more same parts with previous versions, help optimizing products if best design practices are easy to find. (Reddy et al 2015) Therefore, the practical significance of establishing own part standard system in order to improve reusability of parts is clear. One trend in the product design industry is to make more efficient use of standard, catalog parts and product elements by building a management system.

Managing standard parts through centralized library is more flexible and appropriate administrative point of view. Some MCAD software present a hierarchical model three structures for reusable objects as a solution to standard part management. The available library objects commonly include industry 2D sketch blocks, standard parts, such as screws, and family parts. Furthermore, software is having increasing role in defining products features and variation. It is essential to increase the transparency between design areas, which can be done by collaborating and working together in a common system during product development process.

Design process according to the V-model consist of incremental loops that steadily define the product and increase knowledge on the product after each integration is completed. Designing complex mechatronic products require constant collaboration between all stakeholders through common platform. (Eigner at al. 2012) In order to complete the whole product development process effectively, library parts should support model-based design approach and product elements should link to the functional description of the product and simulation systems.

3.5 Summary

For manufacturing companies, item management is one of the key activities. Before planning to deploy the PLM system, it is important that the item management process and the associated classification templates are in order. If the company's item management process is inefficient and if there are no responsible allocated resources in the management of items, the number of items increases, causing inefficiencies, extra work, and errors in the enterprise's operational processes. In manufacturing industry, the number of individual items can rise to hundreds of thousands. The maintaining product data procedures for so large quantity of parts in the ERP system, cause challenges even in the most fine-tuned environment. ERP system’s focus is always on the production processes. Despite the system, item management requires clearly defined processes, enough resources, and disciplined operations.

Martio describes in book *“Tuotekonfigurointi ja tuotetiedon hallinta (Product Configuration and Product Information Management)”* (2015), that good item management includes following characteristics:

- Each item has only one main identifier, item ID.
- Each heading has a multilingual basic description and more specifying technical description.
- Each item is an instance of some types. The types define the attributes of the item.
- As many values as possible in the attribute set are selected from the selection lists.
- The items have been determined with the precision necessary for their use
- The manufacturer and vendors of items are separated. Manufacturers are registered item by item. Approval information is stored for alternative vendor items.
- A process has been defined for maintaining items.
- The item maintenance system allows you to mass update items.
- An item search can be used to create a group of items whose any value, attribute, or relation can be changed as a single operation.

4 OPERATING ENVIRONMENT AND CURRENT WAY OF WORKING AT THE CASE COMPANY

This chapter aims to offer a general description of product data management practices at the case company. This will help the reader to understand the current state of PDM process and participating systems. This chapter also gives reader the background and motives for the part library development.

Business processes are set of technological and organizational processes that are carried out purposefully within a predeterminate organizational structure. The analysis of business processes allows to take a new look at the work of the enterprise, to clarify the duties of employees, to assess the efficiency of resource use, to see deficiencies hidden in the organizational structure.

Restructuration work of the part library is justified, because the level of reliability of the current part library is considered poor, and there are only a few parts available that can be directly utilized in the products. In addition, drawings and parts lists often show the same errors related to incorrect or incomplete part information. The easy-to-use part library also accelerate the design work, due to less time spent on find common parts.

4.1 Product information management in the case company

The case company has a predefined global process for item and document creation, product structure management and management of other technical information related to products. The process defines what information need to be produced, and how it is stored and maintained. Product related design and manufacturing information must be available for the case company’s global network as the manufacturing of same products take place in multiple locations. The amount of part related information and requirements of the data increase as the product is manufactured globally. The case company’s product data creation and maintenance process are managed on the ERP application’s master plant from where information is shared to sister factories via Product Data Replication (PDR) process.

In the company, information management takes place and operations are carried out using the Make-To-Stock (MTS), Configure-To-Order (CTO) and in some cases also the Engineer-To-Order (ETO) operating model. In MTS products variability rate is low, and the products are pre-manufactured in stock, while in the ETO process, only one unit is often produced for the customer. In the current situation, all the information needed for manufacturing is stored in the ERP’s Document Management System. ERP have stayed as company’s primary information management tool while PDM application have smaller role in the background.

Product data management is an integral part of product creation. Majority of the data is created in product creation process and maintained through engineering change process. Product data management process in the case company is divided into catalogue data management, item data management, document data management and product structure management. Output deliverables of the product data management process is the product definition data distributed to process users in order to support business processes. An efficient way to manage product data is key factor in improving product data quality globally. Uniform product data definition makes automatic data exchange possible between production locations. Benefit of this is that new products and product improvements reach sister factories and new market areas faster. In addition, ramp-up of new product in local business units will be easier as the units share single source of product information.

When adequate information is not available through one shared platform, there is increased risk that new information doesn’t reach other departments, and communication with suppliers or sister factories become unreliable. The company's most critical processes are design, manufacturing and sales.

4.2 Current state of product data management

The current state is that item related information is maintained in the ERP system and design is created in separate non-integrated tools. Sharing information with different plants and the ERP application installations if built around “Master Plant Concept”, where one of the ERP application plant has adapted global role. Designers working on global role create all items initially on Master Plant. Master Plant’s database has been born over a long period of time and items from several previous systems have been migrated there. In addition, number of items has increased due to company fusions. Although the ERP system effectively supports database-based data management, but its weaknesses in visualizing data and limited item search capabilities makes finding existing items difficult and time consuming. Also, designers often find the ERP system difficult to use.

Instead of implementing separate PLM system the organization made decision to develop PLM capacities into the ERP system. Although, product data for design and product data for sales and manufacturing have very different needs. Currently the case company's mechanical design area uses PDM application, only for managing 3D CAD objects and drawings. In the intended use it is more rational to call the system a CAD document vault rather than PDM or PLM system. After approval the ERP interface tool, which role is explained in Chapter 4.2.2, transfer mechanical part's data with classification information to the ERP application. In addition, drawings and STEP files are transferred to the ERP application's DMS through ERP interface tool. It is the only design tool that is has integration with company's ERP and other design areas maintain documents in DMS manually and create items in ERP application. Figure 6 represents the data flow from global ERP application's plant to manufacturing plants. Only the mechanical parts are opened via the ERP interface tool and the other part types are opened via a ZITEM transaction customized to the ERP application.

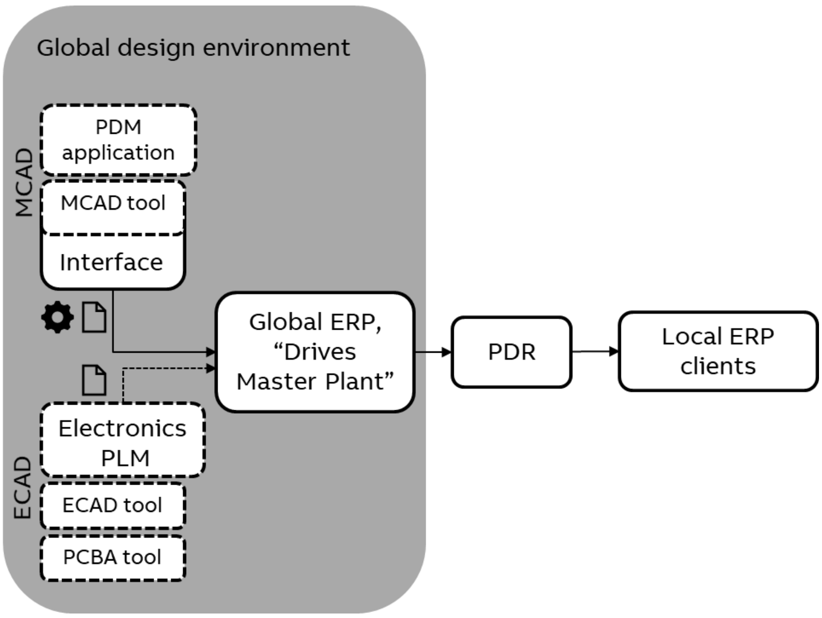

Figure 6. Data flow in the case company's global ERP system.

If part definition includes a bill of material it is created and maintained in the ERP application via separate ZMANBOM transaction. The ZITEM transaction include a part search function where users can search parts using description search. However, the ERP application's transactions available for designers do not support search of technical attributes nor showing attribute values in search results. Furthermore, current PLM application's environment do not support searching items based on their classification attributes as the information is not stored into the system.

In the case company's ERP system, list of descriptions is used when an item is created, and items are classified based on their description. This means that all items opened in ERP application or ERP interface tool in MCAD application are automatically assigned to the design area and all items are associated with the appropriate parameters. Item categories may be useful when designing the part library structure. It is then the responsibility of the designer to fill in the attribute information. It should be noted, however, that the attributes do not have clear instructions and the designer has the option to fill in the same data in more than one field. This impairs the performance of searches. Therefore, identical or very similar parts exist under multiple item IDs in the ERP system which leads duplication of stock and confusion at production. This one of the factors that has prompted PLM system development within the organization.

4.2.1 Item Classification Analysis

The case company is currently utilizing well known ERP application provider and over the years of use the system has undergone extensive internal development aimed at improving item quality and program usability. New part creation utilizes a list of predefined descriptions that the designer has at his disposal. The hierarchical breakdown of the item list is based on the classification of descriptions by design area, material class and description. Selected description automatically defines global and local key attributes for operations in the background. Figure 7 demonstrate how classification scheme of part differentiate based on the selected design area.

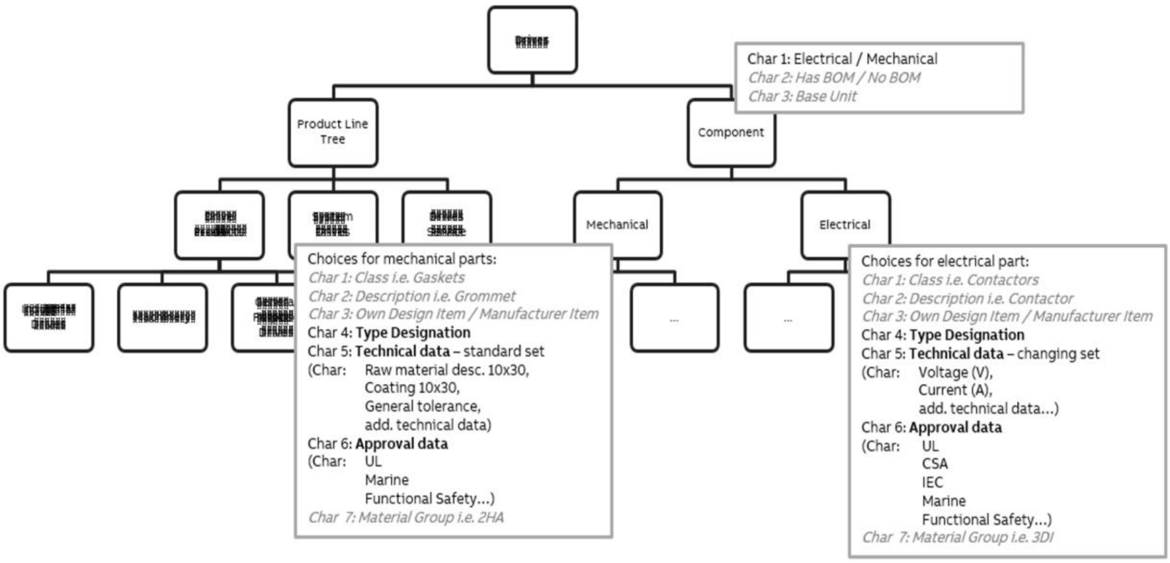

Figure 7. Item attribute example for mechanical and electrical part. Grey cursive attributes are list values.

Item descriptions under the Electrical and Mechanical design area are organized logically. The parts are divided into their own subcategories according to the application or common name. In the case company’s ERP system, the top-level item classification structure is divided into the design areas shown in Figure 8.

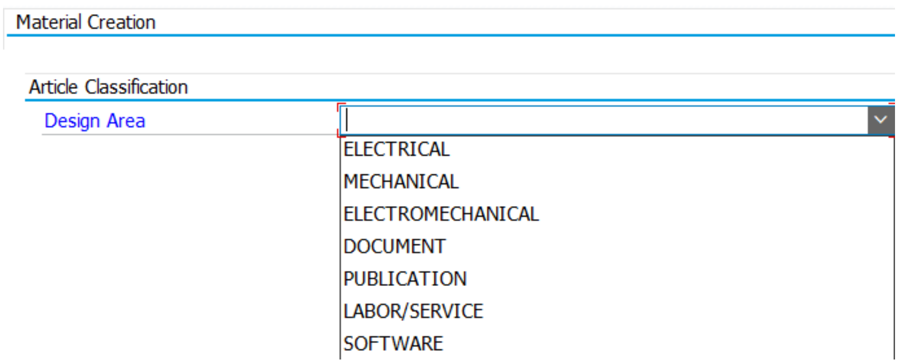

Figure 8. ZITEM item classification selection on the design area level. (ERP application 22.7.2020)

A more detailed analysis of this study will include items under Mechanical design area but will also elevate some observations related to Electrical and Electromechanical design areas. The case company’s article classification model uses the hierarchical classification that is based on function of part. In Figure 9 user choose article class from the dropdown list after design area is defined.

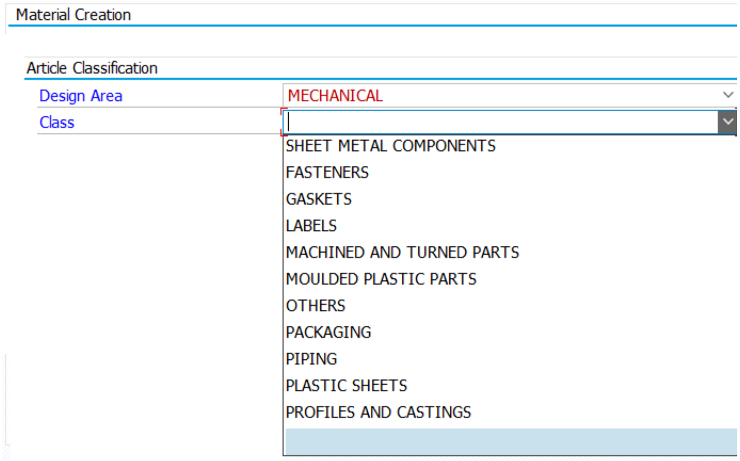

Figure 9. ZITEM item classification selection on the Class level. (ERP application 22.7.2020)

For example, the fasteners class include different type of screws, nuts, washers, sleeves, locking elements and rivets. The Fasteners class hass several descriptions for screws to choose from but the naming is not based on standards and can cause confusion among users. Despite, the names are not based on standards, they serve intended use in the ERP system. Most of the parts in fasteners class are defined by DIN or ISO standard system but there is also many that are case company's own design. Therefore, the analysis cannot conclude that fasteners class include purely standard parts. Table 1 sums quantity of item subtypes and number of active items in the company's ERP system.

Table 1. ZITEM items by design area and quantities in the company's ERP system.

Item Class	Number of subtypes	Number of unique descriptions	Number of items (owned by the case company)
DOCUMENT	1	12	15,989 (4,387)
ELECTRICAL	24	254	20,018 (5,503)
ELECTROMECHANICAL	5	184	54,844 (12,883)
LABOR/SERVICE	1	51	306 (2)
MECHANICAL	11	217	67,636 (10,858)
PUBLICATION	1	23	2,982 (1,961)
SOFTWARE	1	4	2,999 (2,292)

However, there is a clear need to use an accurate descriptive description in an ERP environment. If the item description is too generic in the ERP application, assigning commodity codes and sourcing managers would become a difficult task and would require manual defining. For example, the “Air guide” is too generic and would group plastic and metal parts into same sourcing category. Alternatively, if description is used “Air guide, steel” it specifies that the part belongs to sourcing manager who is responsible of sheet metal parts. In total, the system includes 745 different material descriptions underneath the supertype. Electrical item hierarchy consists of 24 and Mechanical of 11 subtypes, which can complicate the selection of the description if the designer opening new item is not familiar with subcategories. In addition to description the classification solution in ABB’s ERP rely on item types. Manufacturer item refers to one specific third-party part used in an ABB product. Like presented in Figure 10 a catalog item describes generic part and its definition can consist of multiple manufacturer items. Manufacturer item represents an item made by a single manufacturer and usually the item relates to one catalog item.

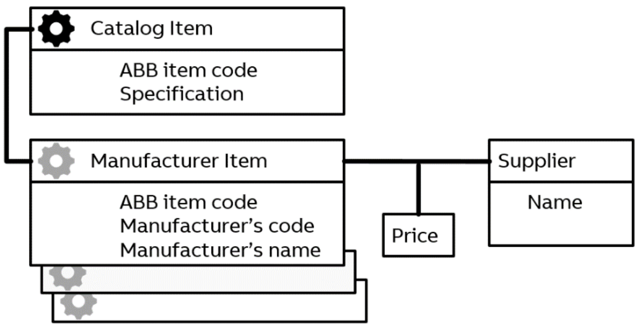

Figure 10. Catalog item, manufacturer and supplier. (Modified from Martio 2015, 89)

The issue with the ERP based solution is that alternative realizations of “catalog item” are very difficult to search from the ERP system. Another major issue with the definition is that the manufacturer item is missing the testing status and quality data. Catalog item can also be a product specific part, because some manufacturer part alternative might not be compliant with the product in question. Manufacturer item belonging to catalog item should have effectivity date and arrival status added to the data model. To solve these issues more investigation should be done around part and supplier management (CSM) system that would make possible search parts from company’s own database and from catalogues by the part manufacturers.

This structure of descriptions has many good features, but also some characteristics which can create complexity from the part library point of view. In this case, the main features of data retrieval are the main and subgroup of the part. Because parts can be sorted into larger entities, information on similar parts is easier to find. Analyzing the data from the ERP system, is was noticeable that designers use variable descriptions for similar parts and assemblies. In addition, the information in the part descriptions was often incomplete or different in the PLM application. Also, the classification metadata of objects was not stored despite it was available in The MCAD tool though the ERP interface tool.

Currently, the part search options are very limited and there is not effective way for designers to browse parts. If the designer has an idea what kind of part he wants to use in the design, it can be hard to find it in the information system. If it is not clear to the designer how he can find the part, it is often easier and faster for him to model a part himself and create new part. This leads to duplicating parts and currently there is many duplicates even in the standard parts. The problem of missing or incorrect naming becomes more apparent, especially when examining the fasteners, in which case working time is spent needlessly for finding the right data from both PLM application's and ERP application databases. One of the key problems with keyword-based classification is that users can start using different names for parts of the same class and filling in the data in different ways in the ERP and design systems. Groups and categories can be set in a wide range of ways, but the most important factor from the reuse point of view is to understand that the similar library parts must be as easy to find as possible. When the PDM application take on the role in managing product information and acts as an interface between different departments in the future, it would also be worthwhile to use the same practice for metadata when importing items into the PLM system. In this way, company's own common standard for setting data can be strengthened and it will enhance data management in other functions in addition to product development.

