Design and implementation of a PLM system for Chalmers Formula Student

An investigation of the current structure and management of documentation

Master's thesis in Master Programme Product Development

RIKARD KARLSSON
ABHISHEK VENKATESH

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
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www.chalmers.se

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Supervisor: Björn Pålsson, Division of Dynamics
Examiner: Dag Henrik Bergsjö, Division of Product development & Department of Industrial and Materials Science

Master's Thesis 2021
Department of Industrial and Material Science
Division of Product Development
Systems Engineering Design
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Computer rendered visualization of the Chalmers Formula Student 2021 car. Courtesy of Chalmers Formula Student member Anthony Kalcic.

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Chalmers University of Technology

Abstract

Complex products typically consist of many different parts which need to interact and function together. In the modern world, the development and verification of parts, sub-assemblies and entire products are done to a large extent with the help of computers. This in turn generates a lot of digital documentation and information which needs to be stored and controlled throughout the life cycle of a product. In order to keep track of the information, a Product Lifecycle Management, or PLM, system can be used.

The study which has been carried out has investigated the current digital documentation structure of Chalmers Formula Student, CFS, with the aim of identifying possible areas of improvement and whether the implementation of a specific PLM system could be beneficial for their continued development efforts. Information about PLM and the aspects related to it has been gathered through a literature review and served as a basis for the study. Information about the current documentation structure was gathered through interviews with current and previous members of the CFS team. In an effort to extend the number of viewpoints of PLM, an additional round of interviews were held with professors and engineers with various experience with PLM system.

Based on the theoretical framework and the held interviews, it became apparent that there were potential improvements to be made mainly regarding the aspects of knowledge transfer and finding needed documentation concerning changes made during the development efforts. The main underlying reasoning was mentioned as lack of time to document properly, last minute changes made without proper updating and a difficulty of navigating the folder structure. The investigation and evaluation of the benefits of a PLM system resulted in the suggestion of a gradual implementation, starting with the PLM system being used to manage Computer Aided Design, CAD, files.

Keywords: Product Lifecycle Management, Computer Aided Design, Knowledge transfer, Product Development

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ABHISHEK VENKATESH
Instutitionen för Industri- och materialvetenskap
Chalmers Tekniska Högskola

Abstract

Komplexa produkter består allt som oftast av många olika delar som behöver interagera och fungera tillsammans. I dagens samhälle sker utvecklingen och verifiering av delar, delkonstruktioner och hela produkter i hög utstäckning med hjälp av datorer. Det i sin tur genererar en stor mängd digital dokumentation och information som behöver lagras och kontrolleras under en produkts livscykel. För att kunna hålla ordning på all information kan ett Product Lifecycle Management, PLM, system användas.

Denna studie har undersökt den nuvarande digitala dokumentstrukturen hos Chalmers Formula Student, CFS, med målet att identifiera möjliga förbättringsområden och huruvida en implementering av ett specifikt PLM system skulle kunna vara fördelaktigt för deras fortsatta utvecklingsarbete. Information om PLM och dess aspekter har samlats från läst litteratur som i sin tur har format grunden för studien. Information gällande den nuvarande dokumentstrukturen har samlats in genom intervjuer med nuvarande och tidigare medlemmar av CFS. I ett försök att utöka antalet infallsvinklar om PLM, utfördes ytterligare en omgång med intervjuer med professorer och civilingenjörer med olika erfarenhet av PLM-system.

Baserat på det teoretiska ramverket och de utförda intervjuerna, framkom det att det fanns förbättringspotential gällande framför allt kunskapsöverföring och möjligheten att hitta dokumentation gällande ändringar som utförts under utvecklingsarbetet. De huvudsakliga anledningarna visade sig vara tidsbrist, sista-minuten ändringar som inte dokumenteras korrekt och svårigheten att navigera dokumentationsstrukturen. Studien och utvärderingen om förbättringsmöjligheterna hos ett PLM-system resulterade i ett förslag om gradvis implementering, med sin början i att PLM systemet ska hantera filer för datorstödd konstruktion.

Keywords: Produkt livscykel, Datorstödd konstruktion, Kunskapsöverföring, Produktutveckling

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We would also like to extend our appreciation to everyone who agreed to participate by being interviewed in the study. The members of Chalmers Formula Student for sharing their opinions and thoughts regarding the current situation. It was truly heartwarming to see how open and interesting the professors and engineers were and for sharing their experiences and knowledge about Product Lifecycle Management.

Rikard Karlsson & Abhishek Venkatesh
Gothenburg, June 2021

0.1 Abbreviations

Bill of Materials - BOM
Chalmers Formula Student - CFS
Computer Aided Design - CAD
Key Point Indicator - KPI
Printed Citcuit Board - PCB
Research question - RQ

Contents

1
Introduction

In a work environment where the amount of digital product data keeps increasing, there will be a subsequent need for managing the information. In order to mitigate this issue, a Product Lifecycle Management, PLM, system can be implemented. In this study, the current situation of Chalmers Formula Student has been examined with respect to PLM related activities. This includes aspects such as generation of information, how information is stored and structured as well as possible areas of improvement. The background of the thesis has relied on a literature study, interviews with members of the current and prior CFS team as well as professors and engineers who had experience regarding PLM systems. The gathered knowledge throughout the work was then compiled into a list of requirements and wishes which were the base for an evaluation of a PLM software solution. An initial PLM structure for the future use of CFS was then created.

1.1 Background

Product Lifecycle Management is an unified approach involving a set of methods and IT tools which aids in managing product documentation i.e., engineering processes, product information and applications during a products entire lifespan, from the initial idea until the point that it will no longer be manufactured or supported (Abramovici, 2007). The management of products is required for all companies regardless of the company size, whether it is a new start-up or a large world-wide business (Stark, 2020). This is an ever increasing necessity due to shorter product life cycles combined with the need of delivering new products to the market faster than before along with increase in product quality (Terzi, Bouras, Dutta, Garetti, & Kiritsis, 2010). In order to handle the situation on a globally competitive market, PLM is close to a must. PLM can provide the possibility of creating better products at a faster rate and at the same time reducing the work effort and achieving a higher profit (Saaksvuori & Immonen, 2008). *Figure1.1* shows a dynamic representation of the different elements of a PLM system.

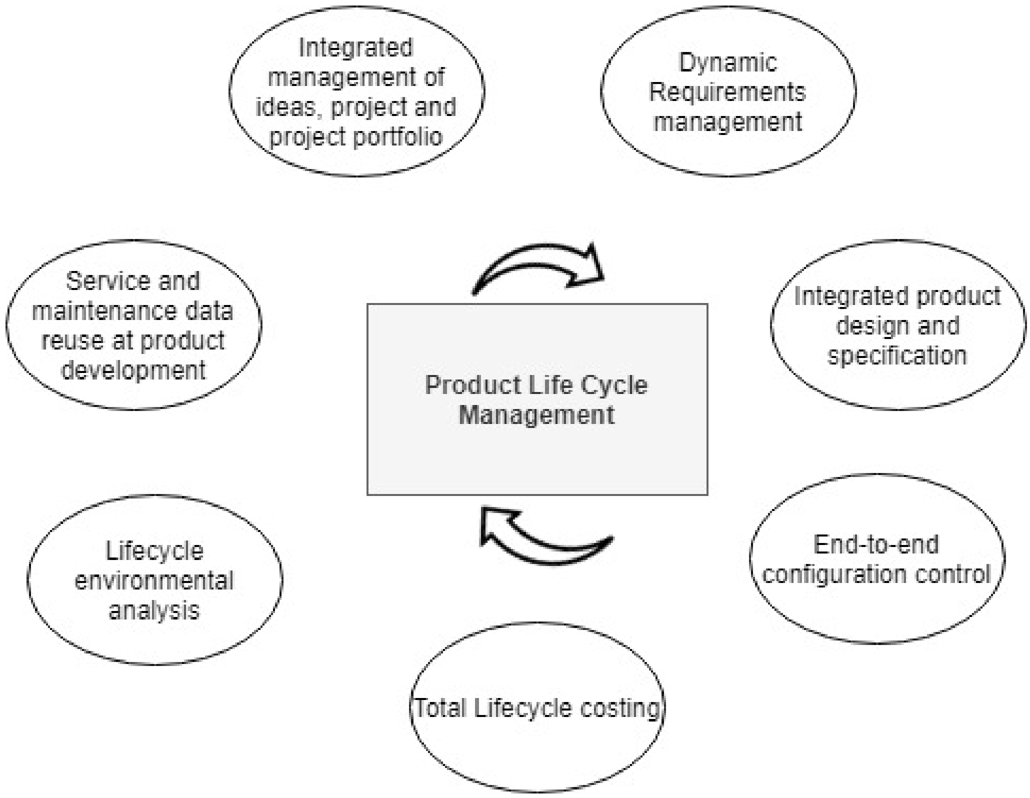

Figure 1.1: Elements of PLM (Schuh, Rozenfeld, Assmus, & Zancul, 2008)

Before the transition to digital PLM, companies were typically more divided between departments (Stark, 2020). Each department had a singular focus, e.g. the Marketing Department kept track of the market, the Engineering department designed the product and the Manufacturing Department produced them, and so on. The idea behind it being that each department consisted of experts in their own fields that knew how to best perform their work (Stark, 2020). However, this led to each department having their own separate way of working and handling its output of documentation and data. This reduced the interdepartmental communication with the result of information being sent down the line without sufficient follow-up. This led to wastes, different versions of documents, repeated work and even recalled products which in turn increased lead-times and cost as well as subsequently reduced revenues (Stark, 2020).

Management of product data is a challenging task for every project (Fasoli et al., 2011). In order to handle the product development processes, a good collaborative engineering and management of product structures, documents and quality is required. Initially, PDM systems were file-based systems (Huhtala, Lohtander, & Varis, 2013). All the documents would be saved in a particular folder and the designer had to know which drawing(s) belonged with each other. This method was burdensome and the arrangement depended on the users. If a user accidentally saved the file in the wrong folder, finding it again was time consuming. This led to an item-based system where everything relies on a certain part being identified. The designer would obtain the information about all the necessary data sheets simultaneously. With the aid of name and the item number, all the items would be easy to find (Könst, la Fontaine, & Hoogeboom, 2009).

The companies in today's day and age, face the unprecedented challenge of assessing their performance. They strive to get good results by constant benchmarking and self-evaluation. Two indicators which assess the performance are effectiveness and efficiency (Walters, 2006). Effectiveness is concerned with output, quality, creation of value added and cost-reduction. Efficiency on the other hand measures relationship between inputs and outputs or how successfully the inputs have been transformed into outputs. The *Figure 1.2* below shows the distinct meaning between the two. Excellent organizational efficiency could improve the performance related to management, productivity, quality and profitability. Efficiency is mainly about resource allocation (Bartuševičienė & Šakalytė, 2013). Effectiveness and efficiency usually go hand in hand. The companies would result in a failure if the resources are not managed effectively. A high efficiency and high effectiveness is a good indicator of a high performance company. In order to attain competitive advantage, companies should strive to increase both effectiveness and efficiency indicators evenly.

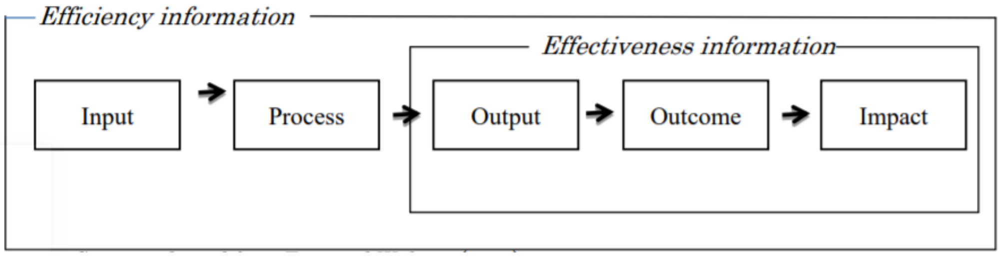

Figure 1.2: Effectiveness and Efficiency (Frey & Widmer, 2009)

1.2 About Chalmers Formula Student

Chalmers Formula Student, CFS, is a team which consists of around 30 students from different disciplines studying at Chalmers University of Technology. The team is formed and works together for one academic year, with most of the members being exchanged between each year. The team itself is divided into separate sub-groups, each with focus towards a specific part, functionality or management tasks related to the project. The intention of the team is to improve the students engineering knowledge through the hands on experience provided during the development of a formula style race car (*Formula Student*, n.d.).

The team is responsible for the design, manufacturing, tests and cost of the vehicle. Since the team members participates throughout the different phases, it allows for evaluating the digitally designed parts and functionalities against the later manufactured output (Pålsson, n.d.). This type of project structure allows the students to get a holistic understanding of the aspects related to working in a larger engineering team, for example time and resource constraints. Once the car has been finished, it is eligible to compete in Formula Student competitions, which take place in different venues around the world, against other universities' entries. The Formula Student competition has taken place since 1998, with a Chalmers team participating since 2002 (Pålsson, n.d.). The competition itself is divided into both static and dynamic events with subcategories, such as *Engineering design* and *Fuel economy*, which are judged and scored.

1.3 Current Problem

The current documents related to the project are stored on different servers and accessed through different software. This may result in available information being difficult to locate, resulting in both delay and rework. Even though the current structure works, it requires additional manual work and is thought to be lacking in transparency. The transparency issue results in a difficulty to overview the available documentation which in turn is believed to cause an unnecessarily high threshold for the new team members each year. The annual exchange of members puts a strain on the knowledge transfer of the accumulated information from previous years, further increasing the need for a unified and intuitive document structure.

1.4 Project Scope

The purpose of the thesis project was to gather information about the existing data management system and identify improvement potential. Based on the knowledge gained throughout the project an evaluation of a PLM system was conducted in order to assess if an implementation could be beneficial for the needs of CFS. The information regarding the current situation was collected through a number of interviews with current and previous members of CFS. Additional information regarding PLM systems and functionality was gathered through a literature study as well as through interviews with professors and engineers with different backgrounds regarding PLM systems. The thesis work took place between January to June of 2021.

1.5 Project Aim

The aim of the study was to gather information related to PLM through a literature study together with interviews. The gained knowledge will be used in an effort to reduce time-waste during CFS's development through the implementation and structure in a suggested PLM software. The goal was to increase the knowledge of a real-life situation and as a result of improved efficiency and effectiveness, subsequently resulting in higher performance levels for CFS in the Formula Student competitions.

1.6 Research questions

The study's research questions are listed below:

- RQ1: How does CFS currently manage their product related documentation?
- RQ2: How can CFS's PLM needs be satisfied through the software which are looked into in the project?
- RQ3: Based on knowledge gained throughout the research, how could a PLM system be structured for the current needs of CFS?

1.7 Delimitations

A common way of measuring changes in working performances, is through the usage of Key Point Indicators (Stark, 2020). However, since the report will only cover the current situation and propose a future way of working, a follow-up with respect to KPI will not be possible.

Due to the COVID-19 pandemic, the number of physical contacts needed to be kept to a minimum. This reduced the possibilities of investigating the current usage of PLM for CFS through observation studies and increased the need for digital interviews with members.

All of the work related to the report has been conducted while being socially distanced. This has led to an increased need of using different communication methods, which has mainly consisted of digital meetings through Zoom or written communication through Slack. The lack of meeting in person could have had an effect on the communication efficiency throughout the thesis.

The thesis work has only focused on the capabilities and functionality of Dassault Systèmes 3DEXPERIENCE, hence referred to as 3DX, and whether an implementation could provide beneficial aspects to CFS.

1.8 Report outline

The report consists of eight chapters, starting with the current Introduction chapter. The report continues to describe the Methodology used as well as the Theoretical framework the study has relied on. This leads to the Analysis which in turn leads to a Requirement Specification. This Requirement Specification is then used as a base for evaluating 3DX. The outcome of the report is mentioned in Discussion and ends with the Conclusion. Apart from this, there are also appendices which can be read for additional information about certain aspects of the report.

2
Methodology

This chapter describes the process of how the study was carried out. The aim is to increase the reader's understanding regarding choices made during the progress from the initial literature study to the final PLM structure proposal. This allows the reader to follow the process and would be helpful in case a similar or repeated study were to be conducted.

2.1 Literature review

The theoretical framework consisted of a foundation provided by the two books Product Lifecycle Management (Saaksvuori & Immonen, 2008) and Product Lifecycle Management (Stark, 2020). The books have previously been used as course literature in Product Lifecycle Management, PPU111, at Chalmers University of Technology. The literature served as an introduction to PLM and its different aspects, upon which the subsequent work could be planned, structured and discussed. Along with this, several articles relating to the project have been studied. Most of the articles were found through Google Scholar, others were provided by interviewees during their interviews.

Information related to CFS has been supplied both through recurring meetings with Björn Pålsson, Senior Lecturer at Chalmers University of Technology, examiner for CFS and co-supervisor during the thesis, as well as through interviews with current and recent team members of CFS.

2.2 Interviews

This section describes how the interviews were structured and the reasoning behind it. The interviews conducted during the project were semi-structured. Qualitative data collection method was chosen for the project as it would help in enriching the understanding of the current problem. The main idea was to understand the different aspects of the problem by gathering in-depth information from the interviewees (Queirós, Faria, & Almeida, 2017). The data was collected systematically through digital interviews. The audio of the meetings were recorded and later transcribed. For the analysis of the interviews, 'The Jiro Kawakita', often abbreviated as KJ method, was used (P.Wallgren, 15-11-2019). The response of the interviewees were classified into different themes for further investigation. The interviews also helped in estimating what could be achieved considering the trade-offs between resources, quality and time. The other qualitative data collection methods was not considered due to the limited personnel availability.

2.2.1 CFS members

In order to gather important information regarding current practices, interviews were conducted with members of the current CFS21 team as well as members from the previous year, CFS20. The interview questions were formulated with the aim of gathering information about different aspects of the documentation handling. This was in order to gather information about the current features, what they liked about it as well as if there were any problems related to it which they had experienced. The questions which were asked can be seen in *Appendix A*.

The interviewees were contacted through the use of the Slack software, which is used by CFS as the main text based communication. As mentioned, the request was made towards all members of the CFS20 and CFS21 teams. As mentioned earlier the interviews were then conducted digitally. In total nine members were interviewed.

The interviews with the CFS members varied in elapsed time, from around twenty minutes up towards an hour. The interviewees were helpful and all of them allowed the interview to be recorded, which made it easier to compare answers and to highlight certain aspects and quotes.

2.2.2 Interview preparation

The questions for both sets of interviews were formulated through brainstorming sessions and discussed with the examiner and supervisor for additional input. The questions were then structured into four major categories, shown below:

- Introductory questions, with the aim of establishing base information regarding the interviewees background, such as subgroup belonging and current and previous university education.
- Information retrieval, with the aim of gathering knowledge about how the current process of acquiring needed information is for the members.
- PLM related, with the aim of understanding current benefits as well as problems that occur during every day usage.
- Processes, with the aim of gathering information about how CAD and PCB models and subsequent drawings are created currently.

As mentioned previously, the interview questions for the CFS team members can be seen in their entirety in *Appendix A*.

2.2.3 Industry Interviews

The interviews were conducted with professors and engineers who had used different PLM software and with various experiences of the PLM environment. The idea behind these interviews was to get a better understanding of the PLM structure managed in real-world situations and adapt similar ideologies during the project. The first contacts were suggested by the supervisors, which in turn suggested additional interviewees. The interviewees were shortlisted based on the relevance to our project. This way of identifying individuals to interview can be seen as a *Snowball sampling* with a combination of linear and a exponential non-discriminative approach, i.e. each interviewee suggests one or multiple other people to interview (Dudovskiy, n.d.).