4.2.2 Changing item management environment

Motion business has started a PLM project to develop Product Information Management. In result, divisions saw a need to start updating working methods and processes, as the focus is moving from ERP-based product information management to PLM system-based product information management. Implementing common PLM system motivate to harmonize processes and seek synergies on product and part level between different divisions of the case company. Currently, the case company organization still rely heavily on the ERP application in item management and uses the PDM application mainly for managing MCAD documents.

The PDM application environment consists of a set of product and library containers known as contexts. These containers contain administrative rules that determinate which products are visible to specific user. On the top-level PLM application's hierarchical structure have Site container to which all subsidiaries are in relation to. Below the Site level divisions have one common organization level container that is shared with users from other divisions related the same product segment. A set of access rules is set for each product container independently and at creation of new product container the administrator defines the access policy rule for it. Overall, access policy rule specifies participants (user, group or organization level rule) and participant's permissions (rights to read, create, modify etc.).

All PLM application's document data are stored as CAD document (wt.epm.EPMDocument) or Document (WTDocument) objects. CAD drawing is the primary content of a CAD document and other CAD files, such as drawings, are linked as secondary content. The case company's current PDM application's set-up have not implemented part type objects (WTPart) in use. Instead it is on designer's responsibility to name the document objects according to ABB's naming scheme and fill in the required data. To assist the designer during data creation process, the case company use ERP interface addon in MCAD, which classify and publish data created in the MCAD tool to the ERP database. It enables the designers to easier follow material standards, classify information and align naming conventions for ERP. It should be noted that only items which are classified underneath mechanical design area in the ERP system can be opened using ERP interface tool in MCAD application. Other design areas rely on the ERP application during item creation process. The PDM application's workflow process determinates that only approved objects can be published to ERP and revision rules must be followed when the objects are modified. All design areas use ERP systems document management system (DMS) for storing production relevant product data. It should be noted that many of the users have very limited visibility to product containers in PLM application and are unable to view or search objects inside product containers. Due to this system set-up PLM application's role in item management and search functions have stayed insufficient despite the system has been in use for long time. In addition, other than Mechanical design function store their data elsewhere which limit the collaboration across design areas as the ERP application is the first common meeting point for the product data as described in Figure 11. Furthermore, other than MCAD tool are not integrated with ERP system and data exchange between systems require manual input.

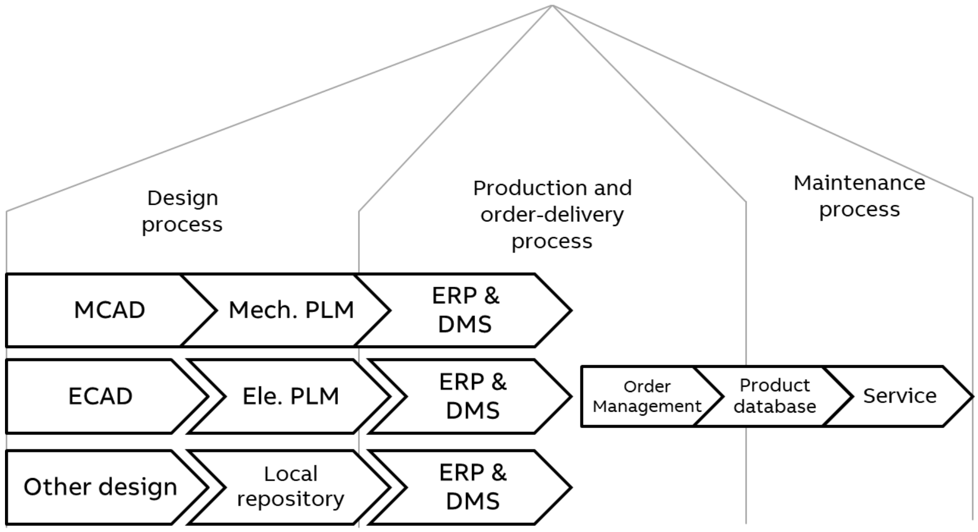

Figure 11. Current flow of design data in case company.

The historically grown complexity of the case company’s product offering, structures and design has become difficult to manage efficiently in ERP system. This have led to high data product data maintenance efforts in all areas, from Product Development and Maintenance over Sourcing and Production all the way to Service functions. Due to this development organization needed to define future vision and improvements to support the case company's new PLM strategy and to find ways to enhance white collar productivity and shorten new product development times. New PLM project have a big role in unlocking the potential of the PLM system in divisions as the transformation of the item management from ERP to PLM is completed. Due to this ongoing change with the roles of the ERP and PLM systems within the organization this thesis aims to study how the common parts library could be implemented after the transformation is completed and what kind of benefits it could bring compared to current state. According to future vision of the company’s PLM set-up presented in Figure 12 the significance of the PLM application’s PLM will be much greater while ERP system’s focus will be on operational activities.

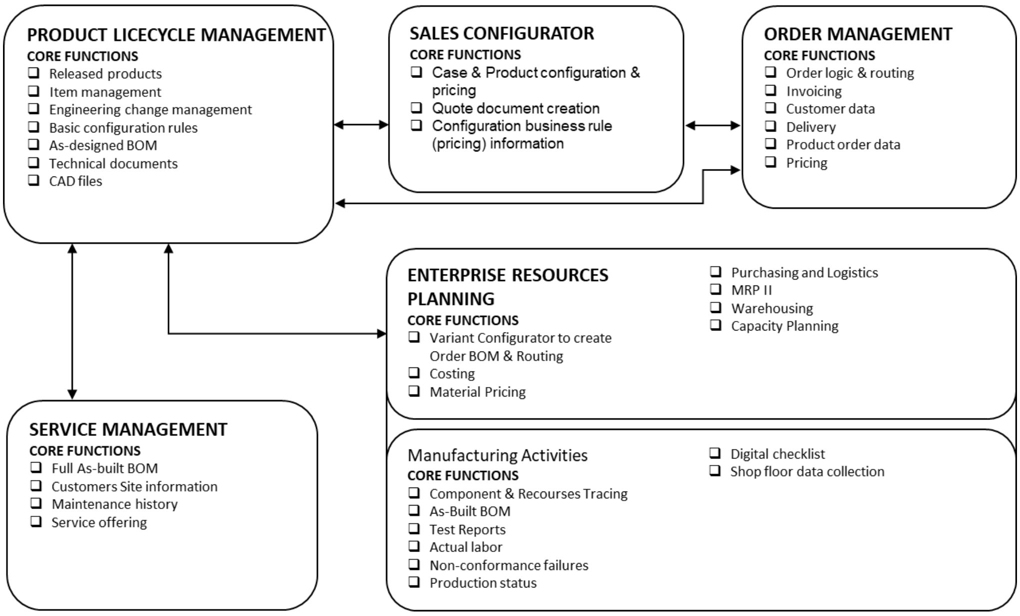

Figure 12. PLM vision and environment. (Modified from source ABB 2020b)

4.2.3 Current part and material libraries

At this moment the case company do not have official unified way to manage and present standard parts or commonly used parts. ABB as a global organization even how have offered tools for standard parts management but they have not been implemented due to insufficient resources or because product information organization has felt the offered tools don't fully serve their purpose.

Case company's mechanical engineering team maintain the list of preferred fasteners on Excel template which is updated every time new item is created. New fastener item creation process is organized centralized and after the team get assignment to open new item, they handle the communication with sourcing and other participating entities. This approach has been found to reduce errors in data quality and to quicken the process. It should be noted that there was also an effort to create a folder-based common part library called MCAD library within the current PLM application's environment, but benefits remained modest due to lack of attributes and inadequate maintenance. Figure 12 presented the folder structure of the current MCAD library in the case company's PDM installation.

Figure 12. MCAD library in case company’s current PDM application.

The MCAD library does not offer a way to browse item other than by navigating between various folders. Same type of parts can be found in various folders and there has not been the necessary discipline in content management. As a result, the library has become virtually unusable over the years. In addition, many of the objects within the MCAD library do not have item code, so they cannot be used in products. Nevertheless, the MCAD library show that there is need for common part library in the case company.

According to the case company’s design process owner, the material lists offered in the ERP interface tool has been updated to correspond to information received from the suppliers. No extra material is maintained in the material list, but if new material is needed it can be added to library. The material selection also automatically adds other information to the part drawing, for example, bending angle and K-factor. Sheet metal parts are mainly simple parts with bends and holes and no special tools are required. MCAD library include basic hole punch and forming tools for designers. Company’s production also follows the quality of the supplier parts and inspects all arriving sheet metal parts. If a dimensional error occurs due to the wrong parameters, the changes will be updated on the drawings and into all the necessary material specifications.

In this way, mechanical design makes sure that production errors are maintained at a minimal level and designers create parts that are easy to manufacture. Mechanical designer model all own design items themselves, so most of the designers are mainly focused on sheet metal parts and have much experience in this field. Designers are in constant communication with the external suppliers that manufacture the parts and get feedback if there are some manufacturability issues before mass production phase start. In addition, the products have increasing amount of plastic parts which are also designed internally and manufactured by external suppliers. The products are very similar with each other's and the material gamut is relatively narrow. All the material parameters in the company are based on practical tests and long experience with working with the materials. Problems mainly occurs in manufacturing due to supplier's quality issues, for example due to missing holes in a sheet metal part.

ABB Group offer supporting tools for standard parts and catalog item management. The Standard Parts Manager (SPM) is ABB's global reference database for standard parts like screws, nuts, washers, etc. It can be used as a central source of technical specifications in local business units. The objective of this library is to provide and maintain a consistent view of standard parts to leverage reuse and harmonize reference information. Other major advantages are, less data duplication and unambiguous definitions, less redundant maintenance effort and easier IS integration. Figure 13 present the SPM database's web interface.

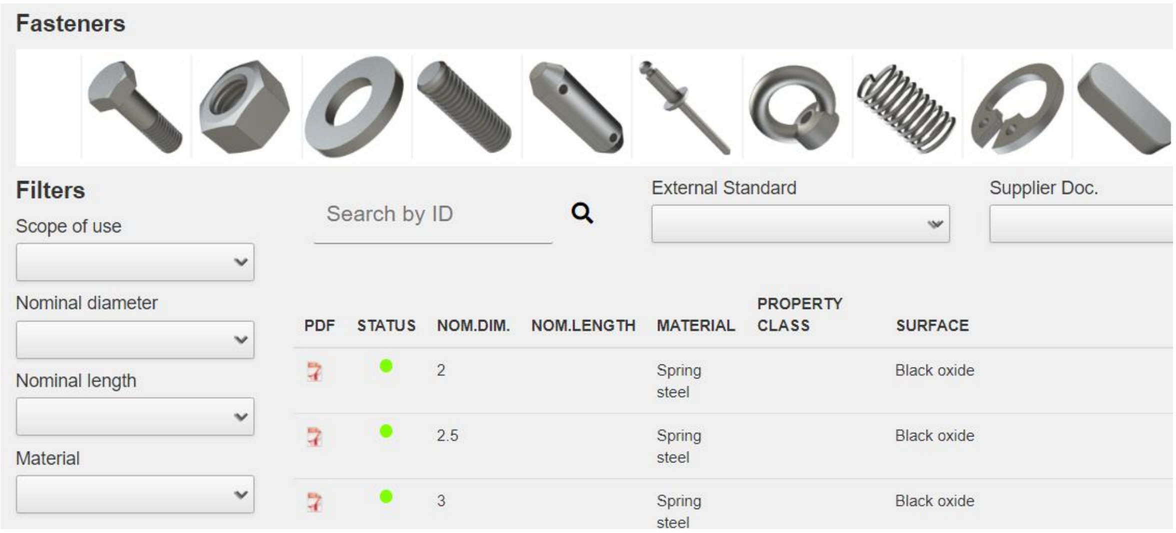

Figure 13. ABB Standard Parts Manager's web interface.

Integrated Cadenas is used for uploading new standard parts to PLM system. After CAD model is uploaded to PLM, part's information is maintained in PLM environment. Introducing SPM and Cadenas require harmonization of redundant ERP material IDs. Due to large amount of work related to harmonization many of the business units have not implement the solution. This is also the current situation in the case company but plans to expand the number of part categories included in the offering make the system more attractive. This is also considered in the Motion level PLM project and in the future Motion PLM and SPM are intended to be integrated together. Figure 14 describe how Cadenas integrate the SPM database with the PLM system and MCAD.

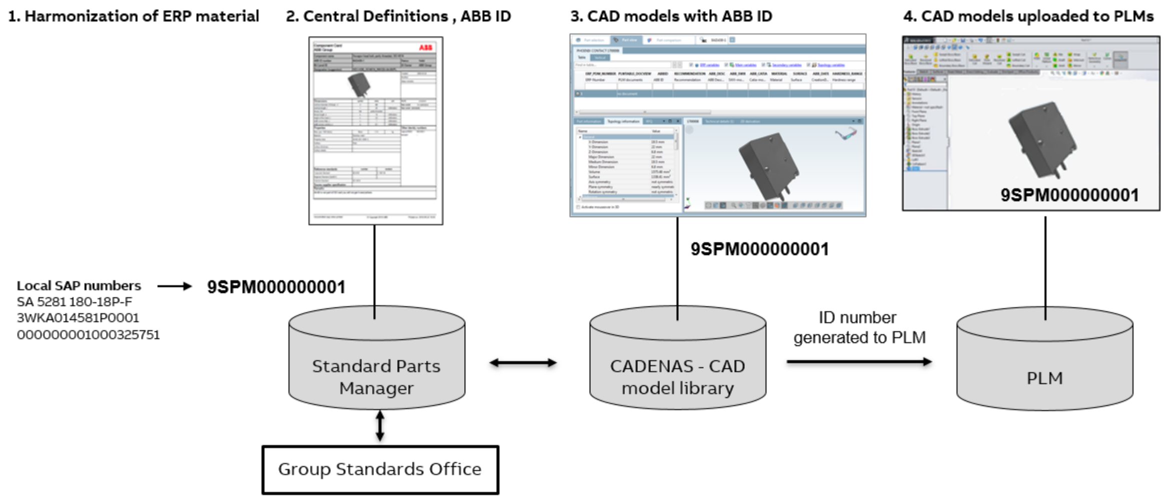

Figure 14. ABB Standard Parts Manager data flow to PLM (ABB, 2019b)

According to ABB's Master Data Manager this model should also be the starting point for designing the part library. Although it is known that SPM currently only supports Fasteners type parts, expanding the part type list is easier when more units deploy it. (Westerberg 2020) Long term benefit is be that after harmonization units start using common ID numbers for purchasing and making global material forecasts as well as running sourcing operations becomes easier. Part library development must also support this goal and even though the research is done from the needs of division the solution must support the whole ABB business organization and the harmonization of the parts. The data model of the standard parts in the new PLM system should at minimum include the basic attributes stored in the SPM system. In addition, the local attributes can be added when a part is expanded from the SPM to the new PLM system. With the standard parts the goal is to use common article IDs on the ABB Group level.

4.3 Retrieving information in current environment

All articles used in products can be found in the company's ERP database. It is natural that most searches are done directly in the ERP application. Figure 15 present the user interface of ZITEM search tool, the search does not include attribute search.

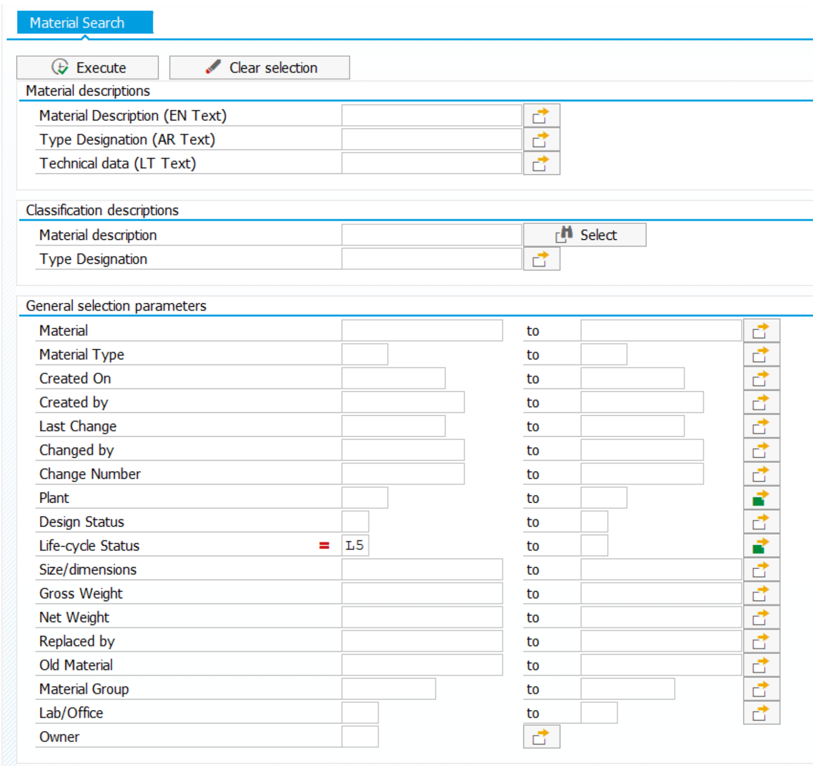

Figure 15. ZITEM material search.

The search for parts is practically based only on the *Material Descriptions* fields and search criteria are added to the search fields according to the desired part. ZITEM search tool, is a material search customization in ERP application that lists all the search results from which to select the appropriate part. There are three search fields for the description of the part, and in addition, restraining parameters can be added to the *General selection parameters* fields so that the search is sufficiently limited. *Classification Descriptions* can be used to specify which subcategories are displayed in the search result. The most important tool in finding parts is the design experience. Parts are easier to find when the user can guess in which category it may have been stored and what information may have been filled into it. The designer may have come across a similar part in the past and can remember which product it was found in or how it was found.

Another search method that can be used for searching mechanical parts is to look through similar assemblies in the PDM system, after which the model can be opened with the MCAD tool and examined to see if there is a suitable part in it. Alternatively, the part can be searched directly by exploring the folders in the PDM application. 3D visualizations can offer useful support when retrieving parts in PLM application. From the parts list, the user can already see when browsing what the part looks like, which helps reduce false search results.