2.2.4 Interview preparation

The questions were generated in the same fashion as for the CFS members. The focus of these interviews were towards gathering information about the interviewee and their respective experiences of PLM.

- Introductory questions, with the aim of establishing base information regarding the interviewees background, such as work title and previous PLM experience.
- PLM knowledge, with the aim of gathering information about their current and previous usage of PLM, lessons learned and what they believed to be important aspects.
- Communication, with the aim of understanding how internal and global communications were carried out in the setting of each interviewee.
- Processes, with the aim of gathering information about how CAD and PCB models and subsequent drawings are created currently.

The interview questions which were asked to professors and engineers can be seen in *Appendix B*.

2.2.5 Software usage

During the thesis work, a number of software was used. For communication purposes, Zoom and Slack has mainly been used. Zoom has been utilized for daily meetings as well as for the majority of the interviews which took place. Slack has been used for written communication during the work, usually messages such as shorter updates or questions.

The internal documentation related to the thesis has been stored and managed in Google Drive. The report itself has been written in Overleaf.

For the purpose of evaluating the web version of the 3DX software, Google Chrome has been used. For evaluation of the performance of 3DX with CATIA V5, an installation of CATIA V5-6R2019 has been used.

3

Theoretical framework

This chapter consists of theory from the previously mentioned literature. The need or want for implementing a PLM system in the first place, rests upon the intended return on investment in terms of improved performance (Stark, 2020). A PLM system itself serves as a tool which could increase the structure of processes, reducing the risk of confusion and improving the development efforts (Saaksvuori & Immonen, 2008).

3.1 PLM maturity level

As described in (Saaksvuori & Immonen, 2008), a PLM maturity model can be used to roughly describe how a company can increase and extend the use of a PLM system (Saaksvuori & Immonen, 2008). They state that in order to successfully improve PLM related activities, the current situation needs to be documented and understood. The PLM maturity model is usable as a tool for the evaluation and analysis of the current situation. The model from the literature is displayed below, showcasing the five different levels according to the literature.

Table 3.1: Table over the five levels of PLM maturity according to (Saaksvuori & Immonen, 2008)

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

The concept of PLM maturity will be used to analyze and discuss the current state of CFS.

3.2 Problems and risks

There are many potential pitfalls related to PLM projects and its implementation. The ones listed below are examples which originate from the studied literature.

- According to (Stark, 2020), studies showed that up to 80% of a design engineer's work time was spent on tasks related to administration and retrieving information. This could for example be the case if an engineer sought information that was deemed as belonging to another department. This could result in the engineer spending time waiting to receive the specific information, possibly halting the development process (Stark, 2020).
- There are typically regulatory demands on a product (Stark, 2020), which is also the case for the car built by CFS (*Formula Student*, n.d.). The fulfillment of these demands are usually presented as documents, which needs to be managed to ensure proper safety as well as complying with competition rules.
- Issues can also occur with respect to Change Management. For example, needed changes could take a long time to update due to long lead-times or be missed completely, causing problems in the future (Stark, 2020). There has been a tendency for people to avoid long waiting times, thus doing minor modification to parts and drawings without going through the structure channels. This causes issues if backtracking is needed since no documentation exists which explains or mentions the changes. In the long run this can cause the product itself to not correspond with the actual documentation, with possible rework efforts needed both in-house and in-field (Stark, 2020).
- The structure, organisation, storage and accessibility of product data can result in a large difference (Stark, 2020). Documents can be easy or more difficult to acquire and find in a given situation. This situation can be converted into the amount of time spent searching or time spent doing tasks which could be automated.
- Another issue which might occur relates to consistency in practices between departments or individuals (Saaksvuori & Immonen, 2008). Potential discrepancies could cause problems, for example if the latest version of a document needs to be stored in multiple locations, it will be difficult to know if a specific version actually is the most recent.
- During the explorative phase of a PLM project, during which software is tested, it is common to mainly focus on the functionality of the software (Saaksvuori & Immonen, 2008). However, there is a risk that this focus might cause insufficient attention to ease of use and maintenance of the system.
- A generic problem with software and IT projects such as a PLM implementation, is the complexity, number of settings and parameters which need to be set up accordingly in order to avoid future problems (Saaksvuori & Immonen, 2008).
- According to (Saaksvuori & Immonen, 2008), there is a risk of product data deterioration if the information retrieval process is slow. This might lead to individuals searching for shortcuts, not following certain instructions or even managing information in a personal way. This behavior might cause a vicious circle where management of data is handled individually, leading to further

deterioration of the structure, making it increasingly difficult to find sought information (Saaksvuori & Immonen, 2008).

3.3 Implementation steps

In order to successfully implement a PLM system, there should first and foremost exist a need as well as an understanding of why the implementation takes place (Saaksvuori & Immonen, 2008). Changes such as this need to be well anchored within the management of the business for continued support of the implementation process. As stated in (Stark, 2020), it is important to know and understand the business processes, for example in order to identify which documentation should be transferred from the previous system into the new one. Since the PLM environment may be difficult to understand, models could be used to lower this threshold (Stark, 2020). This can for example be used for the current and for the future situation. The need for understanding the current processes stems from the difficulty of improving processes which are unknown. Through the examination of a certain process, there is a possibility of identifying work that could be automated, making it easier and faster to perform a specific task (Stark, 2020).

According to (Stark, 2020), there are no standard business processes, meaning that each company or business has to develop their own process to match their scope. This includes the naming of the various processes and the tasks which should be done during each of them.

After the evaluation of the current setting through the PLM Maturity level, the next step consists of choosing a suitable PLM system (Saaksvuori & Immonen, 2008). Usually there would be an abundance of system suppliers, however the amount of objective information regarding each of them is typically more difficult to come by. The procedure typically continues along a specific path with the intent of selecting a system, as shown below in figure *Figure 3.1*.

Figure 3.1: The phases of choosing a PLM system. Figure is based on information from (Saaksvuori & Immonen, 2008)

The continued realisation and implementation of the project is usually done in-house, together with consultancy agencies or with the software supplier directly (Saaksvuori & Immonen, 2008). This part of the project can also be divided into five major parts, as shown below in *Figure 3.2*.
During the implementation of the new system, there will be a need to decide which documentation is going to be transferred from the previous system to the new one (Saaksvuori & Immonen, 2008). Two diametrically different approaches would be to either transfer all of the previous documentation or none of it, starting with a clean slate. However, the typical case would be a compromise between the two extremes.

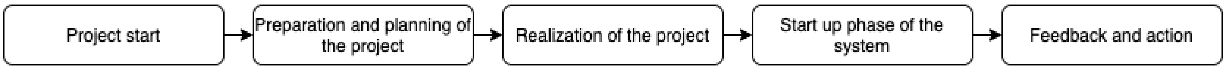

Figure 3.2: The phases of implementing a PLM system. Figure is based on information from (Saaksvuori & Immonen, 2008)

There are no generic guidelines as to which documents should be transferred, but since the transfer will cause extra work there are points to consider (Saaksvuori & Immonen, 2008). They are related to the life cycle status of the documents, i.e. if the document is still used and needed and its importance for the continued work.

3.4 Traceability

There is an inherent need to be able to find information about changes and why they were made. This need results in a requirement of being able to add this type of meta information to different types of documents, such as CAD files, drawings and requirement specification. The traceability aspect can also include the possibility of identifying a faulty part or construction and being able to know exactly which products might suffer the same issue, with possible recalls as a response (Stark, 2020). One way of being able to trace and find certain objects could be to classify them. The classification system could be used to sort and find objects easier (Stark, 2020).

3.5 Naming conventions

According to (Stark, 2020), the need of using a specific identification sequence for documents stems from the vast number of documents related to a product. The identifier itself should be unambiguous in order to make it easier to understand what it refers to. In order to assign a specific sequence to an object, there are numerous approaches (Stark, 2020). In the list below, a number of ways which have been deemed as relevant to the case are described.

- Serial numbers - Refers to an unique identification sequence that oftentimes refers to a product without the intent of describing or giving any additional information about the product (Stark, 2020).
- Significant numbers - As with the serial numbers it should be unique, however it should also disclose information about the document itself. The sequence could include numbers or letters which refer to the type, size or in which country the part or product will be sold. A potential drawback with this kind of sequence is the risk of confusion. For example if a part of a sequence refers to a size of a component, that number could be interpreted differently depending on if the reader believes it to refer to SI units or imperial units (Stark, 2020). There is also a possibility of eventual overflow of the naming system, simply running out of numbers or figures for the given sequence.
- Language - As mentioned above, confusion may arise if the sequence is built to provide additional information. This could also lead to language based

confusion due to a certain sequence that could be self-explanatory in one language could at the same time be gibberish or refer to something else in another language (Stark, 2020).

3.6 Folder structure

Folder structure is an essential component of data handling regardless of the size of the project. An efficient folder structure would contain a logical hierarchy of the files with suitable location. A systematic approach of storing the data increases the quality of product definition and thereby reduces the developmental times (Zimmerman, 2008). A good folder structure helps not only in efficient information retrieval but it also helps in the knowledge management. In this particular project, this is crucial as teams would only be constituted for one academic year.

Figure 3.3 below describes the expected input and output of engineering processes. The combination of processes and information flows is a key part in the Engineering Information Management system.