In addition, it's possible to open mechanical parts directly in MCAD tool by using identifying code because CAD models are stored using the ID as a filename. In the case of a single part, it is still not helpful in the search, as the part could as well be viewed by opening its drawing through the ERP application, if user already know the part ID. In the case of an assembly and if there is a model stored in the PDM application, it may slightly speed up locating a part, at least in case of large assemblies. Large assemblies can take noticeable time to open, in the meantime designer might have already had time to check the bill of material in the ERP system.

Designers and teams store lists of parts for their own use, and they have access to other similar sources such as preferred fasteners excel spreadsheets. These listings are particularly useful in supporting day-to-day design work, but if the listings are for local use only, they do not support the standardization of parts and end products. The designer also supports each other globally and by communicating with others one can get help or information in finding a certain kind of part. Sometimes experienced designers can advise in which assembly a certain kind of part can be found. Here, collaboration and sharing of design information is the best tool. On the other hand, it can be said that if it takes time to find a part globally by many designers, then somewhere it has been done wrong in managing product information.

The problem with the current part search environment is that the parts are stored under very different names on the systems and there is not enough classification information added to the parts to identify. Choosing part from the ERP application's search results is also made more difficult by the fact that the results do not display a preview image or classification information. In the PLM application's search results the preview is displayed, but the system only contains mechanical CAD files and no item attributes. These factors, combined with an extensive parts database, make it difficult to find reusable parts. It is difficult for a designer to find a part filling specific specification, using mere name search fields, if he doesn't know exactly what to look for. This further contributes to the growth of an already extensive item database, as it is often easier for a designer to give up after the first failed search and open a new item for the part one needs.

4.4 Business motives for developing a reusable part library

PLM systems have developed a lot since early adaptations. In the past system providers had reputation to sell concepts instead of solutions and leave the development of the functionalities to the customer. It would have been troublesome for a distributed company, while operating in competitive market, to commit so many manhours to product information management system which is not offering full capabilities and matured enough to respond to the needs of large manufacturing company. The new PLM project, which started in the company 2020, shows the company's trust towards the technology, and this belief is also supported by recent PLM projects from many other large companies.

In the past, there was very little collaboration between company's divisions and product development has taken place in different departments without enough interaction with other departments sharing the business. This is a problem because, for example, the design of case company's products has taken place at the level of individual product families. However, these products are very similar with each in design both mechanically and electrically. When differentiated, the product development produces many new parts that have the same purpose but still differ in appearance. The designer, therefore, opens a new equivalent part for the same use, without knowing that a replacement part exists. To solve this problem, the design information must be stored in a database so that it can be easily found. The designer always knows where he has saved his own work, but the right kind of directory tree guides others to find the finished design work results. A better course of action is to change the existing part to suit both uses and save on overall costs. Such a simple thing will bring cost savings to the company in the long run in the form of a smaller number of purchasable parts and a more efficient supply chain.

A part library is a database that consist of predefined lists of preferred parts that are frequently utilized in the designs of the case company's products. The purpose of the part library is to improve the discoverability of reusable items through a shared platform. The part library provides a centralized part database for designers who is the most commonly library's end-user. By managing part's information in a centralized instead of separate product contexts it is easier to ensure that the data available is consistent, reliable and updated frequently. Typical example of this type of parts are the fastener items e.g. screws, nuts and washers, but this definition can also be extended to product elements and modules. Well-designed part library is easy to expand to cover more item types. Integrated part solution can achieve performance improvements by:

- Improving development efficiency.
- Reducing the development time.
- Improving the quality of products.
- Reduce infrastructure costs.

The main advantage of storing part within the library context is that user can quickly locate common parts, compare parts using design attributes and choose the best fitting whose sourcing information is up-to-date, and the quality is reliable. This frees the designer to do the actual design work and develop new solutions. Improving the cost-effectiveness is one of the reasons that drives the library development. The fact that it is possible to select a custom fan connector from the ERP system that has all the data correctly, but which is only used in local products made in the USA, for example. This fan connector can then be purchased, but the price and delivery time can be many times higher than another equivalent part that performs the same function. Repairing these decisions in retrospect is a very expensive and time-consuming task. If these corrections are not made, in a few years the special connector will be widely used in products where the same function could be done at a much lower cost. Similar cases are often encountered in projects.

There are also risks associated with using part libraries. If defective parts are present in the library, they are likely to cause more damage than product specific parts when placed in production. Errors can be related to part geometry or incorrect attribute information. Designers must be confidence of the accuracy of the information in part libraries. If an error is detected in a library part, it should be reported globally and the information in the section corrected to the library section as soon as possible. The integration between the design, the library and data management environment allow to get the maximum return on investment for the PLM system, and makes it possible to maintain data integrity with minimal manual work or without having custom configurations.

4.5 Drivers for developing own part library system

The item and standard parts management model in the case company has been functional for managing simple products and a limited set of items. Once manufacturing has shifted to a global operating environment and the number of products has increased, the management of reusable parts has not been updated to meet the needs of design and product maintenance. In the case company, designers usually reuse many standard parts and structures gathered in long-term industry design practice. Products which have the same functional requirements and similar form factor often share assemblies, parts and features. The benefit of using parts are common is that they are more cost effective due to higher volumes and immediately available for production. This can effectively reduce the amount of product design iterations, ramp-up time and improve serviceability of the new products.

A common practice is that designers select, for example, the wire connectors from the manufacturer's catalog based on their personal preferences. By choosing the recommended sizes and models for the reusable part library, both the connector and wiring harness can have lower cost and thus benefit in the long run. Corresponding parts in mechanical design include, for example, fasteners, plugs, grommets and seals. The total number of these parts in the business unit could be significantly reduced through standardization.

A designer must take large number of factors when choosing a reusable part for new product and consider how and where the product will be used. Designers are under tight schedule pressure and at the same time they need to create a reliable product that is as affordable as possible to manufacture. Apart from regular design work, there are production-related challenges, for example due to part availability problems, that go beyond engineering control but require quick flexible solutions without compromising quality. The solution to these problems also should not be expensive and have a significant impact on the production schedule. Incomplete information or inefficient part selection processes create uncertainty that creates problems as:

- Problems of quality, reliability and availability.
- Unverified parts are selected that reduce functionality or increase the risk of a critical failure.
- Expensive redesign, delayed production and delivery.

Ineffective processes for managing libraries and parts create administrative costs, requiring redundant resources, duplication of parts and additional costs for production and inventory. The lack of processes for removing old unnecessary parts from use can lead to more design iterations and delays. The impact of poorly made part selection and careless part management can create significant harm for business:

- Reduced profitability due to the costs of redesigning and production delays.
- Increasing the cost of parts due to too small volumes.
- Slowing down the product release due to bad part availability.
- Increased inventory costs due to duplicates, acquiring new parts instead of using common and preferred parts.
- Excess stocks and, as a result, the growth of decommissioned and obsolete parts.
- Increased development costs, as additional prototyping of new parts may be required.
- Increased operational costs due to decentralized infrastructure, that mainly associated with duplication of part data.

An important success factor that increases the predictability of design costs and reduces risks when introducing new products is quick and easy access to all relevant information about existing parts.

5 REQUIREMENTS FOR PART LIBRARIES

The aim of this phase of study was to find out what the requirements for the reusable part library are from the case company. The first phase of the solution development was to find the requirements for the library management based on the interviews and existing literature. The aim was to recognize the needs and later implement them to the solution as a proof of concept. The ERP system database itself may not be touched, but this chapter discuss about how to narrow down parts of categories from large search results.

The library model should be designed in such a way that it is as easy to expand in use on Motion business level. In addition to the needs of users, ABB Group regulations and the company's production chain set their own requirements for the library model and attributes. In addition to the design functions, the PLM system must support the needs production chain (production planning – purchase – procurement – product maintenance – service) as it is source system for product information. The needs are defined by interviewing stakeholders who work with products and design systems daily, as well as based on personal observations.

5.1 General requirements

The Product and Material (P&M) Rule Book is ABB’s internal regulatory document, that instructs how to handle Group master data per domain. It is the basis for domain terminology, identification, classification and master data governance applied to standard, configured, engineered, service products and systems. Current scope of this document does not include definitions for parts or their attributes. However, there is groundwork done to expand the scope to cover also the part definition. The rule book define that every Group master data attribute defined by obligation level Mandatory, Mandatory-conditional or Optional, and commonality level Core, Common or Distinct. As presented in Figure 16 all divisions are required to create core mandatory attributes in every business system and in addition mandatory common and distinct attributes must be implemented to source systems. (ABB 2018b)

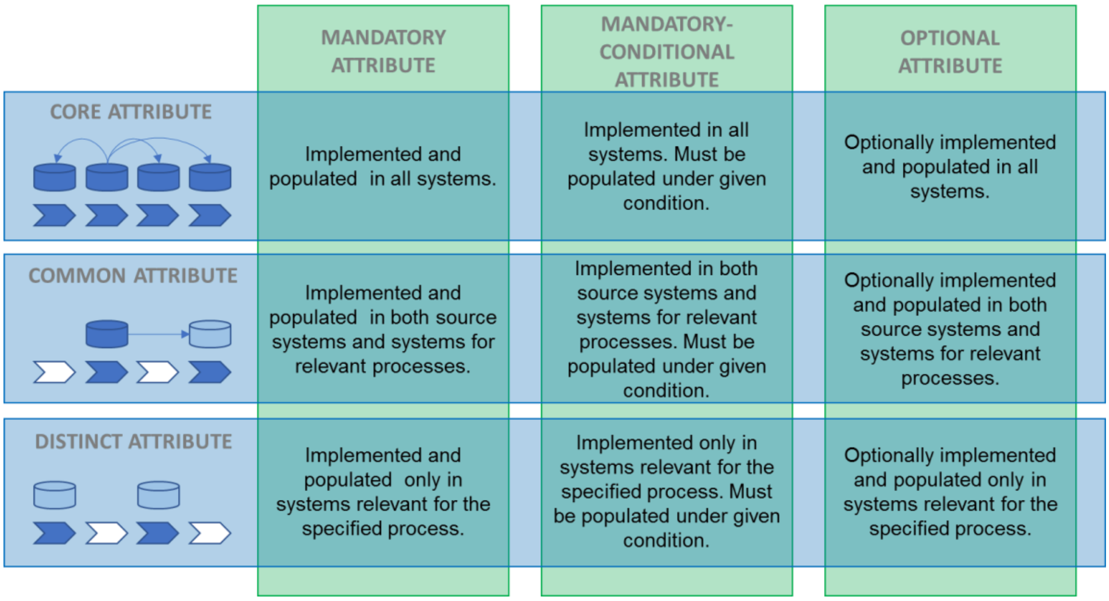

Figure 16. The obligation and commonality aspects that regulate the implementation of the attributes. (ABB 2018b)

Part library specific attributes are classified under Optional-Distinct as they are relevant only for the PLM system and not used in downstream processes. All technical attributes should be adopted from the part's basic classification domain instead of creating separate classification attributes into the library classification hierarchy. Table 2 lists the attributes ABB Rule Book propose for the design object of own design part.

Table 2. Proposed attributes for the design object of own design part.

Category	Attribute	Example
Identification	Global Material ID	1SAM250000R1001
Description	Name	MS116-0.16 Manual Motor Starter
Description	Description	…
Governance	PG	3122
Governance	Responsible Unit	4211, DE-3122
Specifications	Base Unit of Measure	PCE

5.2 Requirements from product development and maintenance function

The research hypothesis is that part libraries can speed up design work and support reuse but based on a form interview with the designers in current form the libraries fail to support design process. One of the main drivers for this study was dissatisfaction with the current state of the part libraries in the design functions of mechanics, electricity and product architecture. Finding parts and checking for reliability takes a lot of time from the actual design work. The needs of the case company's designers were examined by a form interview and by interviews with specialists who are familiar with issues. The purpose of the interview was to find out views on issues related to the structure of the library and the division of parts, as well as attribute information. The results of the form interview in the Figure 17 present the designers satisfaction with current libraries.

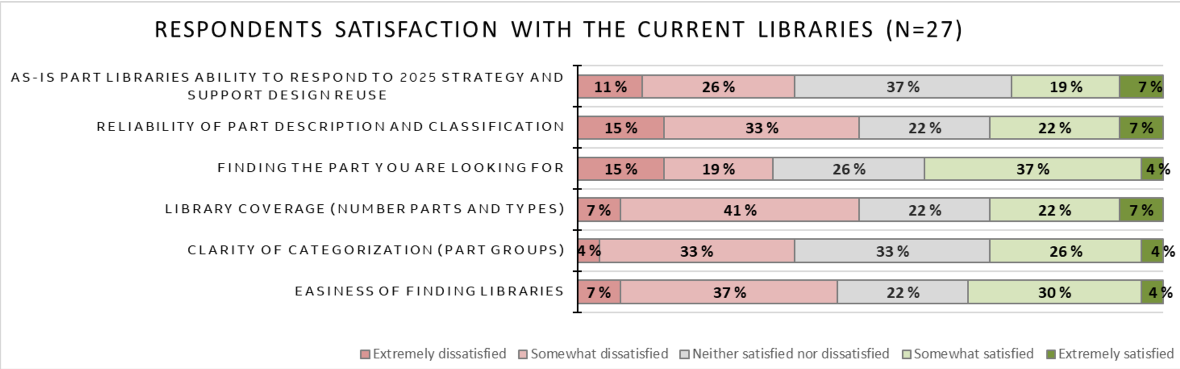

Figure 17. Satisfaction with current libraries according the form interview of designers.

The results of the interview show that 50 % of the respondents doing mechanical design were dissatisfied with the libraries while approximately 29 % of electrical designers were dissatisfied. Among the respondents 64 % use library like part collections and 30 % would want to use libraries if they would support work better. Designers hope, that the developed library model will make it easy to find reusable parts in the design environment that meet the criteria set by the product. There is a desire to increase the reuse of parts, and ideally, when designing a new product, as few new parts as possible would need to be created. Many of the designers find current system difficult to use and some design teams developed also their own solutions for the problem as can be seen in the comments given by designers:

- "Our group has had no communications as to where part libraries are within the PLM application. In an effort to create a centralized location for cad models, our design team has taken it upon ourselves to create a cad library of models we have used within past projects."

- "There libraries as they are, are hard to find and it is hard to filter through to the parts you are actually looking for."
- "I think we could benefit more if also own design items could be taken to part library. Although it can be quite challenging to set the limit, which object area taken to the part library then."

When designer's opinion on functionalities of the libraries were mapped the most important finding was, that the library should have attribute search supporting design area specific definitions, a method to navigate through the part lists using visual representations as well as through folder structure and library parts should have "where used" information easily available. The results of the form interview in the Figure 18 show that having common documents, common parts, catalogue parts and standard part lists available would benefit designers in their daily work the most.

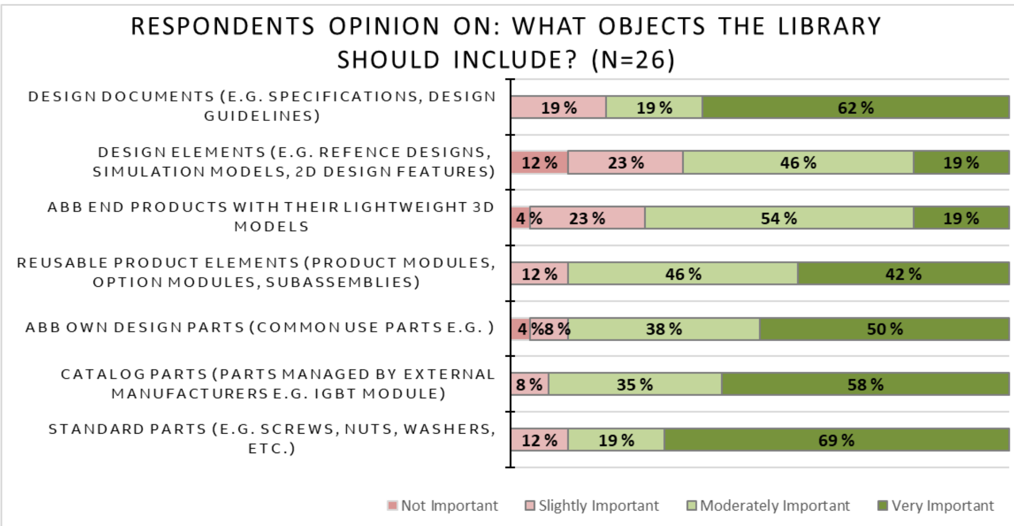

Figure 18. Most important object type according the form interview of designers.

The form survey also asked designers for their opinion on the library's governance model. The findings were that designers felt that the content of libraries should be managed centrally, and changes should be implemented using a pre-defined process. Results of the form interview presented in Figure 19 indicate that many designers would like to be able to suggest adding new sections but the decision and transformation work to add to the library should be made centrally. This is partly at odds with the fact that most designers would like to include custom parts in the library as well. The challenge for custom parts is their ownership, as the design information is in the possession of the responsible designer and if the part is transferred to a library container, ownership passes to the library administrator.

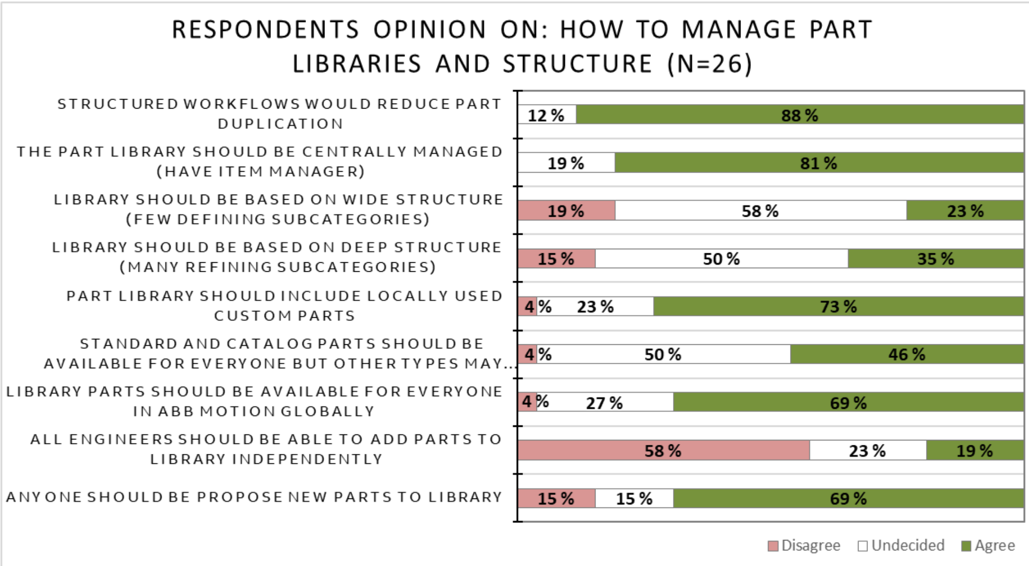

Figure 19. Part library management according the form interview of designers.

According to interviews conducted with the case company's design experts the modules used in the products must be high in the hierarchies and the links between interchangeable parts should be easily found. The number of changes to parts of the library management must be as small as possible and easy to do. (Sääksvuori, 2020a) General principles for selecting parts are following:

- Designer search existing solutions from CAD and PLM library. Typically, designer select initially the part category or use exact part description if he knows exact name.
- The designer compares the parts' technical parameters and filter search results using classification attributes.
- Additional properties of part, such as purchase and quality information, reveal the cost, quality, and estimated lifetime the designer can view through part's information page.
- Supply chain data that is brough from ERP system show is the part already available in stock or and how long the delivery times to stock are.

In the case company, the technical parameters of a part are classified into categories: electrical, mechanical, environmental and safety. Currently all attributes are part of items design information and created as part of new item introduction process. Electrical parameters are usually most straightforward to use, because they prescribe directly the functionality of the part and can be expressed with numerical value. Each sub-category of electrical part has its own attribute set, of which some are part type specific and some generic. Unlike electrical parts, the mechanical parts can typically be classified effectively using generic classification attributes, such as material and coating information, that apply to all sub-categories. Mechanical classification attributes indicate the physical form, mounting method, dimensions and weight of the parts. In addition, material, surface coating, refining standards and conductivity/insulation properties can be fundamental. However, if the classification of a part category can be made more efficient, some class-specific attributes can be given. This may be the case, for example, for screws, to which the Nominal Dimension, Nominal Length and Property Class could be added. Additional attributes should always be based on genuine needs and be approved by design organization. Case company's environmental classification attributes are related to the performance with respect to the different environmental conditions (Flame Resistance, Derating Temperature, Moisture Sensitivity) and, in addition, regulatory authorities (WEEE, RoHS, REACH, etc.) are governing use of hazardous and banned substances. Without evidence of fulfilling environmental regulations, it's dangerous to use the part in product's design. Safety related parts must be recognized in PLM system because their requirements differ from other parts. Electrical parts typically have reference information arriving from other sources:

- Information on preferred parts.
- A list of approved manufacturers.
- A list of approved global vendors.
- A list of second source parts.

Search and selection of alternative parts require more features than a simple comparison of the parameter list. To clearly understand the functional differences between the similar parts, the engineer also needs tools for comparing physical design. Therefore, the parts should also include visual representation. To control cost and reliability, engineers must conduct a detailed analysis and determine if the part meet all product specific requirements. Otherwise, it’s inevitably that there will be need for changes, redesign and increase in the design cost. Most of the product lifecycle cost is laid in the early stages of development. During the decision-making, process should contain answers to questions presented in Figure 20 in order to ensure the required level of costs, reliability and release schedules for the product can be kept. After understanding the generic factors such as part's availability, cost in product the designer can take deeper dive into data through problem reports, change history and the quality reports, that tell the more about part's performance over a period.

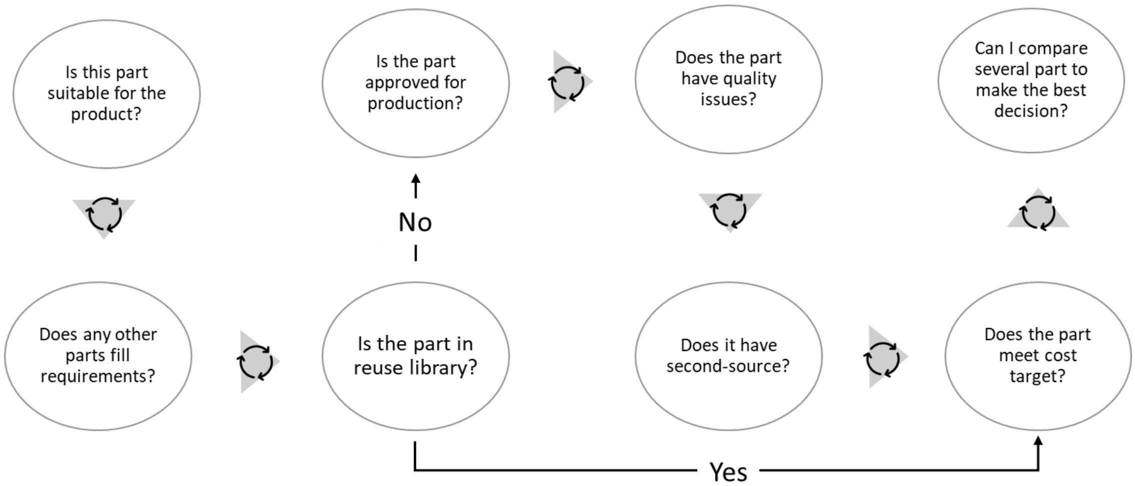

Figure 20. The engineer’s decision-making process.

Product data management system needs to provide the functionality for decision-support and provide enough information to support engineer’s decisions. Based on the interviews and analysis conducted in this research the current design environment does not offer engineers enough information for part reuse and designers must retrieve information through a variety of systems. A lot of time is wasted on searching information that should be easily available for designers and, in addition, systems sometimes have conflicting information. Table 3 summarize the collected library requirements.

Table 3. List of the library requirements. Compiled from the results of the form interview.

Category	Requirement
Support data administration	There should be functionality for seeing in which products individual part is used.
Support data administration	The parts must be placed in easily understandable groups based on behavior. By placing similar components into a common group, the number of individual folders is the lowest possible.
Support knowledge management	The features used in modeling parts and UDF models must belong to the Design Element level library.
Support knowledge management	Simplified and accurate simulation models of components and modules should be included in the Design Element level library.
Support part reuse	There should be functionality for listing part alternatives for various decision-making situations.
Support part reuse	In addition to the description, the user must be able to sort and narrow the set of parts by using the design classification parameters.
Support part reuse	The library must be reliable and there shall be no errors or inconsistencies in the geometry and attribute information of the library parts.
Support part reuse	The library should also contain only components in accordance with the metric standard system in order to avoid confusions.
Support part reuse	Product elements that are complexes must have simplified representation.
Support system integrations	The folder structure corresponding to the categorization model must be created in the PLM's Library Context and be integrated into the MCAD design program.

5.3 System's functional and business requirements

Part information and descriptions of the library parts should be as standard as possible. The categories that appear in the library are assigned based on the desired folders, part files, and attribute information. The library classes must also consider the dimensioning methods and the number of configurations. The dimensional variations of the product elements give an indication of the numbers of configurations. However, it may not make sense to store each product element variant as a own entity in the library if the variants have only very minor changes that can be expressed through configuration. Table 4 summarize the collected functional business requirements for the library.

Table 4. List of the library functional requirements. Compiled from the results of the interviews.

Category	Requirement
Support business process	The library should support the presentation of manufacturer-specific parts through Generic Part. Parts inside generic part must have their own material IDs. Separate items enable the use of the Supplier Management module.
Support business process	Standard parts almost always belong to the library and should be opened directly there. The standard part must have both a Global Material ID and Local Material ID used by different units. Thus, standard parts must have correspondence information where one of the codes is primary.
Support business process	There must be a separate operating model for locally sourced parts. In addition, the library strategy must be able to differentiate between businesses, for example in the case of Application Engineering.
Support data administration	The library must support the reuse of parts without the need to revise or move parts in the PLM system.
Support data administration	Administrator must be able to modify the hierarchy, add or delete categories in the library without changing parts.
Support data administration	A strategy must be created for the reuse library to determine which parts are stored in the library.
Support data administration	A clear division of responsibilities must be established for the library's management model, so that it is not unclear who is responsible for which area. The responsibility model should support both the local and global operations.
Support data administration	The library needs administrators and detailed instructions on how to create library components, as well as strict compliance with the guidelines.
Support data administration	A technical owner must be assigned to each component. Designers therefore remain responsible for the accuracy of the attribute information.
Support data administration	Component category-specific workflows are created for library management.
Support information exchange	Common components in the library must be available to all users.
Support knowledge management	The library should support the reuse of product elements. In addition, the hierarchy tree should support portfolio thinking (product family – product – technical product). The product architecture should develop a model that supports a sufficiently detailed specification.
Support knowledge management	The library should explain which product the part or product element belongs to. When ownership of a product element is clearly visible in the handling of modules in the product architecture becomes clearer.
Support part reuse	There should be a functionality for collecting information and creating new information, which help is useful for decision-makers in their part reuse assessment activity.
Support part reuse	Using categorization, it must be possible to create a part library solution that meets the needs of users.
Support part reuse	The library solution should consider the main and subcategories of the parts. They should be assigned their own attribute sets to support the reuse. Library solution should support the discovery of parts through the navigation view.
Support part reuse	The structure of the library should be as light as possible and unnecessary subcategories should be avoided if they do not support the design. Unnecessary categories complicate the library collection process and make it difficult to find parts.
Support system integrations	Standard parts should support importing from Standard Part Manager.
Support system integrations	The classification of electrical parts must be based on the classification of ECAD, which will be introduced into the PLM system.
Support data administration	Unauthorized access to Business Line specific Product Elements should be prevented.
Support data administration	Unauthorized access to Business line specific Design Elements should be prevented.

5.4 Requirements for workflow

In order to keep workflow efficient unnecessarily steps and bureaucracy should be avoided. This makes the workflow faster, which in the long term saves costs. The principle is that items are not managed independently but are always part of the product. One of exceptions is the manufacturers catalog parts where changes come from outside the organization. The library is not intended to transfer part ownership from designers, instead library classification adds value to parts and make their reuse easier. Changing the way parts are classified, require also culture change, as the designers in many functions are not familiar with classification attributes. Filling in this information is not a library function’s task, but there has been no requirement for designers to set classification information for parts before, the people responsible for the library shall ensure that the information is adequately.

After the migration phase, introduction of new library objects should happen using workflow. If the task transfer is not automated, searching and transferring information to the right people can take a big portion of time. Flexible information flow makes the product data harder to manage and, therefore, there must be a clear division between the basic attributes and the library attributes of the part. There are statutory requirements for maintaining product information for some parts, for example safety related parts, and all changes to the part’s design attributes must be able to trace. Without clear guidelines it is easy to have irreversible conflicts. Workflow ensure that the product data stay reliable, available and accurate.

5.5 Cleansing part database for library migration

In connection with the development of the library structure and classification model, it is not possible in this case to change the data or data structure in the ERP application. Extensive categorization based on descriptions and ERP application’s item classification has been refined so that fulfilling the reuse requirements can be picked. At the beginning of the work, the item types were first selected as the categories to be worked on in the study. For the selected categories, 500 items were retrieved from the ERP system based on the classification, and the resulting list was narrowed down using attributes. ABB items owned by other divisions, item duplicates, items with “replaced by” information and items that are not in “Design Released” mode were removed from the list.

Cleaning up a part database requires is a labor-intensive process and item parameters along with the missing data must be one-by-one before item can be transferred to the PLM system. Condition to the PLM migration is that transferred standard and catalog parts are in active use. Items that occur only in a single local product or have not been used for years should not be migrated to library. The use of an item can be examined using the Where Used search in the ERP system. The occurrence of an item in a single or a few subassemblies does not prevent it from migrating to the library, as the main level item may be widely used across different products. The local standard parts of the divisions should be cross-checked with the SPM library so that the local items can be combined with the Global ABB ID items even before migration. This reduces the migration workload because ready-made attribute information obtained through SPM is used instead of local item information. Standard parts are presented in the library using the Global ABB ID, and local item codes are presented through attribute information, allowing parts to be found using both codes, but products begin to use uniform global codes in the PLM environment.

The item list must be pruned very mechanically in the beginning of the migration in order to move the main set of parts. Later, the migration can be continued for items that require more clarification. It is easier for the designer to select parts from the library if the obsolete parts have already been pruned in advance. When the designer detects a missing part in the library, he notifies the migration manager, who expands the part together with the help of the designer. Designers can also suggest adding new part categories to the library during and after the migration. The library's categories and corresponding part attributes likely to change over time, as they are aiming to meet the needs of users.

6 THE MODEL DEVELOPED FOR THE REUSABLE PART LIBRARY

The solution was formed by researching existing solutions and reflecting them against the requirements found during the interviews. A PLM-based model utilizing type hierarchy-based multi-classification is proposed to the reusable part library. In addition to the ERP item classification, a separate library classification is created for the objects that are stored in library folder. This allows for a flexible classification of parts and the classification of design-used parts that do not have ABB item code. In the model, allow the user to browse parts based on descriptions or library using classification through the Classification Explorer interface. Alternatively, the designer can browse the parts via Library context using the folder structure. The Library folder view uses a hierarchy of the library classification to make it easier to export parts to a common part library.

Part libraries are an integral part of modern design environment. They have two main uses. They reduce duplication of work and unify product development activities by controlling part selection. Used properly, the part library serves as the most important tool for design standardization. Although there are standards like ISO 13584 which define how to build part libraries the case company want to understand how to set up reusable part library system that which is in line with ABB Group’s standards and integrate with design environment for increasing product design efficiency in long-term. To ensure the potential to incorporate future demands the PLM system was chosen as a platform for part library solution.

6.1 Overview of the Reusable Part Library Implementation

The introduction of the PLM system and the accompanying item classification hierarchy change the original needs for part library that were defined in this work before the PLM project began. From the PLM system definition perspective, standard parts, catalog parts, manufacturer parts and own design parts are proposed to have the same part type, and users would be able to distinguish different part types and owner of the part solely based on the classification attributes. The contextual hierarchy and information handling strategy specify that on business level there is single PLM Site and Organization for managing information of all divisions. The product information of each division is stored into Product containers and Library containers. One product context represents complete product or product line that the business units are producing. Product containers hold all product related the parts, CAD documents and other related information. Library context is meant for storing common objects, so that can be shared across multiple products, product lines or even across divisions. In addition, library containers can be used for storing other kind of reusable information such as material definitions, internal standards and templates that designers need to access frequently.

Well organized access management and defining user roles are key to the efficient operation and maintenance of the system. The PLM system strikes a balance between open information sharing and securing the product information capital of divisions. The aim is to support part and information reuse as much as possible but at the same time make sure that users can only view and edit information to which they have authorization. The basic principle of the new PLM system's Access Management concept is that product information is visible for all PLM application users by default but when there is a need to hide sensitive design information system administrator must be able to limit access to product specific containers. Similarly, the basic principle of the reuse library is that design information accessible for all PLM application users to support information sharing between different country units and divisions within given limits. Basic user access management in libraries is implemented at the container level so that three information transparency layers are created: the division-specific library, the product segment-specific library, and the business unit level library. The three layers are implemented as collaborative spaces in the PLM application with read-only access for all users. Adding or modifying parts to one of the three layers requires special roles and processes. In addition, library-specific groups can be established to determine library ownership of the product element. Users belonging to the owner groups of a product element have the right to make changes to the parts. PLM system's user group determines if user have authorization to view or edit the content in library as the simplified model in Figure 21 describes.

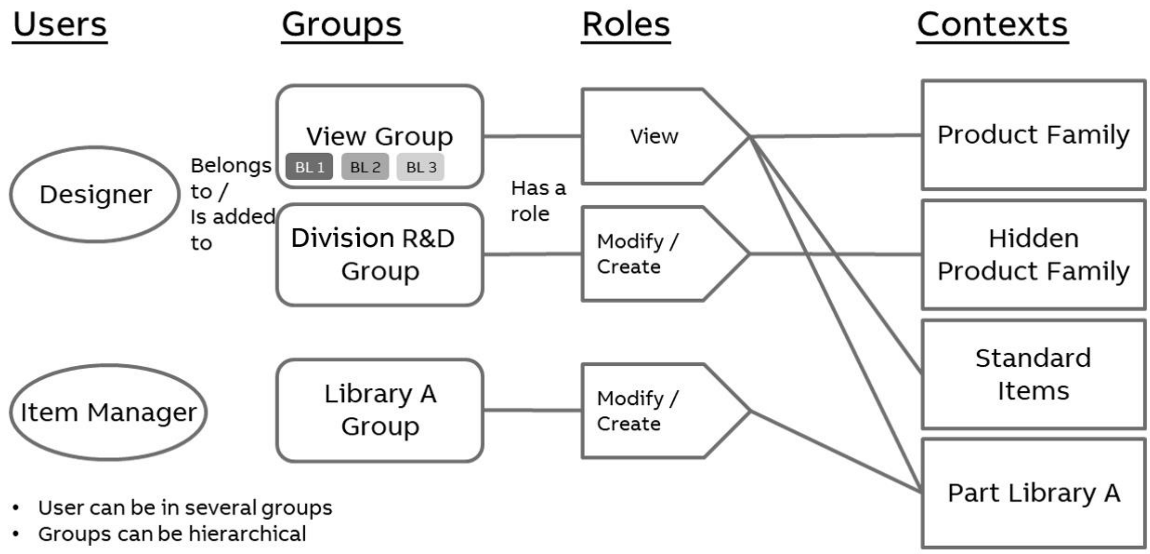

Figure 21. Oversimplified example of individual user's view.

The Item Managers are in key role ensuring that the data in the part libraries is complete, accurate and is maintained. The Item Manager is accountable for the data quality in PLM for his scope of the organization and import standard parts and catalog parts from external systems into PLM on behalf of the designers. Depending on the organization, item manager will own the information directly or then manage the people that perform these tasks. Product element library folders must be configured with owner groups for change management. Some product categories, such as fieldbus modules or control panels, change management teams are easy to state because responsibilities are defined in the organization. However, the current product-centric management model does not support the reuse of product elements and common part libraries efficiently. Product architecture and the definition of modularity play an important role in defining responsibilities in the case company.

The main concept in this library implementation is to divide information into three layers and form own workflows based on the use case. The library system is composed of the part reuse repositories and the knowledge store repositories. For the realization of the requirements, three methods are proposed for the case company:

- Extensible classification model for standard parts and create dedicated common reuse library.
- Dedicated common reuse library for catalog parts, classifying using basic design classification.

- Multiclassification for product elements and establishing libraries with ownership in mind.

In all cases classification attributes enable a dynamic parameter-based search interface for displaying part collections and delimiting search results. This way the library model has flexibility to adapt to changing requirements, changes in part definition and organizational changes. In the case of the knowledge store, the common objects are stored exclusively in the library container and standard document classification hierarchy is used. Reusable parts can be placed in a library container, where the item manager is responsible for its maintenance, or the product in a container, where designers are responsible for it. In the model there is flow of information between product containers and the part libraries and within the library between the part and knowledge libraries presented in Figure 22.