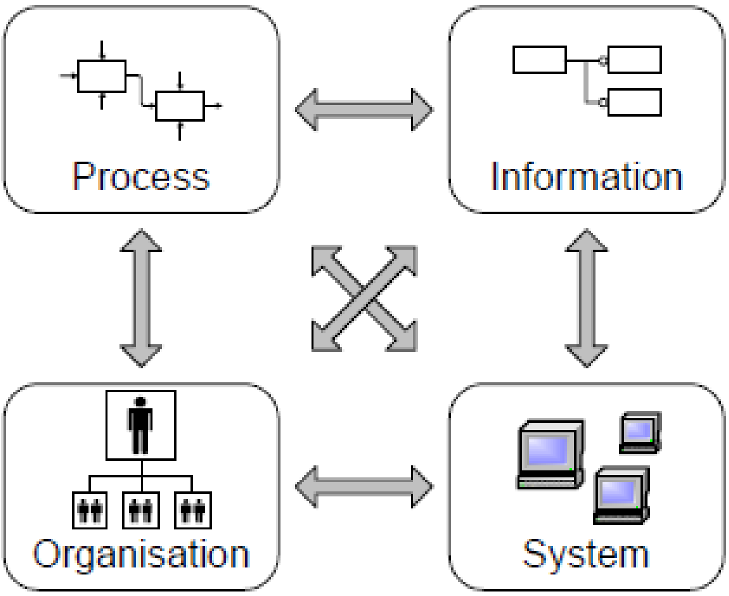

Figure 3.3: Information Management (Svensson, Crnkovic, et al., 2002)

A good findability of the files has always been an important facet of having an excellent digital employee experience. A good folder structure should have the right balance between granularity and findability (Giddaluru & Gao, 2019). One would find it cumbersome to have hundreds of folders in a single document and also having hundreds of documents with a single folder in them. It has to be spaced out evenly by having a good depth. It should also be consistent and sustainable. It should have the ability to evolve and grow without having the hassle of reorganization.

4
Analysis

This chapter aims to highlight the various aspects which have been identified through the interview phase of the project. This refers to both the interviews with CFS members about their current situation as well as the interviews with engineers and professors regarding PLM.

4.1 Current Product Lifecycle Management of Chalmers Formula Student

According to Product Lifecycle Management (Saaksvuori & Immonen, 2008), it is of great importance to study the current structure and process of the documentations. The next section describes the current documentation storage and management of CFS. Information about the current situation has been gathered through interviews with current members of CFS21 as well as members from recent years together with discussions with supervisor Björn Pålsson.

4.2 Interviews

The interviews with members from CFS were carried out between 1st of March and 12th of March 2021. The interviews were conducted in total with nine members of the current and previous years team from various roles. The interviews with professors and engineers took place between 31st of March until 16th of April, during which six individuals were interviewed. As mentioned previously, the interview questions can be seen in their entirety in *Appendix A* and *Appendix B*.

4.2.1 Identified problems and risks

In this section problems and risks which have been identified through the interviews and discussion with members of CFS, professors and engineers have been listed. They have been interpreted and traced to a number of root causes, which are displayed below.

- The search for information can be troublesome. Certain pieces of information have been described as being difficult to find or even missing. This has caused an increased need to ask other members regarding the whereabouts of information. This problem spans between the years, i.e. current members might need

to contact previous members in order to understand certain changes or the reasoning behind it. Information about who has worked on a certain document can in turn be difficult since that information is not always available.
- The commonly used software for written communication, Slack, has a limited number of saved messages as per the currently used licence. This results in older messages being deleted, messages that might have been able to answer questions which might reoccur during the work as well as between the years.
- Due to experienced errors or changes being made, either intentionally or unintentionally by other parties, CAD files have been reported to crash and not function properly. This has in turn led to cases of local storage of certain files in an effort to ensure an individual's full control of specific documents.
- Missing information regarding updates and changes during the development process has been described as an issue. The end result being that the final product does not correspond with the intended design documents. This has been reported to cause problems since changes have been implemented but without traceability, causing similar issues to occur repeatedly between the years due to recurring last minute 'quick-fixes'.

The formerly mentioned problems and risks were converted into stakeholder requirements which are displayed further in *Chapter 5*.

4.2.2 Traceability

The traceability of data was discussed during the interviews with CFS members as well as with Björn Pålsson. During the discussion the interviewees were asked both about how they acquire needed information from subgroups which they themselves were not a part of, how accessible the information retrieval process was perceived, as well as an estimation about time spent on searching for information on a weekly basis.

Based on the interviews, a process flow diagram was compiled in order to show the typical information search process of CFS members, see *Figure 4.1* below.

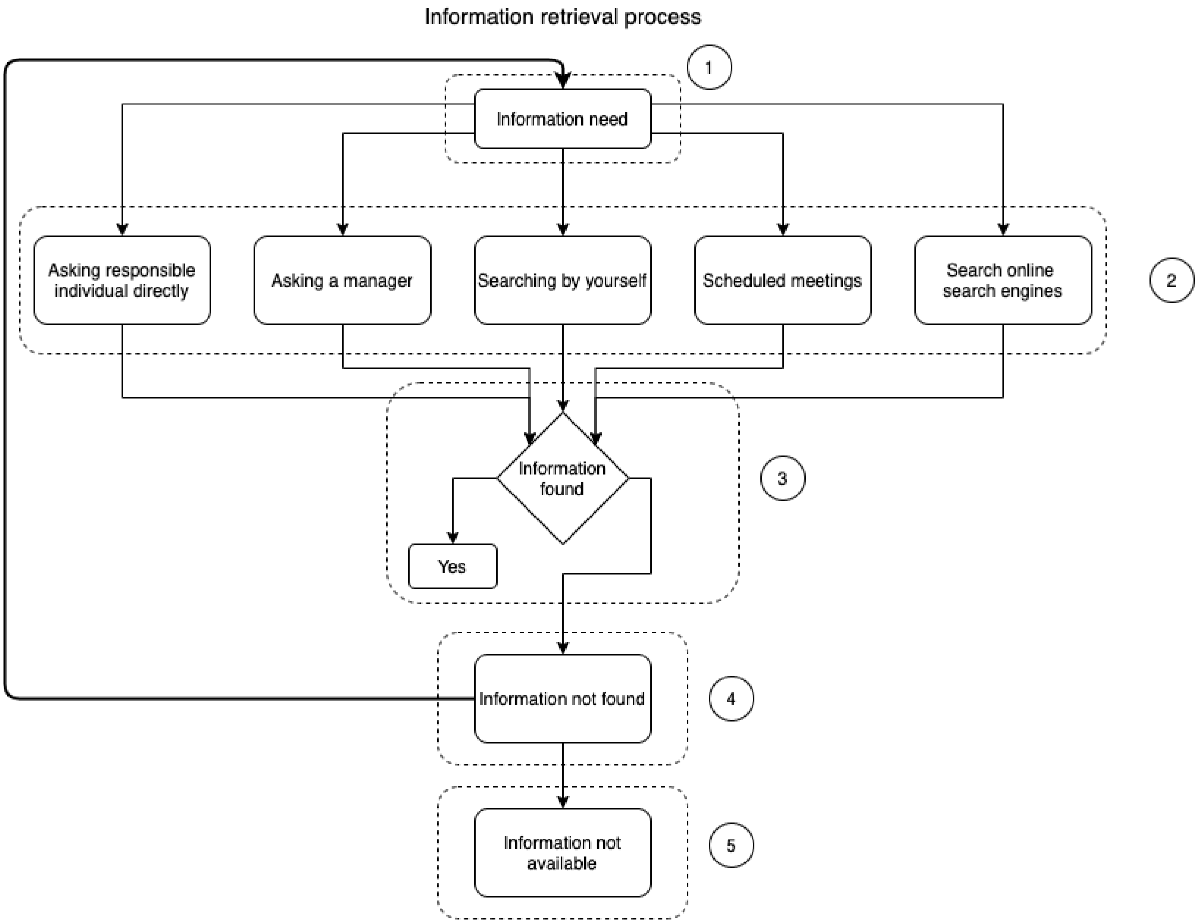

Figure 4.1: Current information retrieval process of CFS members.

The process began with the need for a specific piece of information, seen as step 1 in the flowchart. The next step was typically one of the following ways of gathering information, shown as step 2. The result of step 2 is either that the information was found or that it was not found. If it was not found, the member would typically go back to step 1, as shown with thicker lines in the flowchart. If the information has still not been found after iterations of this process, the information is deemed as not available.

When a member needed to know the whereabouts of certain pieces of information, Slack was commonly used. During the interviews, it became apparent that the time spent searching for documents varied between the members as well as during which phase the development process was at. The search time was commonly estimated to be at least two hours per week, some stating that the search could consume up to one or two days a week.

4.2.3 Model over CFS

In order to increase the understanding of how CFS is currently structured and how the work proceeds, a number of flowcharts has been constructed based on the interviews and discussions during the thesis work.

In the figure below, *Figure 4.2*, a simplified structure of CFS is shown. It presents the different stakeholders which are a part of the on-going work effort. The organisation is not stationary and is reorganised during the different phases of the development.

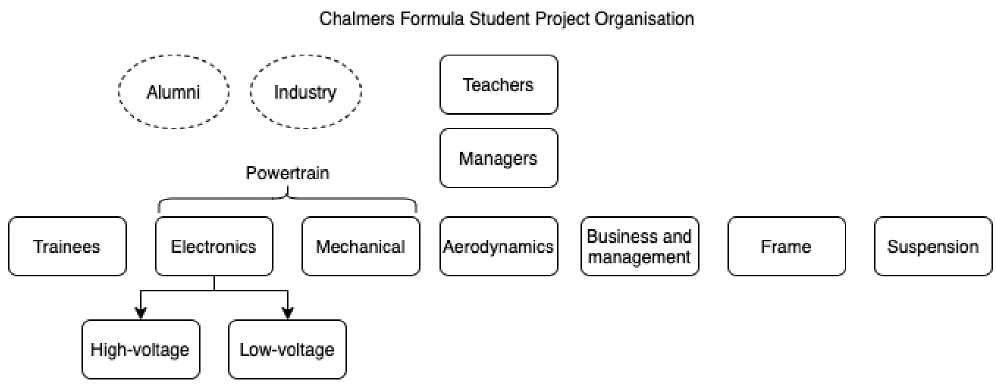

Figure 4.2: A simplified organizational structure of CFS. Based on information supplied from (Pålsson, n.d.)

4.2.4 Naming conventions

This section contains the current naming convention used by CFS with respect to CAD files. The naming convention follows a certain pattern. The name starts with the CFS team year, for example 19. The naming convention used for the CAD parts and assemblies can be seen below, in *Figure 4.3* and *Figure 4.4*.