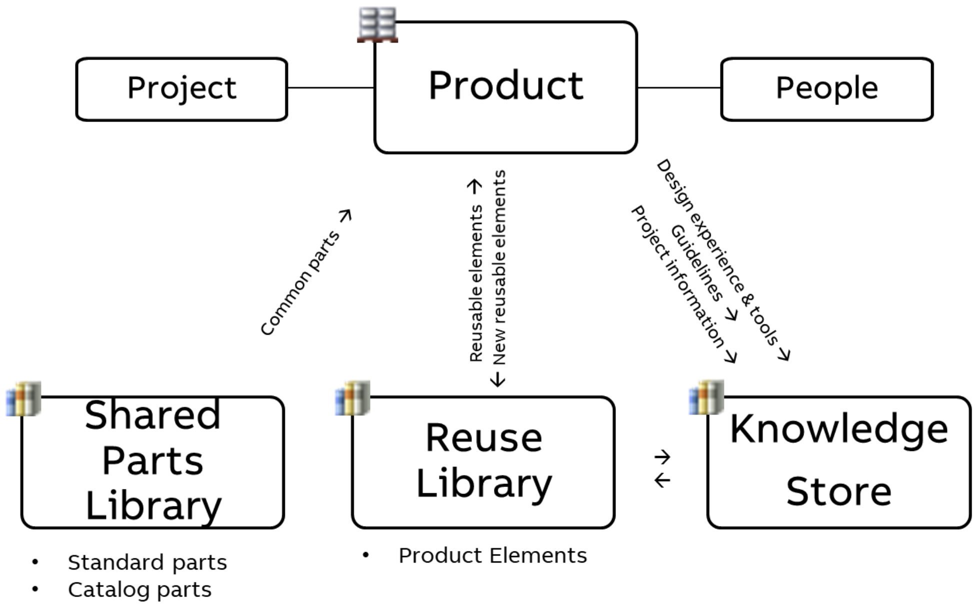

Figure 22. Relationship between product and library containers.

During the development of a new product, the designers work exclusively inside the product container defined for the project and open all new parts there. As the product maturity degree increases and the product moves to the production stage, new reuse parts are entered in the reuse library at the end of the project. The knowledge store supports the daily work of designers by providing tools for doing design work. Any type of object can be kept in the knowledge store: requirement lists, links to standards, CAD material files, CAD modeling features (2D and 3D), design guidelines, design illustrations, etc. How information flows take place in the process is management issue outside the scope of this research.

To support this model proposed in this study, it is recommended that standard parts and own design parts are differentiated by the part type and new classification branch is added for standard parts in the case company’s PLM system, which enable defining type specific business process characteristics. In addition, attributes must be added to the part classification model in the PLM system to identify own and third-party parts. At the beginning of the development of the library model, the hypothesis was that library parts should have own classification model in order to form part collections. After testing the library classification model in the PLM application environment, it was found that the use of two different classification structures may cause confusion and additional work without major improvements in usability. From this it was concluded that the library views are based on the attributes obtained from the design classification and the context information tells the user whether it is a shared library part or whether the ownership belongs to the product container. The common classification model allows comparison of similar own design parts, custom parts and catalog parts, and makes maintenance work easier. In order to adapt to variable conditions and requirements, the part library is divided into four use cases presented in Figure 23 to distinct the functions and make the library interact with CAD and roles individually.

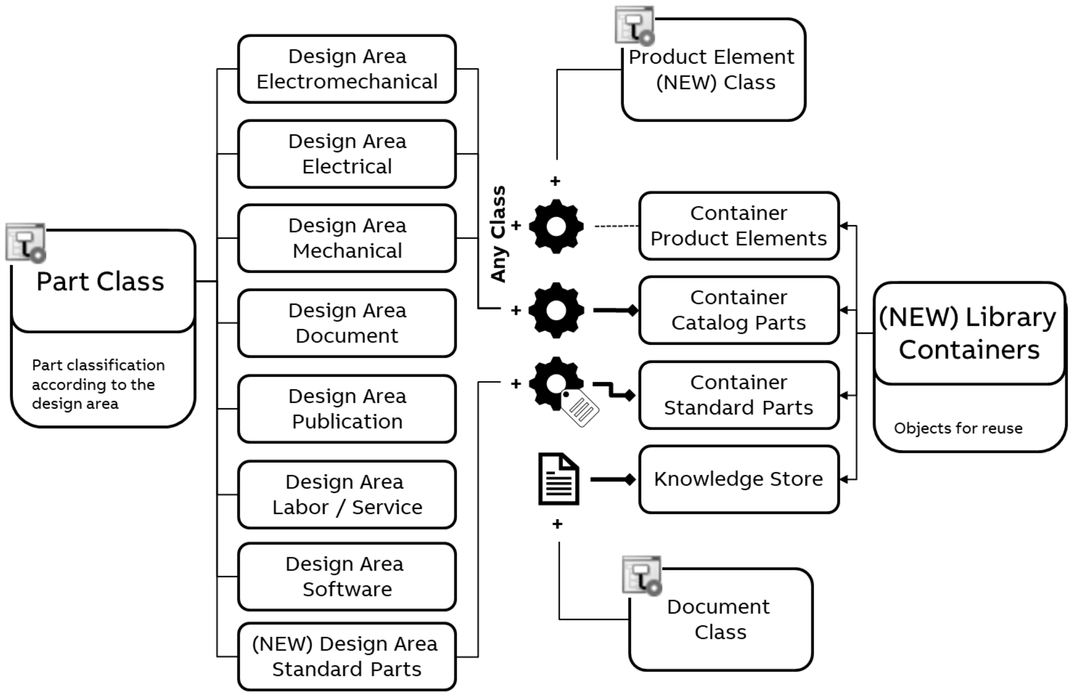

Figure 23. Interaction between object classifications and library containers.

Within library containers, objects are divided into subfolders based on their function, as described later in Chapter 6.3. If administrator want to add new containers to the library model later, you can use the existing libraries as a template. From the part reuse point of view there is two different cases in library, the first being parts that are intended for common use in products from the beginning, like fasteners, catalog items and modules. Second case is the parts that evolve to be common use parts in products, for example power module that used as a platform for the development of other product variants. In the later case, the need is to categorize the parts in "library" but keep the ownership in original product context. Since the PLM system do not allow changing part type after creation an alternative way for recognizing reusable parts must be incorporated.

6.2 Operating Guidelines for Reusable Part Library

The PLM application's Workflow Administration enables procedures in which information, tasks and documents are passed automatically between contributors in predefined pattern. Contributors should know and understand all roles and their different responsibilities. Teams that are maintaining libraries should consist primarily of active roles and shouldn't contain many distinct passive roles. Each team member in the library container should understand container's commonality aspects, objectives and business rules.

Deliverables of library management process should support common objectives and data must have clear ownership on division or business level. The management process must be consistent within the container and business rules should not have significant variation for similar data elements. If there is a requirement for significant variation a new library container should be created. Management model should aim to minimize conflicting business rules existing for similar data elements, and in the relationship of team members to the data.

As already stated, three different processes can be identified for parts library, of which the maintenance of catalog parts is probably the most challenging. The design of catalog parts is not the property of the company and changes to the design are made by the manufacturer. This poses a challenge to ensure part compatibility and quality if a manufacturer changes a part or manufacturing process. If changes occur in a catalog part, the effects of the change must first be reviewed by the item manager and only then can it be decided whether a new revision can be introduced to library. Workflow for introducing new standard part can be described as follows:

1. Designer design a need for new standard part in CAD software and give input to item manager.
2. Responsible item manager finds corresponding standard part from the SPM. If part does not yet exist, the manager gives SPM organization input to create it.
3. Item manager import new standard part to the PLM system using Cadenas interface and inputs part information into standard part folder.
4. When there is a need to edit or update parts, the item manager move parts to work folder.
5. When a part is out of date, the item manager deletes it in Library context by replacing part with updated one.

Workflow for the catalog parts resembles previous description and main source for catalog parts should be Cadenas. However, in many cases catalog items cannot be found through the Cadenas and part is imported from other external catalogs or need to be modeled by the designer. More generally the workflow of library part can be described as presented in Figure 24.

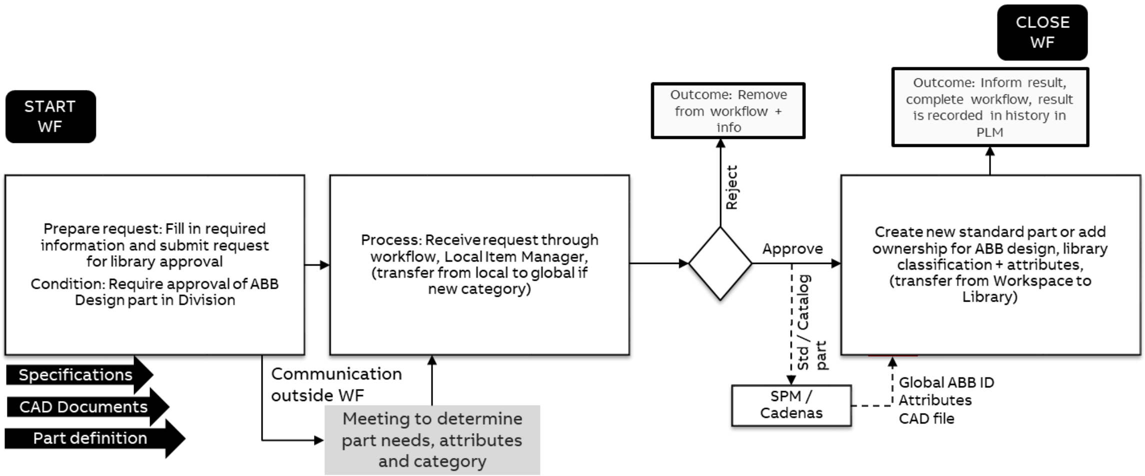

Figure 24. Library maintenance workflow.

The Cadenas system, which integrates with the PLM application, also prevents the creation of partial duplicates. The database stores information about all parts exported to the PLM application. When a part is opened in a CAD program for the first time, Cadenas imports the available attributes and the part is stored in the PLM database. After that, if the part is opened by another user, Cadenas downloads the part information directly from the PLM system. This feature also helps replace end-of-life parts, as the Cadenas database shows the units where the part is in use. The basic idea of Cadenas is that the catalog parts are not revised, and the part once transferred to the PLM system does not need to be updated. Parts transfer end of life and are replaced with new ones. Integration from Cadenas to PLM system use Global ABB IDs by default but parts system allows to create variants that use local material codes for controlled. This allows, for example, more accurate revision control for certain quality-critical parts. In the case of standard parts, it is important to keep in mind that if a part is subject to more stringent requirements than the standard specification, it is a custom part.

There are two options for maintaining libraries, the first of which is that each top-level category have an administrator with specific expertise in the design area. There are already administrators for PCBA parts and mounting hardware in the case company. Libraries access management and workflow will take care of that changes are made only by library administrators and designer role do not have permission to edit library parts. Users can contact the administrators if they have modification needs and moving part to the library working area frees it up for the designer to edit.

Another alternative for maintain the library is to outsource library maintenance. An external company to act as a part library administrator and would make all the changes. The changes would depend entirely on the tasks assigned to the administrators. Adding new parts and updating data is easily accomplished using this model. If new attributes or other changes need to be made to the system, the administrator will contact process owner to determine if these changes are genuinely necessary. Parts are revised and versioned in both models through the ECN process. In addition, it is necessary for the administrator to keep a record of other changes to the log file stored in the PLM system and the administrator is also expected to report from time to time on the use and status of the library in order to identify possible development needs.

6.2.1 Adding parts to the library

The topic was limited to designing the structure of the part library. Thus, the intention was not to create a ready-to-share part of the library or to migrate data to the PLM system. Due to example and structure testing, a few small batches of parts were added to the library containers by migrating them from company's ERP system. The compilation of the library started from the standard parts folder, as the classification information for these parts is quite well available in the database. To make the work easier, the associated CAD files were renamed with a corresponding to the material code, which allows the use of automatic association in the PLM application. Common Screws were already listed in Fasteners table and was modified as a result of this work created in accordance with the attributes. Even when working with a small set of items, it was found that the data in the standard parts have not been filled in uniformly, and the data cannot be mapped directly without manual processing.

Mass creation of new part, as well as adding classification information, is a straightforward process in the PLM application. To do this, it is possible to create an importable Spreadsheet file to which the user adds the values of the attributes by classification category. Each part file is one row in the import file and the attribute name is placed in the column header field.

Before import function create parts into a library, system validate data consistency and that all the attribute values fill the requirements set to them. When validation of the spreadsheet is passed, new parts are created in the set target library, and existing parts are modified with the new attribute values. If existing parts that are modified during the import they are automatically iterated. Same process can be also be used for importing information about part replacements.

When the part attributes are modified and supplemented according to the rules, efficient retrieval of parts is possible using the Classification Explorer. The data in the parts must remain correct when transferred to the ERP system. The classification of parts is strengthened when the designer is forced to select values before the part can be released for use. The list of allowed values attached to the classification model confirms compliance with the rules and the designer is unable to select attributes or material that cannot be found in the company specifications. This reduces the amount of incomplete data and errors from the beginning of the quality chain.

ABB's Standard Part Manager provides over 30,000 standard parts through Cadenas integration. This so-called Basic Library covers the main bolts, nuts, screws, rivets, etc. general mechanical machine parts. These should be utilized in the design system selectively. It does not make sense to store all possible standard parts in the PLM system, but to bring in at this stage the necessary fasteners that would be desirable to use. Delivered in this way, the part library becomes a standardization tool and guides designers to select recommended parts.

6.2.2 Using PLM application’s PartsLink to classify objects

Classifying objects commonly used way of organizing library parts, and helpful when searching for other type of objects. This allows library parts to be grouped under pre-defined classifications available in Classification Administration tool. In PLM application’s the main purpose of classification is to define the physical attributes that describe the object’s form, fit, and function. Furthermore, same functionality can be extended to classify and organize a product or library database to promote reuse of design parts. Individual object can be classified multiple times in PartsLink to reflect different functions. When opening new item on the case company’s ERP system it must be associated to the generic item classifications through the description. In instances where the part cannot be adequately categorized by predefined descriptions, the designer often selects some description under the miscellaneous category. Figure 25 gives an overall impression of the interaction of different parts of PLM application's in the library and searches.

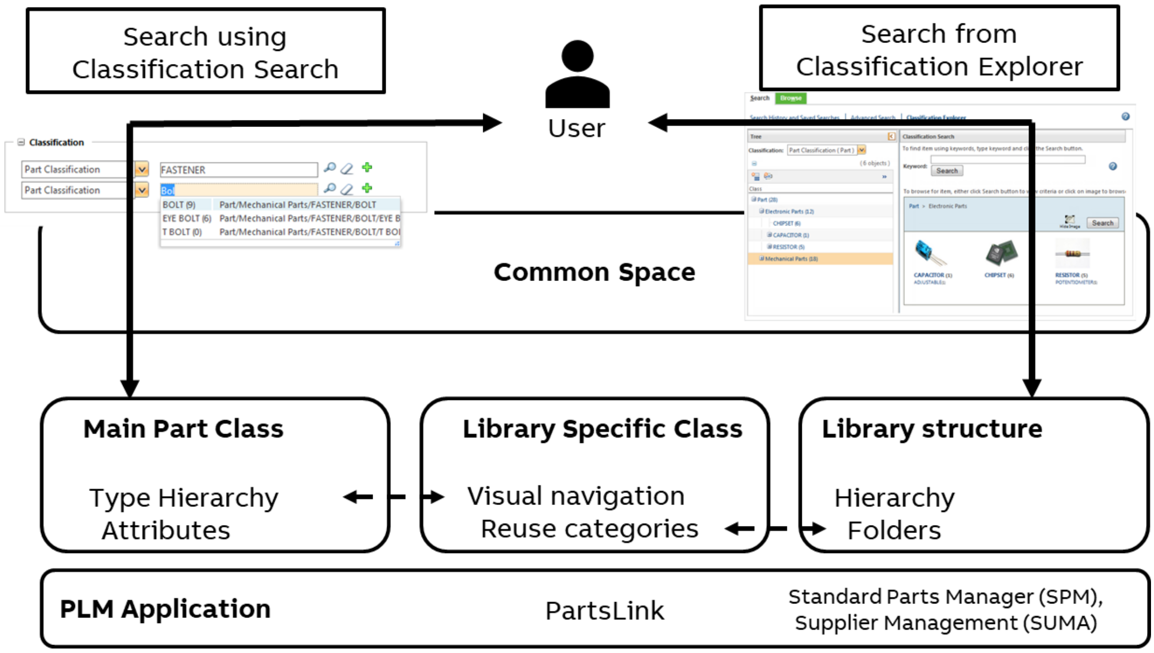

Figure 25. Overview of library management in the case company's new PLM system.

To implement the classification in the PLM application, the definitions of what attributes are needed and what other attributes need to be made were clarified. Editing the classification structure and assigning reusable attributes to classification nodes is done using the Classification Administration editing tool in the PLM application. The "Add attribute to class" button allows user to add new attributes by defining a reusable attribute name. The attribute description and parameter type are defined by the PLM application admin in Type and Attribute Management Utility. But the description displayed in the part details views can be changed by localizing the master text value. Figure 26 shows the Admin tool definition window for managing classification attributes.

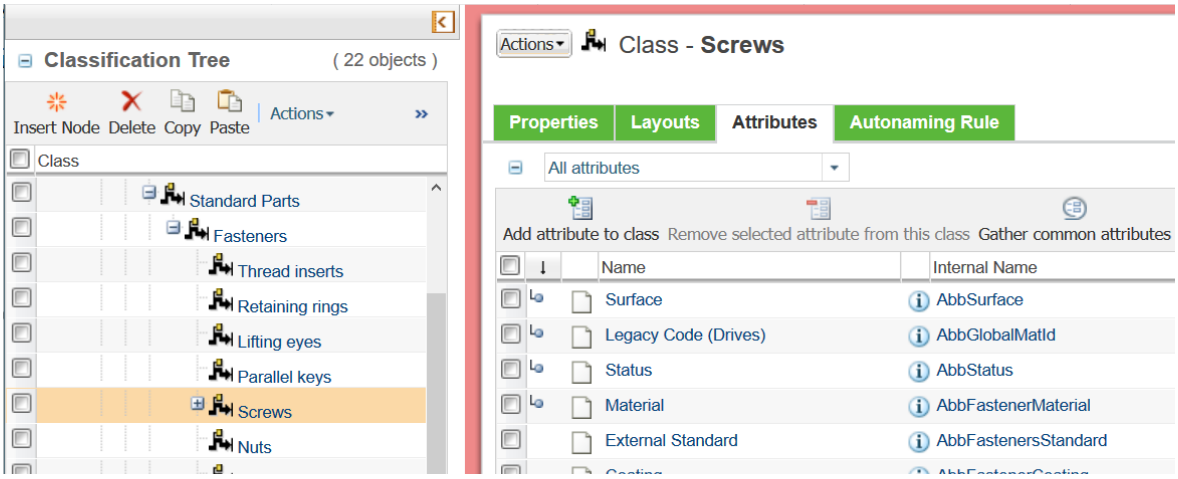

Figure 26. Classification attribute management in the PLM application.