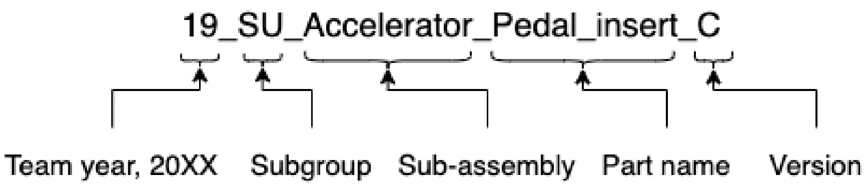

Figure 4.3: Current naming convention of CAD parts in CFS.

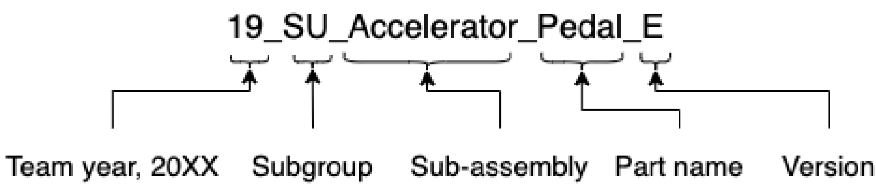

Figure 4.4: Current naming convention of CAD assemblies in CFS.

4.2.5 Folder structure

The current documentation is mainly stored in four different locations, Google Drive, Chalmers Formula Student drive, Teamcenter and GitHub. This is shown below in *Figure 4.5*.

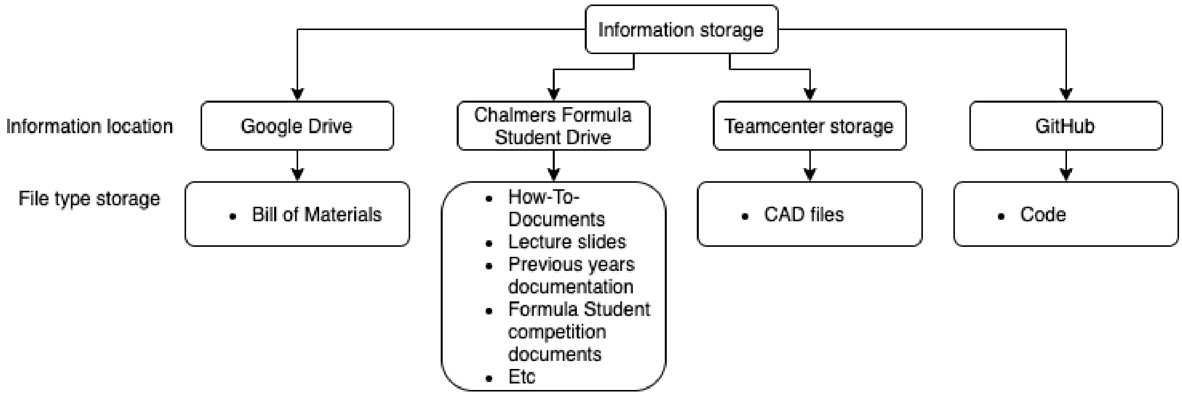

Figure 4.5: Current information storage setup.

As can be seen in the *Figure 4.5*, the drive of CFS contains the largest amount of documentation, with the others being used for a more specific type of file storage. During the CFS interviews, it was mentioned that the CFS drive could be difficult to navigate and locate files quickly. The folder structure was also stated as an important part of a PLM system by the interviewed professors and engineers. According to one of the interviewees, there should be someone that takes the lead in creating the required folder structure.

As described earlier, the interviewees from CFS mentioned that the CFS drive could be difficult to navigate. This digital storage was also the one with the most files, for example containing collaborative documentation, teaching material and personal folders. It was identified that a systematic, hierarchical system would be necessary.

4.2.6 PLM maturity level

Through the gathered knowledge concerning CFS's current PLM maturity level, the level that CFS is currently at has been identified as level 3, the *Defined* level. As shown previously in *Table 3.1*, the basic functionalities are structured and documented. However, there is still an inherent reliance on human factors and a possibility of increasing the PLM structure.

4.2.7 Professors and engineers

Based on their experience, an aspect which was mentioned multiple times was the usability and logic of the PLM software. This referred to the level of difficulty in order for a new user to familiarise themselves with the software initially as well as during the continued usage. As one interviewee described it;

> 'I think it [ease of use] is more important the first time you use it than the hundredth, because you can get used to all systems'.

Similarly, it was also mentioned that a self-explanatory and intuitive PLM software would be preferable. This could for example be through a graphical design of the user interface which would be as easy to understand. It was also discussed that problems could occur if routines for saving documents are not followed. This possible issue had also been identified in the literature, see *Chapter* 3.2.

5

Requirement specification

The output of the theoretical framework, the interviews and discussions carried out during the project, was condensed into a list of stakeholder requirements displayed below, see *Figure 5.1*. It consists of both requirements and wishes.

As mentioned previously, the interview answers were transcribed. The answers to each question were then compiled and listed. These answers were interpreted and possible ways of solving the listed issues were discussed. The issues and possible solutions were then formulated as requirements and wishes to be used for the evaluation of the software. The ones which have been prioritised as demands have their background in functionality which needs to function in order for the software to be deemed acceptable. The wishes are functionality that could prove to be beneficial for the development efforts, but based on interviews and discussion has been deemed as good to have, but not essential. A longer justification and rationale behind each of the requirements and wishes can be seen in *Appendix C* and *Appendix D*.

No	Stakeholder requirement	Stakeholder code	Priority
1	Standardised data organization aiding backtracking of information.	CFS-01	Demand
2	Software needs to work as a Knowledge Management System.	CFS-02	Demand
3	The software should provide the possibility of communication between team members.	CFS-03	Demand
4	Assignment of different roles to team members.	CFS-04	Wish
5	Approval of changes during the project.	CFS-05	Wish
6	Being able to store all types of documents.	CFS-06	Demand
7	Providing transparency of work.	CFS-07	Demand
8	Possibility of creating customized folder structure.	CFS-08	Demand
9	Possibility to create structured work flows.	CFS-09	Wish
10	Possibility to clone entire projects.	CFS-10	Demand
11	The software must be able to store and handle CAD files.	CFS-11	Demand
12	The software must be able to store additional information regarding documentation, for example when it was changed and why.	CFS-12	Demand
13	Version and revision control.	CFS-13	Demand
14	Effective document search capabilities.	CFS-14	Wish
15	Possibility to add notes to updates and changes of documents.	CFS-15	Demand
16	Being able to integrate and keep track of Project Mangement and Project Planning in the software itself.	CFS-16	Demand
17	Generate Bill of Materials.	CFS-17	Demand

Figure 5.1: Requirement specification based on the needs and wishes.

In *Chapter 6* the table can be seen with the addition of an evaluation of how the software has been deemed to perform regarding each requirement.

6 3DEXPERIENCE

This chapter aims to present and explain the investigation process of the evaluated PLM software 3DEXPERIENCE, 3DX. This software was chosen to be evaluated based on discussions with the examiner and supervisor in an effort to increase the knowledge of the software and if an implementation could be beneficial for the CFS. The study was carried out with the usage of two Formula Student licences.

6.1 Definitions

In order to explain and understand 3DX, a number of features and functionality needs to be introduced. The list below presents a few of the most basic concepts.

- 3DX Edu Space - An online library which contains educational tutorials concerning the use of 3DX. It serves as a learning catalog for all the applications. The tutorials serve as a guide for specific roles such as Project manager, Simulation engineer and so on as well as providing descriptions and explanations.
- Collaborative Space - The working environment on the 3DX platform. The Admin or Team leader has the authorization to create Collaborative spaces. The information added on the collaborative space is visible to all the members who are a part of it.
- 3D-Dashboard - It is the layout of the webpage. It gives an overall view on any topic or activity, gathering content from various sources. It is made up of tabs, which in turn contain the widgets. It can be personalised according to the user. A user can create multiple dashboards depending upon their needs. It is in the dashboard where the user can see what roles they are assigned and navigate between the selection of applications and viewing the community content.
- Tabs - Similar to the definition of tabs in a web browser, they help in opening multiple applications at the same time.
- Widgets - Widgets are software applications which can be inserted on the dashboard for quick access.
- 3D Compass - It is a tool used for navigation within the software itself.

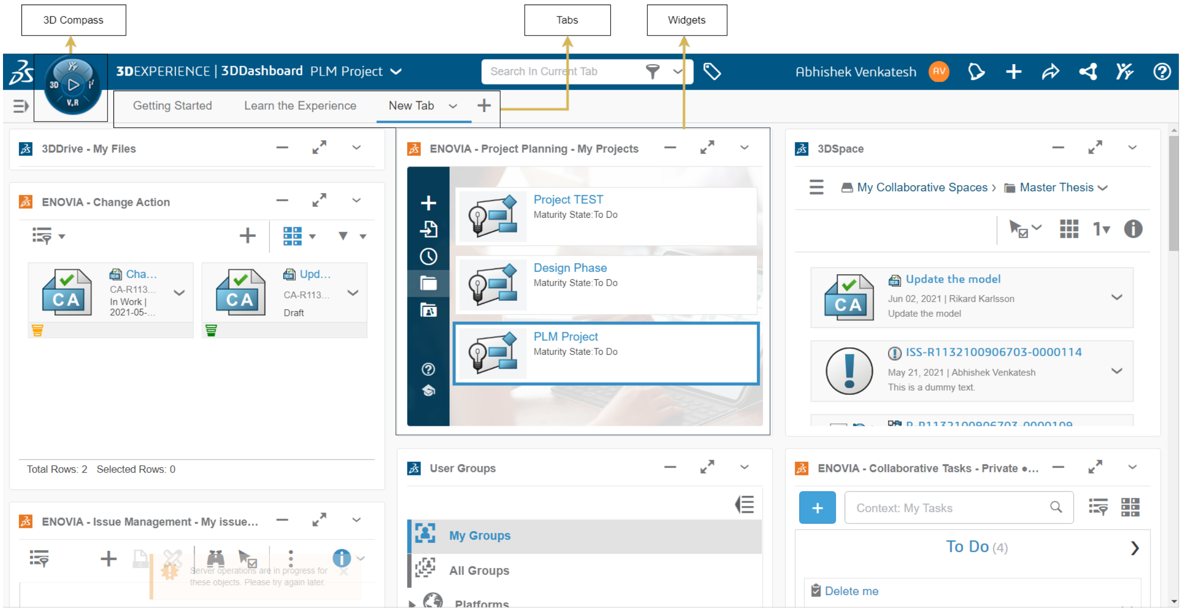

Figure 6.1: 3DX User Interface.

The *Figure 6.1* shows the basic layout of the 3DX interface. The 3D Compass, Tabs and Widgets are as indicated while the page visible is the Dashboard.

6.2 Background

3DX has been developed by Dassault Systèmes and described as per their website;

> *The 3DEXPERIENCE platform is a collaborative environment that empowers businesses and people to innovate in entirely new ways and create products and services using virtual experiences. It provides a real-time view of business activity and ecosystem, connecting people, ideas, and data (3DEXPERIENCE, n.d.).*

To describe it in other words, the software can be seen as a cloud service, accessible through a web browser, which can store and manage documentation and information that would be needed by various parts within a company or externally. For example it can manage files for the development department as well as for the marketing department (3DEXPERIENCE, n.d.).

The licence provided a typical cloud storage as well as a Collaborative space. Additionally, there is an integrated community where questions can be asked and topics discussed with other 3DX users as well as experts. 3DX has also integrated other software from Dassault Systèmes, for example formerly mentioned CAD program CATIA V5, which can be open and accessed through the web browser software.

6.3 Method

The learning process of 3DX relied on reading online material, watching available training and learning videos, asking questions in the community as well as a digital meeting with experts from Dassault Systèmes. The meeting helped to bring clarity in functionality of the software which increased the understanding and enhanced the continued work efforts.

Based on the knowledge gained throughout the process, a preliminary structure was set up with the aim of being a base for evaluating the aspects from the requirement specification and to test them in a situation resembling the real case scenario. For example, a number of CAD files and assemblies were supplied by the CFS team in order for the testing to be closer to a real scenario.
The analysis of the software and the evaluation of the fulfillment of the requirement specification were mainly based on user tests. The requirements which could not be evaluated through testing are discussed below. After the setup had been created, the evaluation and fulfillment of the requirements began.

6.3.1 Folder structure

In an effort to enhance and streamline the usage of 3DX, a number of ideas and guidelines were collected as shown previously in *Chapter* 3.6. Based on this information a suggestion for the structure has been identified. It consisted of creating a Collaborative space for each subgroup as well as one shared space. In this way, each subgroup can manage their own CAD files and store interconnected assemblies in the shared space. This would help the subgroups add documentation in the form of CAD files, PDF files, images, in their respective Collaborative space. The Collaborative space would contain all the information in an ordered way. The members would have the option to sort the information alphabetically or chronologically. The Collaborative space would also contain the information from the used widgets. Information can be moved from one collaborative space to another as well. The creation of collaborative spaces provides traceability and also the current naming convention system as mentioned in *section 4.2.4* can be followed .

6.4 Requirement evaluation

Once the setup had been created, the testing of the stakeholder requirement began. As described previously in *Chapter* 3, the evaluation process and implementation of a PLM software can span over a large period of time. In order to handle the evaluation of the formerly mentioned requirement specification, the evaluation method mainly consisted of tests. In the cases where tests were not sufficient, other methods were used. This was due to the difficult nature of managing a complete and thorough test of each of the functionality of a rather complex software. In *Figure* 6.2, the Stakeholder requirements list can be seen with the addition of level of fulfillment. The levels of fulfillment consists of three degrees, *Fulfilled*, *Partially fulfilled* and *Not fulfilled*. The reasoning behind the fulfillment of each requirement is listed below.

No	Stakeholder requirement	Stakeholder code	Priority	Fulfillment
1	Standardised data organization aiding backtracking of information.	CFS-01	Demand	Fulfilled
2	Software needs to work as a Knowledge Management System.	CFS-02	Demand	Fulfilled
3	The software should provide the possibility of communication between team members.	CFS-03	Demand	Fulfilled
4	Assignment of different roles to team members.	CFS-04	Wish	Fulfilled
5	Approval of changes during the project.	CFS-05	Wish	Fulfilled
6	Being able to store all types of documents.	CFS-06	Demand	Fulfilled
7	Providing transparency of work.	CFS-07	Demand	Fulfilled
8	Possibility of creating customized folder structure.	CFS-08	Demand	Partially fulfilled
9	Possibility to create structured work flows.	CFS-09	Wish	Fulfilled
10	Possibility to clone entire projects.	CFS-10	Demand	Not fulfilled
11	The software must be able to store and handle CAD files.	CFS-11	Demand	Fulfilled
12	The software must be able to store additional information regarding documentation, for example when it was changed and why.	CFS-12	Demand	Fulfilled
13	Version and revision control.	CFS-13	Demand	Partially fulfilled
14	Effective document search capabilities.	CFS-14	Wish	Fulfilled
15	Possibility to add notes to updates and changes of documents.	CFS-15	Demand	Fulfilled
16	Being able to integrate and keep track of Project Management and Project Planning in the software itself.	CFS-16	Demand	Fulfilled
17	Generate Bill of Materials.	CFS-17	Demand	Partially fulfilled

Figure 6.2: Requirement specification with level of fulfillment.

1. Standardised data organization aiding backtracking of information.
   - Fulfilled: Once documentation and data had been added to the collaborative space, it could be stored and accessed later on. This allowed for backtracking information to the source as long the information was added and updated accordingly.
2. Software needs to work as a Knowledge Management System.
   - Fulfilled: Since documentation can be stored with metadata, information about changes should be accessible between the teams of different years. This would allow for knowledge to be transferred with a reduced need to ask other members of the team or alumni members.
3. The software should provide the possibility of communication between team members.
   - Fulfilled: The software has an integrated possibility of sharing information both with images, texts as well as videos. These can be viewed by other members of the development team, for example to see changes that need to be made to a certain part.
4. Assignment of different roles to team members.
   - Fulfilled: The top of the hierarchical structure, the Admin or the Team leader, can assign roles to members of the team. These roles already exists in the software and are used to provide a pre-made setup of apps to be used. A team member can be assigned multiple roles and switch depending on the need.

5. Approval of changes during the project.
    - Fulfilled: If a structured flow were to be set up and used, parts and assemblies could be sent for a potential inspection by another member of the team for approval.
6. Being able to store all types of documents.
    - Fulfilled: Based on tests of adding documents to 3DX, as well as discussing this topic with experts at Dassault Systèmes, the software is able to store all file formats. However, it is worth noting that all files can not be previewed in the software itself. For example, PDF files can be previewed, but not Microsoft Excel or Word documents.
7. Providing transparency of work.
    - Fulfilled: Users can be assigned tasks which can be seen by other members of the team. This creates a visual feedback regarding the distributed work and workload.
8. Possibility of creating customized folder structure.
    - Partially fulfilled: Users are able to create their own folders in the existing drive. However, since only authorized members are allowed to create Collaborative spaces, not all users will be able to customize their own structure fully.
9. Possibility to create structured work flows.
    - Fulfilled: The software provides the feature of creating specific flows with Route management. For example, this could be used for tailoring the path of which a part or assembly needs to take in order to be approved.
10. Possibility to clone entire projects.
    - Not fulfilled: The ability to clone projects has been tested on a smaller scale consisting of assemblies and parts. However, since the test has not been performed with an entire project this requirement can not be evaluated as fulfilled.
11. The software must be able to store and handle CAD files.
    - Fulfilled: The storage and handling of CAD files has been tested with CATIA V5. It was possible to open and save parts and assemblies located both in the Drive as well as the Collaborative space.
12. The software must be able to store additional information regarding documentation, for example when it was changed and why.
    - Fulfilled: It is possible to add notes and comments and link them to the specific changes and updates.
13. Version and revision control.
    - Partially fulfilled: It is possible to use both version and revision control in the software which has been validated through video tutorials. However, during the tests of the functionality it did not work properly and certain options did not appear. This is likely due to the used setup and should not be an issue going forward, thus the requirement was deemed as partially fulfilled.

14. Effective document search capabilities.
    - Fulfilled: The software provides search capabilities. This includes a feature named 6W, which allows for searching with respect to the *Where*, *What*, *When*, *Who*, *How* and *Why*, which has been deemed as an effective search feature.
15. Possibility to add notes to updates and changes of documents.
    - Fulfilled: Information regarding updates and changes can be added in multiple ways. It can be added in text form, as images or even as generated videos.
16. Being able to integrate and keep track of Project Management and Project Planning in the software itself.
    - Fulfilled: The software contains Project planning capabilities which has been tested and seems to function accordingly.
17. Generate Bill of Materials.
    - Partially fulfilled: This requirement has not been able to be tested properly. However, it has been shown to be possible through video tutorials as well as through talks with 3DX experts. As a result, this requirement was deemed as partially fulfilled.

In order to summarize the fulfillment of the requirements, out of a total of 17 requirements:

- Thirteen requirements were fulfilled
- Three requirements were partially fulfilled
- One requirement was not fulfilled

7 Discussion

This chapter contains thoughts about the work process, factors which could have limited the progress as well as things that could be improved if a similar study were to be carried out in the future.

7.1 Limitations

The computational setup which was used during the learning process of 3DX as well as the testing of the software could have been sub-optimal. In order to be able to operate CATIA V5 on personal computers, a VPN connection to the Chalmers network was required. To access the CFS drive, a separate connection needed to be established to a computer at Chalmers through Microsoft Remote Desktop. This setup was believed to have caused issues during the evaluation phase. This mainly affected the evaluation for the version and revision control, which were deemed as partially fulfilled as a result.