Once all the attributes have been entered and the user saves the changes, they will appear in the layout table on the tab. After editing the layout, the user saves the settings in the database and the classification tree can be attached to the part definition in the Type and Attribute Management Utility. The Classification Administration tool allows you to create and maintain classification constrains, such as the Legal Value Lists. Settings and customizations made with the Admin tool take effect immediately when the user saves the changes. PLM application retrieves always the latest Classification settings made and new values can be updated for parts individually or in bulk.

Library parts mainly use only attributes obtained through the Main Part Class. However, the study found that the data currently defined in the part definition are not enough for the retrieval and classification of Fasteners parts. As a result of the work, the subscriber company will receive a classification system for the standard parts. Most of the attributes are available for standard parts through the SPM tool and the rest are added by the Item Manager upon import to PLM system. Parts in the catalog part library use only the Main Part Class scheme, but it is important that users can make difference own design, catalog and manufacturer type parts. To enable this, the study suggests adding an identifying part type attribute to the Main Part Class.

The classification of library parts aims to create concise lists to make it easy to find and select the desired part without the user having to browse through multiple folders or perform multiple searches for different descriptions. The same principle is reflected in the folder structure of part libraries. As a result, the classification tree does not extend to the level of a single description but instead supports the user to use attribute information for filtering and searching.

6.2.3 Retrieving information from a Library

A PLM library can be understood of as a location for storing and providing access to design information such as documents and other objects that are not related to a single product or product family. When a user accesses the Library tab in PLM application's they always see last page viewed for a specific library and can easily select another Library from the Libraries List. User can search objects under any page, group views by attributes and view relevant attributes by picking predefined or user-specific view. In addition to parts and documents the PLM application's libraries are used for storing and controlling CAD parts that have been approved for reuse. The CAD parts in libraries can be searched, viewed and access controlled the same way as the part itself. If a library is a frequent source for parts in The MCAD tool application, a best practice is to set the configuration option to point that specific library as a default directory. This makes it possible to navigate to library directly through Creo's File > Open window and makes access to the main CAD parts resource faster. In addition, the full list of libraries can be viewed by navigating to PLM application Commonspace' s libraries directory shown in Figure 27.

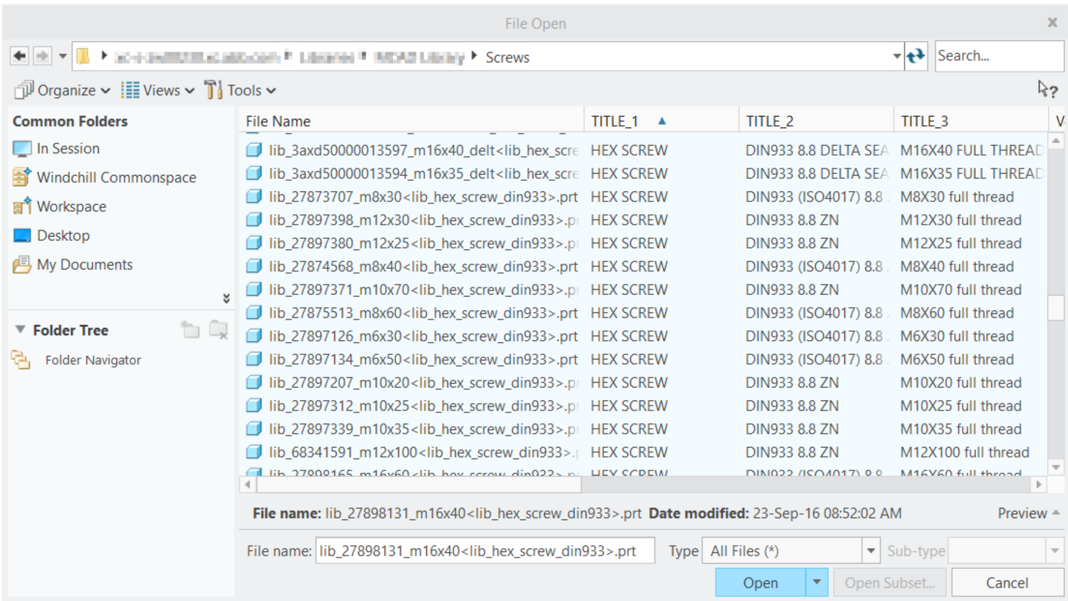

Figure 27. The MCAD tool file navigation window.

This library is not meant to contain everything, but the categories have been selected according to which listings would be useful to designers in the case company and product architecture definition. Some categories have been added based on the form interview and some of them have been used by the designer in some other format in the past.

6.3 Structure of the Reusable Part Library

The structure of the new part library was developed based on the collected requirements and experiences. The design was guided by previous part libraries, where the structure was already partially well-functioning. The aim was to make the new structure more approachable to the special features of the parts, more standardized and more users friendly. The creation of the part categories was based on finding parts with common features and their classification. The folder structure progresses hierarchically from the main categories of parts to sub-category designations. The work progressed by outlining several different options for how the folder structure could be implemented and how model would effect on usability. At the same time a question how to present adequate part information in different library views arose.

When discuss the future library container landscape the CAD document management, roles, authorizations, workflows, and classification must be considered at the same time. The type hierarchy for the part library consider the data model proposed in the company's PLM project and the definition for the Product Architecture. Product Architecture Management (PAM) define and manage the architecture guidelines, principles and application of modularity in relation to company product range. In addition to part object (WTPart) the containers store related documents (WTDocument) and CAD documents (EPMDocument). These elements and their subtypes have different behavior in the PLM system, but instead of creating multiple subtypes it is preferred to manage object's behavior though classification in order to maintain flexibility. Library containers have two use cases, of which the first is to store objects necessary for design work and tools that designers often need in their work. In the second use case, commonly used parts are placed in the library container to make it easier to find parts for reuse. From the operational point of view having subfolders is not mandatory in PLM application, but humans tend to think, search and navigate in folders more intuitively. Therefore, it is important to determine the extent to which this intuitive folder-oriented approach will be supported in the future and to what extent designs can be trained to use classification approach.

On part library classification top level supertype is Library Class. Reusable content can be divided into physical parts and design object types. Physical parts represent a part that can be used in product structure whereas design type objects are used in design of a part or specifying them. At the beginning of folder design, consideration was made for presenting a larger subset through a library. But when further investigated, it was found that PLM application's classification and search functions allow parts to be searched at an adequate level using design attributes. As a result of this, the library was reduced to a more limited subset. In the outline of the structure of the libraries according to Figure 28, the main level of the library is divided into the design and part library containers.

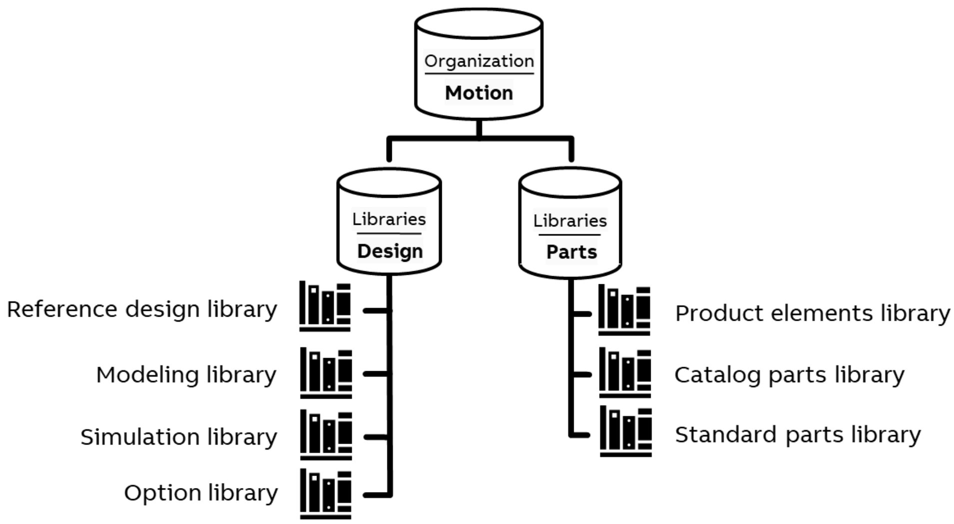

Figure 28. Description of the container strategy in PLM system.

Its basic idea is to first clearly divide design information according to its intended use into design-assisting functions, such as the design and parts libraries. The objects used in the design, such as material files, start parts and drawing templates, are placed in the design library. This classification group also include hole punch and other standard features that are needed for mechanical design. These are objects that the designer uses when doing design work. In the case of product containers, the information contained in the folder cannot be unambiguously defined because the same parts can be used in multiple structures, but the part cannot be placed in two locations in the system. Users have the right to change the contents of their own products or projects through the designer role. Designers have read-only access to library containers. This can prevent uncontrolled changes to the folder structure and the parts they contain.

The uncontrolled way to create directories leads to the confusion of the directory tree as has happened with current systems. In some cases, a clear unified line has been followed, while in some cases directories have been created at will. In the PLM application, library directories can only be created by administrators, but they must have a clear understanding of the structure of the database so that they do not begin to act too much on the requests of individual designers. The folder structure of the product element and catalog parts mimics the currently used ERP system's item grouping. This structure categorizes parts more accurately than the data structure designed for the case company's PLM system. It is well suited as a structure for such a part library.

6.3.1 Standard parts library

Standard parts library aims to improve product data quality by providing standard parts for constructions. All existing and newly added parts in this library have high requirements for classification. Classifying the parts ensure that duplicated are avoided, preferred parts are used and that engineers can find the information they need effortlessly. Before deploying the library, existing PDM data must be prepared for loading. The Group's Standard Parts Manager team maps connections with ABB Global IDs and updates local data to the database, and opens new Global IDs as needed. Standard parts library and the case company's new PLM system introduce a new classification, naming conventions, and classification search for existing and new parts.

At the time of this study, the new PLM system's stakeholders have not yet agreed on a uniform naming convention for standard parts. There is no uniform way to form designations between divisions, and there is no specification at the ABB Group level for designations or attributes to ensure the quality of master data. There is no common policy in the organization on how to keep information up to date. It is not clear how to proceed if, for example, the DIN standard is withdrawn and replaced by an ISO standard. The case company's information system has many standard parts with inconsistent field entries as shown in Figure 29.

Material	Descr.	Type Designation
3AUA0000005656	SCREW	M4X12, COMBI, TORX
3AUA0000020059	SCREW	M4X10, THREAD FORMING, PH, PZ2, Z
3AUA212001B37	SCREW	PAN HEAD TORX, M4X70/38
3AXD50000011944	SCREW	WN 1443 5X12 ZN PZ

Figure 29. Inconsistent field entries in the case company ERP.

Standard part naming and definition for the attributes in mandatory preliminary work that cannot be overlooked. Although the information is displayed through attributes in the PLM system, but still case company's ERP system will require a descriptive short name. The case company's new PLM system specification requires that the part object has three description fields, each with a limit of 40 characters. This thesis recommends that automatic standard part naming be introduced for these types of objects. The short name syntax can be formed based on the technical attributes of the part as presented in Table 5.

Table 5. Example for screw naming syntax.

Short name syntax, screw				
Title 1 (Description)	Supplementary title (Type Designation)			Title 3 (Technical data)
<Clear name>	<Thread size>x<Nominal length>(Y<Thread length>)*" "	<Drive type>" "	<Material>	<Defining standard>" " <Property class>" " <Coating>

When the as-is classification mode for the fasteners was investigated it was noticed the basic attributes of the mechanical parts class is not enough to describe the fasteners with enough accuracy. Therefore, the thesis proposes to create your own classification for standard parts. Classification attributes are created based on the SPM data model so that all the necessary data is available via SPM data sheets. The study also suggests that fasteners should not be classified by using design classification, but that the items be attached only to the library classification. In the SPM the parts are divided in own categories based on their description and defining standard. The author believes that the grain size in such a breakdown is too precise and when a designer is looking for a suitable fastener for their product it is better to see a wider range of parts that can then be filtered by providing attribute information. The list of part type specific attributes are shared with the target company only.

In the library model, mounting hardware is categorized into folders in the PLM application according to SPM level 1 categories. A library of fasteners has been created on MCAD tool and contains corresponding CAD files. Other fasteners categories are already explained in their name. The lists contain all used subtypes, but are not further subdivided on folder level, as the lengths of the part lists are already reasonable. Contrary to the old practice, the work suggests that MCAD model files are no longer named using the LIB_ prefix but only with their Global ABB ID. For clarity and library management, it is first necessary to define what is meant by the standard part. Standard parts are usually defined as follows:

- Standard parts are manufactured according to published specifications; so that the minimum requirements set for them are met.
- Standard part of one manufacturer can be replaced by the corresponding standard part of another manufacturer.
- If a part does not have a published specification or if a part has higher requirements than the standard specification, it is no longer a “standard” part.
- Standard parts, such as screws, nuts and washers are manufactured to exact standards sizes and they are commonly available around the world.

In addition to the parts suitable for this definition, the standard part library includes customized parts derived directly from the defining standard, for example captive screws that has a thinner diameter shoulder over the length of the screw. From product information management point of view maintaining this kind of parts is relatively straightforward if there are clear roles set for maintenance and classification model that support category-based search and filtering.

Identification is one issue related to standard parts, as suppliers use their own part identifiers when exchanging information, and the “same” part may have local ABB identifiers opened by several different units. When designers use standard parts in products, they must start using global ABB identifiers in the PLM system in the future, and if a local identifier is used for the item at the manufacturing location, it will be assigned to the MBOM structure of the product. Clustering of the standard parts is done by recognizing part families which the standard part library intended to describe. The parts in this context are described by their class and all parts which share same attribute definition are stored in common folder. Proposed folder structure for standard part library is presented in Figure 30.

Figure 30. Standard parts library folder structure.

Standard part library will be common part database for the whole business. In the standard library maintenance model, the item managers working on division level maintain the library together with sourcing managers. Item manager evaluates if the new standard part is really required by checking duplicated don't already exist in the library. Item manager discuss new standard parts with Supply Chain Management to get approval for new type and upload part with the 3D model to the PLM system from Cadenas. Table 6 describes the key roles related to standard part library management.

Table 6. Proposed roles for standard part library.

Technical area	Role	Description
Standard part library	Global Item Manager	Is the administrator of the library maintaining the structure and is owner of the process. Have full access to all information within the standard part library context
Standard part library	Local Item Manager	Has responsible role to create / update / classify / document parts within the standard part library context
Standard part library	Local SCM Manager	Approve new parts and arrange them to the shelf service through local vendors.

(continue)

Table 6. Proposed roles for standard part library.

Standard part library	CAD Administrator	Has full access to CAD files and drawings within the standard part library context
Library team	Change Admin I, II, III	Accountable roles for ECM process of standard parts
Library team	Promotion Approver	Accountable role for promotion request
End-user	Design Engineer	Has full read access on parts within the standard part library context. Can request new parts

For clarity, the naming convention for the bolts, screws, studs and nuts should be changed to correspond ISO 225 standard in the future. Creating more specific subfolders for each screw type does not seem appropriate at least at this stage, as the Classification Explorer tool as well as folder filtering functions allows for a more accurate search of parts.

6.3.2 Catalog parts library

The parts in this library context have external suppliers and have a catalog that is specific to their company and can be either single or multi-source. Suppliers typically distribute their part information in a variety of file formats, set of attributes and presentations. Having a common interface can save a lot of time and frustration. The lifecycle status of this type of parts should be controlled using effectivity date and if the part is revised in Cadenas the system should alert the item manager that there is more new revision available. Therefore, the item engineer should verify manufacturer part’s validity regularly. Especially, effective spare part management is troublesome if the catalog parts and generic parts relating to them are not up to date in the design system.

The ISO 13584 standard also point out the issue with the parts that have multiple manufacturers. As a solution the standard propose distinguishing manufacturer parts and generic parts between different levels folder hierarchy in library. In this model, a level 1 library can only be used for storing manufacturer parts, whereas a level 2 library store generic parts which are used in products. Then one generic part can include multiple manufacturer parts in its definition. If catalog parts are maintained in product containers management becomes more difficult and the risk of incorrect information increases.

The folder structure of a catalog library can be organized in several different ways, and there is no single right way to present it. Because stakeholders may have their own opinions on organizing the folder structure, finding a common view at the business organization level can prove challenging. Commercial catalogs divide parts into describing category, based on their function, or by manufacturer. Case company uses a categorical three-level division where parts are divided at the upper level into mechanical and electronical. Below the upper level, the parts are placed in a subcategory based on the description. This thesis concludes that, the library structure should follow the structure of the parts classification tree defined by the new PLM system introduction project. Since the classification tree defined by the PLM project is not yet available at the time of this study, the classification and library structure according to Figure 31 has been made to test the catalog part library.

Figure 31. Model implementation for catalog structure.

Typical mechanical parts in this category are plugs, gaskets, springs, vibration dampers, bushings and other outsourced mechanical items. These types of parts are described by external specifications and design is owned by external organization. Electrical catalog parts use ECAD classification defined by the PLM project. This classification model adds all necessary electrical attributes and there is no requirement to add more attributes by having separate class for parts in catalog library. All catalog parts and manufacturer parts related to them should be stored in a library context where their information is easy to maintain in a systematic way. Catalog part and manufacturer part should be clearly distinguished in the PLM application by part type to avoid confusion.

In order to know which catalog parts are preferred in the case company's new PLM landscape parts need to be classified by Purchasing Department. This classification can be given in the PLM application's Supplier Manager module if it will be implemented in use. If the implementation of the module is not done, the same information can be expressed by creating a catalog status attribute. Four different types can be identified for the catalog part:

- Preferred, used whenever possible. Best availability, price and shortest delivery time
- Approved, there is a business relationship and supplier evaluation has been done
- Limited, global vendor but no contract to ensure deliveries or single source
- Local, the catalog is provided, and the purchasing decision is made locally.