During the process of setting up the 3DX environment and the subsequent testing, it proved to be more difficult than initially anticipated. Certain issues took longer to understand, solve and test which to a degree affected the time-line of the study. The meeting which was held with experts from Dassault Systèmes, helped to increase the understanding of how the software worked and operated which in turn allowed the progress to continue.

7.2 Requirements and needs

The stakeholder requirements have not been ranked according to importance during the study. However, the distinction between the demands and wishes could be seen as a rough estimation of the requirements' importance. The requirements with the demand priority has been seen as the most important ones. The demands have been deemed as necessary to fulfill in order for the software to be a valid option moving forward. The wishes were not deal-breakers, but rather as features which were currently not used by CFS but could prove beneficial if functional. Even though a few of the requirements were deemed as *Partially fulfilled* or *Not fulfilled*, these are expected to be possible to fulfill with continued work efforts, possibly with additional help from the software supplier.

7.3 Implementation

The possible implementation of 3DX as a PLM software could infer problems as mentioned in general terms both in *Chapter 3.2* and *3.3*. The change of system will be a potential risk, since information will be stored in another setting than previously. This will require a learning process of the new system in order to make the most use out of it. In relation to the current setup for handling CAD models, which is done through Teamcenter, it is believed to be able to provide a more homogeneous solution.

7.4 Theoretical framework and the needs of CFS

During the study, it became apparent that problems and risks related to PLM which were highlighted in the literature were also present in CFS. This can be seen both in the case of spending considerable time locating information as well as lack of information about made changes. These needs were later translated and formed into requirements, showing an overlap between the theoretical framework and the investigated case.

The naming convention linked to CAD files has not been identified as an issue and seems to work well according to the interviewees. The current naming convention follows guidelines found in the literature, thus no changes to naming conventions has been made or suggested.

7.5 Sustainability

This section will bring up aspects related to sustainability and how it could affect CFS if 3DX were to be implemented. The main focus has been to highlight and discuss economic and social sustainability.

During the interviews, it was mentioned that rework of CAD files was required from time to time due to errors. This was linked to the current way of storing and managing CAD files. It is possible that these issues would be less frequent, or removed completely, through a change to 3DX. The reduction of rework could benefit CFS from an economic standpoint since less time and effort would be required to be used on non-value adding activities.

3DX would also serve as a unified tool handling variety of other applications of the project like planning, resource management and similar. The integration of variety of applications in 3DX would reduce the need to invest in additional software for those specific purposes.

The usability of 3DX, the possibility of using it on portable devices could provide more flexibility and mobility for the members of CFS. This could increase the accessibility to files and reduce the reliance of having to be situated in a specific location. This could be beneficial if any member would need access to files when not being on campus. For example, if work would need to be carried out from home or in another setting.

For the members of CFS, working with a PLM system throughout their development efforts of building a functional formula race car, could increase their knowledge of information management. This in turn could be a preparatory step for their future careers as engineers.

7.6 Add on Advantages

As mentioned previously, the meeting with experts from Dassault Systèmes was an appreciated help in discussing the software and increasing the understanding of it. If the study were to be redone, an earlier communication would have been sought with the software supplier. This could potentially have lowered the threshold of the initial learning process of the software as well as providing a continuous dialogue during the continued work efforts possible.

The main parts of the literature study relied on (Saaksvuori & Immonen, 2008) and (Stark, 2020). During the thesis, they proved to be linked to the investigated case in numerous ways. However, literature concerning the case at hand was few. The general topics were deemed to have been covered by the books, whereas information regarding a similar case was limited.

7.6.1 3D-Experience

This subsection mentions a few features which are believed to be beneficial to utilize if 3DX is chosen as a PLM system.

1. NetVibes - Metric Reader: It would help in gathering and enriching the Big Data in a simple, structured way according to the user needs. As seen in the *Figure 7.1* below, this widget is useful for CFS in a variety of ways such as task breakdown, budgeting, managing inventory and tracking improvements. This widget helps to analyse the 'Big data' of CFS analytically and it can be plotted in different graphs for visual representation of the same. This would provide a competitive advantage for CFS as they can take real time and informed decisions to improve their processes.

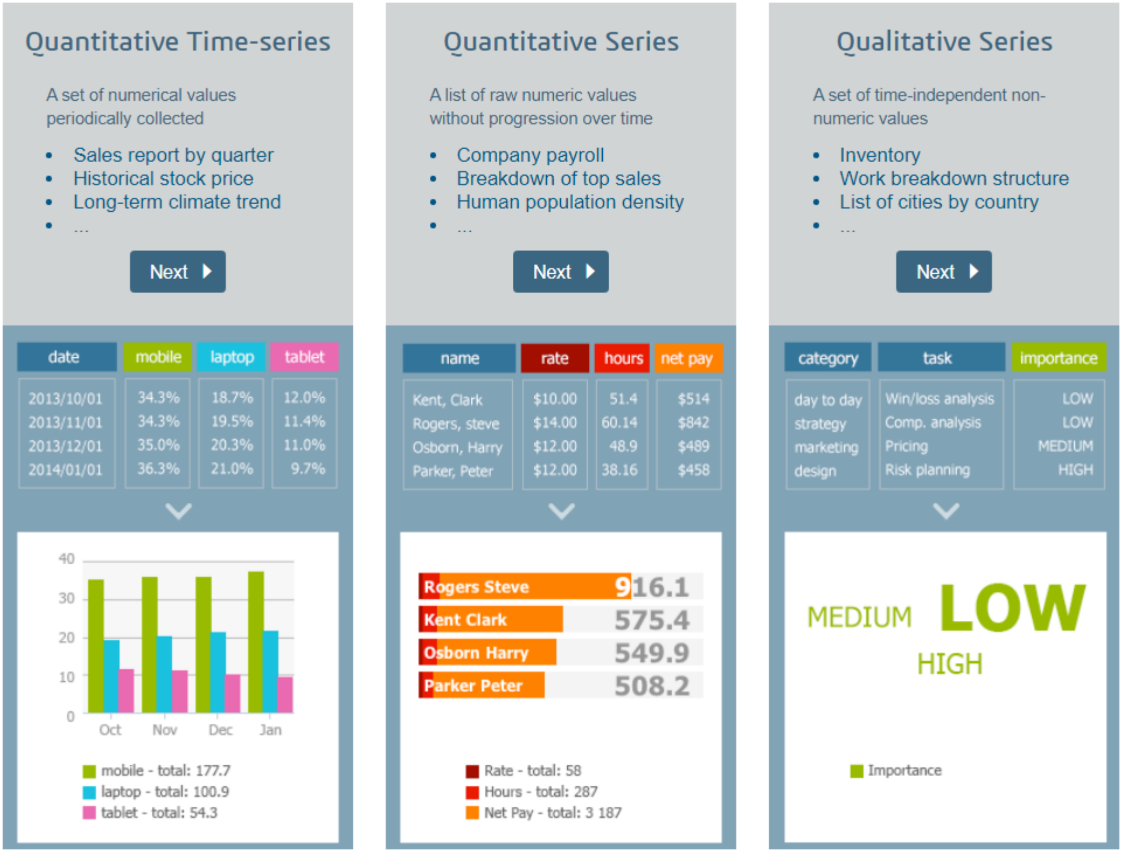

Figure 7.1: Different uses of metric reader

2. 3D Swym Communities: 3D Swym enables the creation and management of communities and also helps to initiate social collaboration through conversations in different communities. It also provides various content creation tools which help in innovation. Based on the type of roles, members would not have the same responsibilities. The content can be added based on its functionality which could be posts, which contains images or videos, polls, or textual paragraphs. The visibility of the posts can also be modified based on the sensitivity of the posts. The *Figure 7.2* shows the various types of information which can be added to the community. The users would benefit from learning about the experiences from other people as well as sharing their thought process.

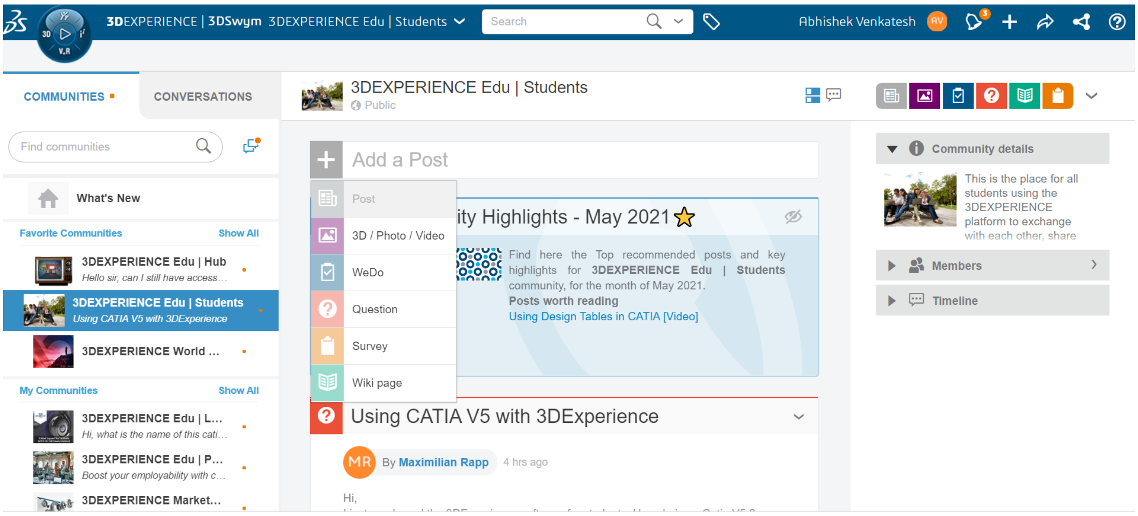

Figure 7.2: 3D Swym Overview

3. Bookmark Editor: The Bookmark Editor widget acts as an organizational tool. It is a file manager application. It enables the user to tag files for them to be located easily later. It is used to structure the documents and organize them in a suitable manner. An added benefit is that the bookmarks itself can be more structured. In other words, the user can create a main bookmark for a new project and divide it into sub-chapters to further structure the data. The files to the bookmarks can be added in a variety of ways which include drag and drop from the local drive, adding it using the upload option in the bookmark editor widget and dragging it directly from the collaborative spaces. The *Figure 7.3* shows an example of the various bookmarks as well as the sub-chapters to the bookmarks. The documents can be classified into different categories based on the type of file.