Catalog part library should be common part database for whole Motion business. In the catalog library maintenance model, the item managers working on division level maintain the library together with sourcing managers. Item manager evaluates if the catalog part is qualified for reuse from local business line perspective and check quality of the provided data. Item manager discuss new catalog parts with Supply Chain Management (SCM) and upload of missing or new catalog parts to the PLM system. Table 7 describes the key roles related to catalog part library management.

Table 7. Proposed roles for standard part library.

Technical area	Role	Description
Catalog part library	Global	Is the administrator of the library maintaining the structure and is owner of the process. Have full access to all information within the standard part library context
Catalog part library	Local Item Manager	Has responsible role to create / update / classify / document parts within the catalog part library context. Discuss new buy in parts with SCM

(continue)

Table 7. Proposed roles for standard part library.

Catalog part library	CAD Administrator	Has full access to CAD files and drawings within the standard part library context
Catalog part library	Local SCM Manager	Maintain catalog part status information / approve new vendors
Library team	Change Admin I, II, III	Accountable roles for ECM process of standard parts
Library team	Promotion Approver	Accountable role for promotion request
End-user	Design Engineer	Has full read access on parts within the standard part library context. Can request new parts

When a design engineer identifies the need for new catalog part, catalog part acceptance process is initiated. Condition for starting the process is that the vendor in question is approved by the SCM. After the SCM approval item manager retrieve part data from supplier catalog and import 3D CAD data. Item manager analyze the CAD data quality and make required changes. After this item manager open ABB ID for the catalog part, classify the part and CAD file is renamed to match ABB ID. Once all the information has been determined by the item manager and SCM responsible, the part and documents will be shared in the ECO release process and the part can be used in EBOM.

6.3.3 Product elements library

The degree of modularity variate between product families but majority of the products in the case company are optimized for mass production in order to minimize BOM cost instead of paying much attention to modularity. It is known that, forming reusable product modules from existing nonmodular products using brownfield method design is a long and resource consuming process. Nevertheless, product management is increasing the weight of modular design solutions and it is expected that in the future the degree of modularity in these products will increase gradually. Interestingly, the interviews done with the designers during this thesis has shown that the reuse processes suffer from significant lack of support in both system and process side. Thus, the library models to backing reuse strategy were invested as part of the research to permit a modular design method to progress support for reuse of product elements.

Product element library containers can be defined in Motion, division or reuse area level. A part is redefined as a reusable product element by associating it with the product element classification, which updates that part to the product element list in PLM application's Navigator. Even if a product element is associated with a classification, the product context can be kept as its storage location. Such element could be for example cabling field. The need for each product element container and ownership are defined by the platform managers and responsible product architect in divisions. Product elements need platform- and category-specific breakdowns for individual contexts to determine ownership, stakeholder, and change management process. Figure 32 propose following folder structure for the case company's Compact Platform.

Figure 32. Product element library container for Compact Platform.

The Compact Platform contains elements created during several different product development projects and these parts are used in several product segments. A product owner has been defined for the product platform in the organization, and several such similar product platforms have been identified. Product architects define product platforms but are owned by specially appointed chief engineers.

A product element is not a separate part type in the PLM application, but a reusable part that requires a more precise definition than other parts of the product. In principle, any part or assembly that is either for commercial or technical reuse can be classified as a product element in PLM application. Such a part can be placed either in the library folder, in which case the owner of the library has control over it or in the corresponding product container. The product architecture definition team, working alongside the PLM project, has developed a definition and attributes for the product element. This thesis applies the definition made, in order to bring product elements visible in PLM application's Navigator tool. To implement this, a separate re-use classification model has been developed for Product Elements. The principle for classifying product elements is adapted from the case company's new PLM project's Product Architecture Management study. Table 8 present attributes defined for the Product Element Class.

Table 8. The library specific class for product elements. (Sääksvuori, 2020b)

Attribute, Display Name	Description
Object Type	Define is the part Technical or Commercial Product Element
Product Element Reuse	Define what define the product element, for example PE reuse, Global ABB Standard, MV/LV Standard, Regional Standard, Product Platform Standard or Product Specific
Reuse Type	Define is the part intended for Physical Reuse or Design Reuse
Behavior	Define is the part Static element, Configurable element, or Parametric element
Platform Product	Define base product for Product element
Responsible Unit	Define product element ownership and responsibility for cross used element

Product element classification attributes bring a new dimension of product architecture to their search and classification. The advantage of the system is that the designer can start a search through the navigator from a higher-level category if he does not know the exact name. The designer can then narrow the results using both technical and product element attributes. The product element class, along with the part class, seeks to describe the product element's function, behavior, and key characteristics. However, this model does not consider product element's interfaces that tell designer how to implement a part into a product. For example, inverter module can be searched using technical attribute information such as Power, Voltage or Current, and results can be narrowed down using Platform Product information. Figure 33 shows the user interface through which the user can search for product elements and select more search attributes.

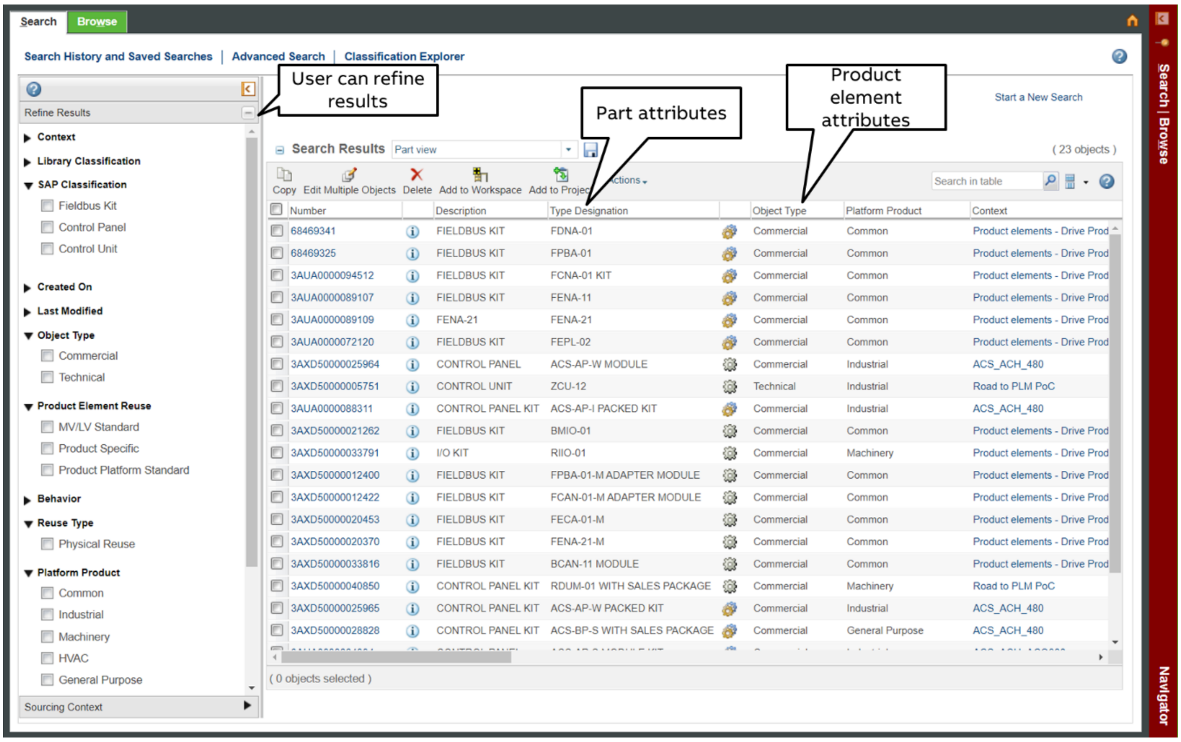

Figure 33. PLM application’s Navigator presenting product elements.

As mentioned earlier, the product element library can be placed in the Motion organization hierarchy on many levels. However, a common framework and roles can be defined for library management. As with other library folders, the role of the Item Manager is emphasized in quality management. In the product element library, the Item Manager works together with the Platform Manager or Product Architect. The product element library must define roles and stakeholders in the same way as in product contexts to ensure that only authorized users can make changes to parts. Table 9 describes the key roles related to product element library management.

Table 9. Proposed roles for Product Elements library.

Technical area	Role	Description
Product elements library	Library Administrator	Is the administrator of the library class and have full access to all information
Product elements library (division specific)	Platform Manager / Product Architect	Has responsible role to classify / document product elements
Product elements library	Local Item Manager	Evaluate data quality, approve qualifications, transfer designs to library context.
Product elements library	CAD Administrator	Has full access to CAD files and drawings within the context
Library team	Change Admin I, II, III	Accountable roles for ECM process of product elements
Library team	Promotion Approver	Accountable role for promotion request
End-user	Design Engineer	Has full read access on parts within the standard part library context. Can request new product elements to be added

When a design engineer or platform manager identifies the need or opportunity to provide a design in product element library, product element design acceptance process is initiated. Condition for starting the process is that the part in question is ready for release. All CAD documents related to the part and EBOM shall be released before product element is transferred to library, if not the ECO for release is part of the process. The requirements for the parts placed in the product and library containers differ for the 3D model. For a product element to be used, a lightweight representation of module or product must be available through the library. Design Engineer is responsible to provide documents in PLM application's PLM to start the process for product element design acceptance.

6.4 Knowledge store

The purpose of the knowledge store containers is to support designers in their daily work so that the instructions often needed in design and the types of objects related to design systems are managed centrally and up to date. Some of these objects are specifying the corresponding parts in the Product Element Library and, therefore, it is required to be able to create links between the objects. When new item is created in reference of an object from the Design Element Library a link is established between describing document and the part. PLM application's allow connecting objects using reference document link that establish two-way connection between two objects. This allows to view object relationships in tables, structures and reports throughout the PLM application. Furthermore, PLM application's document structure allows user to define parent-child relationships between documents, document can have reference other documents and they are maintained separately while their revisions are controlled.

Classifying documents and other objects in the Knowledge Store is not as effective as in part libraries. Documents are classified based on the general document classification defined in the PLM project. As a result, more hierarchical levels can be seen in the folder structure. As presented in Figure 34 this model also enables to create reference link between any part and document in knowledge store.

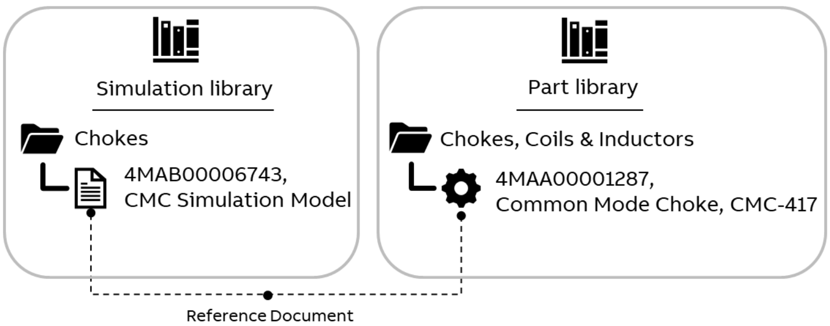

Figure 35. Using reference link maintain connection to the document regardless of the version of the document.

This allows the user to access directly attached documents via the part object. Similarly, the information page of the document displays the full list of parts to which they are connected. However, discretion should be exercised when storing files in the PLM system. If the document is specifically related to the design of a product element, it can be useful in situations of change at different phases of the lifecycle. In this case, it is a good idea to store the information in PLM application's and link it to that element. Such files include, for example, thermal simulation and strength calculation reports, injection molding simulation reports, or installation images. If the element contains complex relationships with other products, a simple text file can be valuable in change management situations. In addition to documents and CAD files, the library can store URL links that direct user to external systems, for example Confluence articles or group level standards. This makes all design guidelines and standards easily accessible to all designers.

6.4.1 Modeling library

The need for a modeling library has come to the fore in discussions with experts and in connection with the definition of a PLM project. The company has a similar though less extensive library in local PDM installation. The idea of a modeling library is to provide designers with access to the objects they need in their daily work to use design programs. Storing these objects in a common database ensures that designers have access to the changes. The logo and profile sketch library can also be used to track which parts need to be updated if, for example, the ABB logo changes. All the folders presented in Figure 36 can be placed in one library because the content is owned by the CAD administrator.

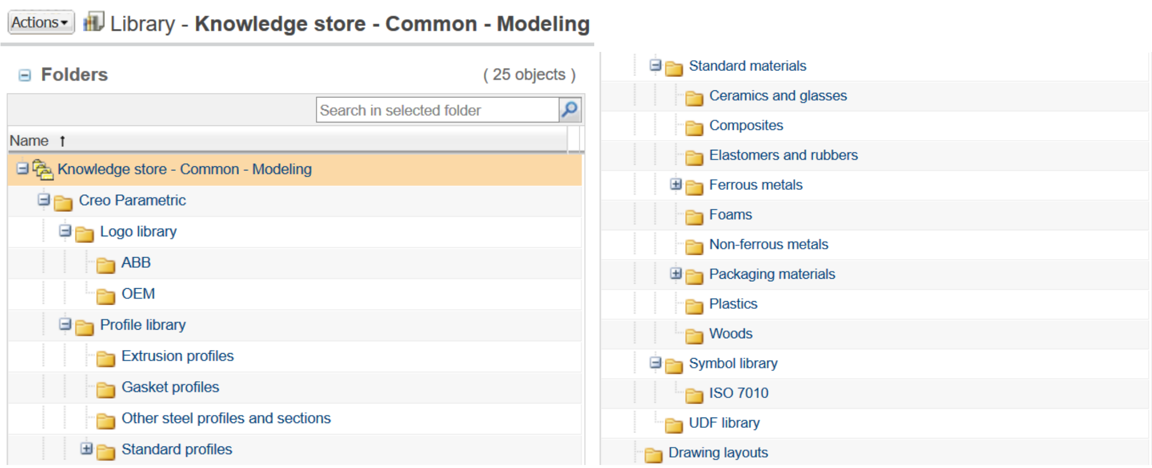

Figure 36. Folder structure for Modeling Library.

The material files and property parameters that are stored to case company's new PLM system in the standard materials folder come from the program vendor. In contrast, the material lists of the case company's current PDM system are maintained by the designated administrator. Material file is associated with the part through the MCAD tool which used the information for example to calculate the mass. This approach is good because in the prototype phase, parts are often ordered directly using a 3D model. The material files are divided into main folders by material category. Steel and plastics are still divided into their own categories due to the large number, while elastomers and rubber are listed in the same list. Categories can be added later if a list becomes too long to interfere with use in CAD programs.

When using the MCAD tool design system, standardization can also be extended to the feature level. The Profile, Logo, and Symbol folders contain sketch files that designers can use when doing modeling work. Sketches can be either defined by an external standard or made by ABB's own designers. Features that are difficult to model and commonly used can be standardized by storing them in the system as User Defined Features (UDF). The geometries of plate cutting and shaping tools that are most used by the subcontractor are stored in the system as UDF files. Sketch and UDF file naming conventions are emphasized from the point of view of maintainability, because such CAD objects do not have a naming convention that must be formed. The Drawing layouts folder contains drawing templates for 3D CAD programs.

The Modeling library is shared to all users, but the main user group is MCAD tool users. Ownership is the sole property of the Creo administrator and other users cannot edit the content. Specific material library for CAD tools is required because, in the future, the way of working is to be changed so that the material is expressed using the material files from the library. The material or materials are linked via a part’s information card in the PLM system. When material files are managed through a central library, an individual user does not have the ability to change material information or select material that is not allowed to be used. Material data management requires its own network of administrators around it, which is responsible for the accuracy of data in different material groups and make sure that all necessary approved materials are available to designers.

6.4.2 Simulation library

The MCAD model produced by mechanical designers can also be used in external simulation software with certain limitations. Generating a mesh model often requires a lot of manual pre-processing. For example, in the thermal simulation model of the complete product, the simulation model utilizes only the features that are essential for heat transfer. Therefore, holes, chamfers, and other small features must be removed from the product model because they only increase the complexity of the calculation model. The manual workload of generating a mesh model is high and building a single model can take up to several days of work. However, the purpose of the simulation library is not to store project-specific simulations of individual products, but information that has wider use. Such as the thermal model of the IGBT module or fan models that can be used to perform thermal simulations of products.

Simulation software produces data in several different file formats, and the total file size of an entire calculation project can be considerably large. It does not make sense to store an entire project in a PLM system. The need to store simulation data is driven by the engineering change management process, in some cases the analysis may need to be repeated, but the old result files have no use. Designers must save the mesh geometry file as well as the simulation result report to the PLM application’s Simulation Library. When linking simulation documents to the part for which the simulation has been utilized, change management is also easier. By following this process, the necessary information is retained by the designers and unnecessary use of server space is avoided.

The parts used in simulations are described using different levels of model complexity. Depending on the simulation case a high detail model or averaged value descriptions are required in order to quarantine computational efficiency and usefulness of the tool. Creating simulation models is a time-consuming operation and if the simulation model can use ready-made results and models from previous times can be reused, the computational efficiency can be significantly improved. Problem solving also speeds up when designers can go back to old simulation models and refine the models. For this purpose, a simulation library can be created, in which the models produced by different simulation software and the results of the simulations are stored. Figure 37 show folder structure for simulation library owned by the business line.

Figure 37. Folder structure for Simulation Library.

This thesis suggests that the simulation library is owned by the business line because they cross use many parts in their products and have similar products. Library could be owned by the design process owners.

6.4.3 Options library

The PLM system provides capabilities to support configurable EBOMs and variant generation, and track changes across the enterprise. To provide capabilities to manage modular and overloaded product structures, option sets must be maintained. The PLM application allows to define a list of fixed options and choices using these option sets. Purpose of the Option library is to have a common library where full options dictionaries for products are defined. PLM project's Functional Design Dossier specifies that configuration options and choices in must be managed in common library context. Option sets define the variation of configurable products and configurable modules within a product family.

The option library is a tool for configuration knowledge management. Option choices for configurable products are not standardized in the case company, and the same option choice may mean different things depending on the product family, as options aim to control not only the BOM but also pricing and product market positioning. The structure of the Options library will be defined later by the PLM project. Managing configurable structures is outside the scope of this thesis. Centralized management approach aims to ensure that options and choices are managed according to pre-defined principles and guidelines. In the library context, only authorized users change option sets, options and choices and quality of the process is easier to monitor. From the library the designers can assign option sets to specific product containers and part configurations.

In the PLM system the option set must be assigned to a product or library container where the configurable product structure exists in. Option set are used for product option choice assignment and filtering the product structure. In addition, option set can be assigned to configurable product or a configurable module level. Objects in Options library is managed by the Configuration Manager group. Option library manager stores options and choices in library repository, manages rules to condition choice selection, and synchronizes option pool with external systems i.e. Configit.

6.5 Other aspects to consider about libraries

Safety and compliance factors are a major concern in the electrical manufacturing industry. Designers have limited knowledge about product requirements, and it is often difficult to identify the related standards. Design solutions affect throughout the lifecycle of a product and it’s crucial that engineers have easy access to design guidelines and standards. Using the design knowledge library could help designers to bring best practices into their designs along with required design features. Clear use case for reference design library was however not found and, therefore, it was scoped out from the library definition. In addition, transferring generic design guidance to a PLM system is completely separate topic as this kind of documents are commonly stored in distinct information management system, It is still noteworthy that URL link objects can also be added to the library, making it easy for the designer to find the help they need directly through the PLM system.

The ECAD component visualization library has been excluded from the scope of this study. However, it has specific requirements that need to be considered when implementing a PLM system. The process currently used in the case company is technically functional, but the ownership of the library must be defined in the case company’s new PLM system. The circuit boards are always attached to the mechanical parts and should also be visible in the MCAD assembly model of the product. In PCB design software, it is possible to create space allocation models that support conversion to MCAD file format. This possibility of data transfer enables parallel design of the circuit boards and mechanical parts when new products are developed. Circuit boards 3D models can be used e.g. for the following purposes:

- Collision detection
- Space optimization
- Heat calculation
- EMC simulation
- Manufacturing instructions.

Like other CAD objects, the circuit board components' CAD representations must be available in the PLM application. These CAD objects must have the same filenames as in the external ECAD library. In addition, the CAD objects must have the same coordinate system as the components in the external ECAD library for the positioning to work properly.

6.6 Key improvements brought by the solution

The new model was piloted in case company's PLM application's development environment. The test was carried out but adding and classifying approximately 400 parts. The approach uses part classification combined with the library context to create reusable part library. Libraries created for use cases enable flexible storage model, case-specific workflow definition and role-based access control. The libraries can be browsed through the PLM application's navigator window, called Classification Explorer, which makes filtering the part lists easy and quick. Selected library approach supports standard parts, catalog-based reuse and reuse of product elements. The design attributes that are given to all parts created into the PLM system form the basic search attributes. Several benefits were recognized, which supported ongoing with the model:

- Specify either an exact part category or searches for parts more broadly
- See section lists of results instantly without a separate database search
- Easier to read and visual search results
- View the attribute values of the parts in a list view
- Identify duplicates easily by combining attribute values
- Lower risk of choosing an expensive or single-sourced part.

Knowledge store libraries support designers in their work and are a necessity for the usability of a PLM system. Similarly, as in the case of component libraries, document-type objects stored in the library can be searched using classification information. Product element classification can be extended to knowledge store objects if necessary.

Parts share some common classification attributes in the PLM application. Together, they form shared key characteristics in the Classification Explorer and allow comparison of parts belonging to different categories. Now the attribute values must be defined manually in PLM application, but later this process could be carried out automatically by utilizing artificial intelligence for classification of parts. In the current system, users cannot easily compare the attribute values of similar parts with each other, let alone compare parts belonging to different categories. This makes part retrieval easier and available parts are faster to find in the PLM system. Furthermore, the risk of creating duplicate parts is lower when it is easy to check, for example, the available sizes for support insulators from the library. This prevents the wrong height busbars from being designed or a new item being created for a new support insulator.

The changes mainly concerned the classification of parts in the PLM application and do not need to be reflected to the ERP system. Not all the software and interfaces in Figure 38 were tested on schedule with the library in practice, but they will be tested as the implementation phase of the case company's new PLM system begins.

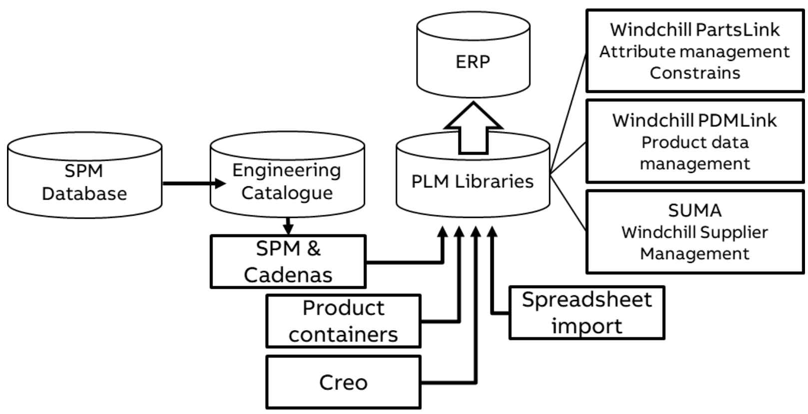

Figure 38. Future PLM software environment.

In connection with Figure 38, Table 10 summarizes the benefits of each application. The impacts are based on the assumptions associated with the PLM project and the actual benefits will be seen over time as each application is implemented for use in the PLM system. The principles of the Lean model can be introduced in a new design environment by improving the efficiency and economic productivity of product development and product management.

Table 10. Benefits of each application in library solution.

SOFTWARE / MODULE	IMPACT ON OBJECTIVES
MCAD tool	• A more detailed 3D model of the product • Finding CAD objects is easier and common parts are available to everyone
SPM & Cadenas	• Reduces the amount of modeling work when the designer finds standard parts quickly • Reduces the number of part duplicates • Allow geometric similarity search when integrated to CAD model database
PartsLink	• Allows admin to configure and maintain a classification tree
PDMLink	• Minimize product information errors and eliminate manual data flows • Integration of design and ERP platforms
SUMA module	• Management of catalog and manufacturer item relations

In connection with previous chapters, roles have been defined in the work that are recommended for maintaining the library model. This clarifies for the case company what kind of person should be placed in the maintenance task. In addition, a process has been defined for maintenance that allows library specific workflows to be configured in PLM application.

7 DISCUSSION

The purpose of this study was to identify different methods for managing part libraries and to understand how they would work in the case company. This was done by interviewing experts in the Motion organization who work on product information management. In addition, a form interview was conducted with the case company's designers to get their practical needs heard.

7.1 Comparison to with former research and common industry practices

Supporting parts reuse through libraries has been extensively studied (Wu et al. 2011; Chen et al. 2012; Du & Cao 2012) and several standards have been developed for the classification of parts such as IEC 61360, UNSPSC or eCl@ss. ABB does not have its own group-level standard for part classification, but the divisions have decided independently. Many part libraries studies focus on integrating library structures into a 3D design system, but scientific sources on the PDM system are also available. In the target company, part libraries were last studied more than ten years ago and as part of a PDM system upgrade. The PDM system was used only to store CAD files and item data was managed in the ERP system as it is today.

Previous studies support the assumption that product development function create a large amount of product information, which is not properly utilized in later phases. Applications need to be intuitive and fast to use and integrated with each other to get designers to adapt new methods. The amount of manual integration and the need to store information across multiple systems generates errors and knowledge of doing unnecessary work.

According to studied on reuse, the reuse can provide the greatest benefits to the product development process when measured by development time, product and maintenance cost, quality or products and performance of system. The most important facets in allowing the benefits of design reuse in business environments is to focus on the design of reusable products and the development of functions and support systems. This makes it easier to use reusable elements. (Duffy et al. 1998; Frost et al. 2016) In the case company, part library management in a PLM system has not been tested before. In some other divisions, such, the

PLM system was introduced earlier, so the work has an internal benchmark. Companies are reluctant to share information related to information systems and data quality and, therefore, it was difficult to obtain benchmark for this study from outside ABB.

7.2 Reliability of the research

The study was carried out according to the description of the research method based on triangulation. Efforts have been made to improve the reliability of the study by documenting the requirements, the research process and describing the baseline situation. However, the researcher's observation and interviews are very difficult to repeat the same way, which impairs reproducibility and generalizability.

The created maintenance model requires the development of culture in the organization and is vulnerable if the necessary resources are not available. In this case, designers may lose confidence in the benefits of the new process and return to the old ways of working. The reliability of research in a practical environment depends on the organization's willingness to make changes. Some divisions want to maintain the free definition of data and the possibility not to fill in attribute data for parts of their own organization, this is a clear vulnerability in terms of data integrity of the PLM system and the operation of the presented library model.

The library classification structure can have many different starting points based on the company's operational model and diversity in organization. Comparing the practices internally to benchmark solutions with the reference group revealed that the operating methods in the division are arising from divergent starting points. This have created different kind of practical implementations in part libraries. Division A classifies parts in its own local PLM system based on their product-specific function. In this case, for example, all the parts included in the body of the product are easy to find. This classification model can work well if all products are structurally very similar and can always be assigned a clear location in the product architecture. However, there will be many different types of products in the new PLM system. In this case, there is a risk that the classification will be differentiated by product line and that reuse of parts will become more difficult. Division B has previously managed library parts list through a SharePoint database. The designers have manually added basic information about the parts and described how it works. This model has worked well for them because each delivery is a separate project. Their products are largely standardized and tailored to suit the customer's needs. They want to transfer these databases to the PLM system. In this case, there is a risk that project- and customer-specific parts will be listed as library parts.

In addition to the previous sections, it should be mentioned that the ERP systems used by the divisions operate differently and the information exported to them differs significantly. If the units start to define the PLM system from the ERP system point of view and limit the operation of the PLM program, the functionality of the library model will be compromised. The research has tried to forget the constraints created by the ERP systems and assumed that the classification tree and relationships to the library are not required to the ERP system in the future. However, PLM system must export some of the attributes to the ERP system through an integrator.

7.3 The key results and conclusions

The aim of this thesis was to find suitable method for creating part and reuse libraries in the case company's PLM environment. The results are based on the lessons learned in concept development and practical testing. The method to for part views utilizes PLM application's PartsLink tool for classifying objects and the part classification model was optimized for the case company. The author sought to understand how the target company has arrived at the current state in product information management systems and through this considered possible developments for the systems when moving to a common PLM system at the business line level. Development will continue in the case company's PLM project.

RQ1. Which elements of a part library enable the designer to find existing parts so that they can be used more often in the design of a new product and thus reduce the number of parts to be redesigned?

Based on the analysis and interviews the ERP application do not offer adequate search functions and finding parts is slow if the designer does not know which product structure to look for a part. Case company's current PDM system does not contain enough identifying information to find parts and does not offer adequate search functions. The study found that the data model of the parts can be significantly developed so that the attributes useful to the designers enable retrieval in the PLM system. A new classification tree was developed for the standard parts and product elements in the PLM application's development environment, which made them much easier to find.

Designers are most often looking for fasteners and other similar generic catalog parts. In addition, designers often need to find modules and product options that can be classified as product elements. In addition, mechanical designers use the UDF model and material library in their daily work through the MCAD tool. The concept of the library model includes standard parts, catalog parts and product elements. Retrieving parts directly from the PLM application with the Classification Explorer saves the designer time of about 80 – 90 % compared to standard and other reusable parts through the ERP application interface. In addition, the thesis proposes the creation of knowledge store that support daily work.

Results of the form interview showed that designers using ECAD systems are relatively satisfied with the current state. However, designers that are using the ERP application and PLM application find it difficult to find any parts for reuse. As a solution, the design teams have created their own part lists in Excel and other formats. As a result, the thesis proposes new standard part classification model to be created in order enable support for fast searches in the PLM system and help part retrieval. If the designer does not find the required part of the system, he creates a new part himself or searches for it in external directories. This creates duplicates and creates high-price and low-volume parts. The method allows parts to be found quickly. Classification also brings new possibilities for controlling the use of library parts, for example, a sourcing manager can rate the parts based on their preferability. In addition, the creation of certain part types can be limited on system level, allowing only the Item Manager to create new standard parts. Electrical parts of will utilize the ECAD part classification in the future which allow same search functions to be used.

RQ2. How should the part library be structured and managed so that the information it provides is adequate, reliable and unambiguous?

Classifying parts using PartsLink brings a significant improvement to search capacities. In addition, the integration of the SPM / Cadenas database reduces modeling work when 3D models of standard and catalog parts are available ready-made. PartsLink classification and parts retrieval were tested through PLM application's Navigator. The method was found to be very effective. Based on the evaluation made at the beginning of the case study, PLM application together with Cadenas software is the most elaborate way to manage standard and catalog parts management in a library. The functionalities of these applications were proven to be enough for future needs. At the same time, the possibility of integrating other add-ons such as the PLM application's Supplier Management module was created. To achieve the objectives of the work, PLM application's PartsLink was used which allows the company to standardize classifiable objects. The operation of the Cadenas system could not be tested independently due to the schedules of the PLM project. PartsLink is a robust choice for parts classification management and allows classification tree maintenance to be easy on the PLM application. During the work, the classification model of the standard parts was customized further to meet the needs of the case company. A classification model was created for Product Elements to allow any part to be classified for reuse. In addition, efforts were made to gain experience in classification tree editing functions. When divisions start transferring product information to the common PLM environment, PartsLink tool creates opportunities for increasingly accurate product information management.

Using classification attributes improves the quality of the information produced during the design process if rules and constraints guide the designer to fill some of the information correctly into the system. Regarding the improvement of product quality, the development can be seen mainly in the reduction of possible defects. It is more difficult for a designer to select low quality parts when the options are limited. The person in the Item manager role plays a key role in managing parts of the library. However, ownership is determined on a case-by-case basis. The thesis proposes a description of the structure, roles, and library ownership for each case. The system can also be used to guide designers to use recommended standard and catalog parts. PartsLink allow admin to tailor specific attributes unique to individual classification nodes and it is easy to assign attributes to a part type.

However, the thesis did not find a universal solution that would support the library and reuse of parts of a complex electromechanical product such as high-tech industry products. Classification systems such as eCl@ss contain large parameter lists, which, however, do not add value to the designer or promote the reuse of parts. The method provided by the PLM application's PartsLink tool for finding and comparing parts is a new capability in the PLM application. These capabilities allow company to standardize parts, perform parametric classification searches and promote reuse of parts. Having this kind of function available can increase the reuse of existing parts and reduce the creation of redundant part.

7.4 Generalization, utilization and novelty value of the results

The library model was created as a case study based on the needs of the target division and the general requirements of the target company. This work does not provide an explanation of whether some specific industry will benefit from implementing corresponding a part library structure into PLM system. The results of this thesis can be applied more widely in other ABB units and can also be used in the future when evaluating other product information management development projects. The experience gained will be used in the design of the case company's PLM project.

The results of this thesis can be considered to have novelty value, as they showed that the applications to be implemented can be used for more efficient library part management than case company’s existing solutions and support the more efficient product information management needed to advance the PLM project. A decision has been made in the target company to integrate the Standard Part Manager and Cadenas into the PLM solution.

7.5 Topics for the future research

This thesis does not take a position on how compliance or requirements management is linked to library part management. The requirements management system should have a direct link to the product elements and further to the change management chain. As a further development, it can be explored how to extend the definition of a library to support model-based design so that product structure requirements are considered earlier in the design value chain. These needs give rise to reusable product elements stored in the library.

Another area of future research is the use of artificial intelligence to generate part classification information. Artificial intelligence is a rapidly evolving field whose potential can eliminate the need for manual part classification and library definition. Artificial intelligence can be used to find closely resembling parts in a design database, to eliminate duplicates, and to find expensive low-volume parts.

8 CONCLUSION

The thesis was done as part of a product lifecycle management system development project to identify development needs for existing processes, take design needs into account in development, and connect with other divisions. The case company's new PLM system will cover the entire product range in the future. The aim of developing the library concept was to improve, among other things, the reuse of parts and to bring economic benefits.

ABB's divisions have hundreds of thousands of items in their ERP systems. Designers are making new parts every day when designing new products and making improvements to existing ones. Divisions have a growing need to standardize the parts used in products and move towards managing product platforms. At the same time, a new PLM system project is underway in order to combine the separate divisions into one common PLM system. The problem was that it was not clear how the parts should be classified and how they should be stored in the PLM system in order to support reuse. When selecting a part, the designer had to find out its price, availability and suitability for the application. This was time consuming because the information is not easily available in the ERP system and repetitive with each project.

Improperly selected parts result in additional costs in sourcing and logistics, quality risk in products, and longer project lead times. Most of the problem parts are eliminated by ABB's sourcing managers who are responsible for their own part categories. Single source and other less optimal part selections have still passed through the screening occasionally and result quality issues in products. In addition, product could have lower BOM cost and forecasting part's global consumption get easier by choosing the right part. Parts selected from the library also reduce the workload of the purchasing department when parts are selected from reliable vendors that guarantee availability in the future as well.

In the case company, product information management is built strongly around the ERP application, which is why the capabilities offered by other systems have been overlooked. The reuse rate of the parts is low, and the information systems do not support modern part search methods, the parts can be found mainly by using the ERP application transactions or by browsing separate design databases. For designers, finding standard parts is cumbersome and time consuming. Efficient standardization and increasing the number of library parts in products make operations more cost-effective, shorten product development times and reduce errors. It is not appropriate for every product development project to create their own grommets or fan grills. The case company has a strong need to use more existing parts in order to reduce the workload of designers. In this way, resources can be invested in the most important product development tasks.

The most important part of the thesis was the development of the part library concept. The operating principle of the current system was presented in more detail in order to get an idea of the starting points for the development work. This was followed by a discussion of the new operating environment brought about by the case company's new PLM project and what benefits can be achieved by improving the current situation. Based on the requirements and wishes gathered from designers and experts, a new concept was built for the part library. Based on the product information model presented at the beginning of the work, a new classification method was created for standard parts and Product Elements to meet the needs in order to meet the requirements.

The development started in the thesis was taken to the point where we the real benefits of the PLM system in terms of part library became obvious. Currently, the biggest benefits are seen in more efficient part search capacities due to improved classification as well as description of roles. Within the schedule of the PLM project, not all development points could be completed, but the development projects that were not completed after the thesis will be further developed as the PLM project continues. The changes in the schedule were also influenced by factors outside the company.

The library can be deployed in conjunction with the new PLM project, when parts are extended to a new database and the product information management process is transferred to the PLM system. According to the current project plan, in the first phase, global standard parts will be transferred to the library and the library will be expanded to cover other parts later. The product element library structure is modified according to the definitions of the product architecture of each division. The future of the library is significantly determined by how its maintenance is organized and how responsibilities are shared within the organization. At the time of completing the thesis, no one has been appointed for maintenance, but before the library is even created, the common rules and responsibilities must be clear, as it forms the core of the entire library. The new PLM project will later face the introduction of a library, training its use for designers, and engaging designers in new ways of working.

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