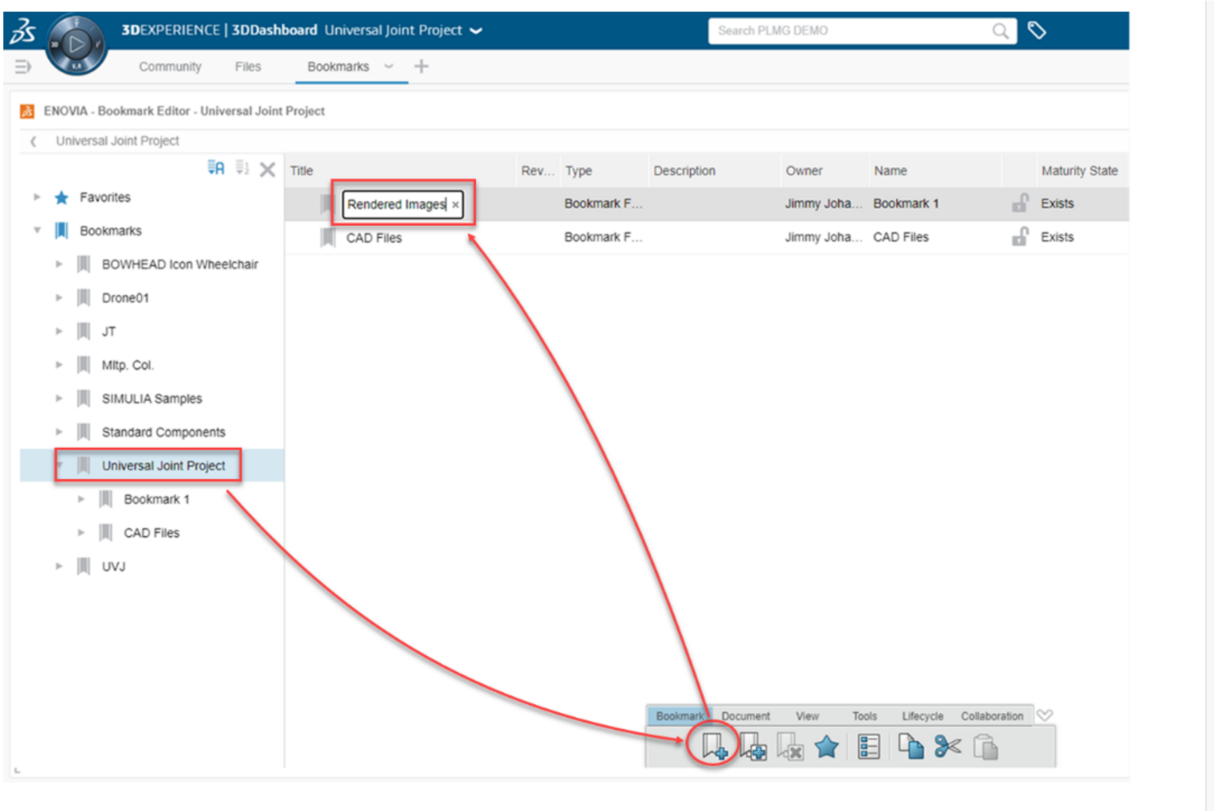

Figure 7.3: Bookmark Editor Widget Overview

8
Conclusion

This chapter highlights the identified answers to the research questions, recommendations for CFS and possible future research.

8.1 Research questions

The three research questions and their respective answers can be seen below.

RQ1: How does CFS currently manage their product related documentation?
As mentioned in *Chapter* 4, CFS currently stores product related documentation in four separate locations. The Chalmers Formula Student drive contains the most varied information, from documents related to lectures, documentation regarding previous years development to documents regarding competition rules. The management of Bill of Materials is done with Google Drive, Teamcenter for CAD models and GitHub for software. The current structure, mainly the CFS drive, has been described as being hard to navigate and find files.

RQ2: How can CFS's PLM needs be satisfied through the software which are looked into in the project?
The Stakeholder requirements which has been listed in *Chapter 5* and its subsequent evaluation in *Chapter 6.2* aims to answer this question. The requirements are quite diverse, thus the needed functionality of the software which would be able to fulfill the requirements are to a large extent also diverse. A few of the requirements were not able to be fulfilled during the study. However, it is believed that these requirements would be possible to fulfill with additional talk and support from Dassault Systèmes.

RQ3: Based on knowledge gained throughout the research, how could a PLM system be structured for the current needs of CFS?
An implementation of 3DX as a PLM system for CFS, would rely on the previously mentioned functions in *Chapter 6.1*. The file storage would be handled in the Drive or Collaborative Space. Regarding the folder structure setup for CAD files in 3DX, the recommendation would be to have one Collaborative space for each subgroup together with one commonly shared space. The setup would provide each subgroup to store their respective CAD files in their own space and the commonly shared one would be used for the creation and management of interconnected assemblies.

8.2 Recommendation to Chalmers Formula Student

If 3DX were to be chosen to be used as a PLM system for CFS, it is highly recommended that team members look through video tutorials and guides which are available. This is in order to ensure understanding of the functionality and to merge the usage patterns of the members. If questions would emerge during the development phase, the 3DX Community could be used in order to discuss certain topics or ask questions which can be answered by other members of the community as well as Dassault Systèmes own support organisation.

As mentioned in the literature, an issue that might occur is a lack of attention regarding the implementation and maintenance aspects of a PLM system. It is therefore advised to continue a future implementation together with Dassault Systèmes. Due to the complexity of such systems, CFS is recommended to as a first step phase out the usage of Teamcenter and handle CAD models in 3DX instead. Based on the literature and the knowledge gained throughout the study, this could serve as a suitable starting point. The possible data migration of an increased number of documents should be considered once the initial period of managing CAD files has been evaluated.

Even though it proved difficult to be able to evaluate and confirm fulfillment of all the set requirements, a change to 3DX is believed to be possible and to provide benefits exceeding the current documentation structure of CFS.

8.3 Future research

The study has been limited to the current setting and needs of CFS which has led to conclusions and recommendations suitable for the specific case. Although a number of them could be put in a more general context, the information was gathered from the literature in an effort to apply them for this case. A future area of research could in that regard be made with the aim of comparing needs of other Formula Student teams.

If an implementation of 3DX were to be made, it would be interesting to do a follow-up evaluation. If the initial implementation would mainly be CAD storage and management, it would be valuable to know how it was perceived to function compared to the current usage of Teamcenter. If it were to be implemented to a larger extent, a follow-up would also be beneficial in order to identify both improvements made as well as possible problems compared to the current way of working.

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A

Interview questions for Chalmers Formula Student members

1. Intro questions:
   - Do you want to be anonymous?
   - Is it okay for us to record the interview?
   - In which part of the team are you working, both for the design phase and the manufacturing phase? What does the role include?
   - What have you been studying before joining CFS, Bachelor and Master?
   - Which software are you using currently and for what purposes?

2. Information retrieval questions:
   - How do you get technical information from the other subgroups, e.g. Frame, Suspension etc?
   - How much time do you spend on information retrieval during a regular week?
   - How accessible is the information retrieval process?
   - Is there anything that bothers you with regards to documentation during the work?
   - Is there any information that you have difficulties finding when you need to access it?
   - Do you have any example of when you were searching for information but were not able to find it, or found it much later?

3. Questions regarding Product Lifecycle Management:
   - What are the benefits of the PLM system you are using right now?
   - Have you experienced any problems related to documentation?
   - How do you keep track of different versions of documents?
   - Do you have any examples of anything that previous years students have documented very well that you benefited from?

4. Process related questions:
   - How would you describe your current process of searching for documents?
   - How would you describe the process of creating CAD-models in the current setting? Any problems related to the current process?
   - How would you describe the process of creating PCBs in the current setting? Any problems related to the current process?

- How would you describe the process of creating software in the current setting? Any problems related to the current process?

5. Conclusion questions:
    - Do you have anything to add that you have come to think related to the topic?

B

Interview questions for professors and engineers regarding PLM

1. Intro questions:
   - Do you want to be anonymous?
   - Is it okay for us to record the interview?
   - What is your job title? What does that role include?
   - What have you been studying before you started working?
   - How much experience do you have with PLM systems?

2. PLM Knowledge:
   - Which PLM software are you using? Is it a customized version or is it an 'off-the-shelf' version?
   - Which PLM software have you used previously?
   - When using PLM software, do you have any examples of when things have gone wrong or not worked properly?
   - What do you believe are the most important aspects of a PLM system?

3. PLM Benchmarking:
   - Do you have any experience of conducting a benchmarking between different PLM software?
   - How did you benchmark PLM systems before you chose which software to use? Which features did you focus on or deemed as important?
   - How do you quantify the unquantifiable requirements?

4. Communication:
   - How do you usually handle internal communication?
   - How do you usually handle global communications?

5. Conclusion questions:
   - How would you describe an intuitive PLM solution?
   - Do you have any specific requirements or wishes for a PLM system?
   - Do you know anyone else that you think that we should try and contact for an interview for further knowledge about this topic?
   - Do you have anything to add that you have come to think related to the topic?

C
Stakeholder requirements

This appendix includes the Stakeholder requirements.

Stakeholder requirement code	CFS-01	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	Standardised data organization aiding backtracking of information.				
Stakeholder requirement type	Primary	Stakeholder requirement priority			Demand
Rationale	The current document structure can be difficult to navigate and find sought document. There is also a need to find information regarding potential changes made during previous development.				
Stakeholder requirement code	CFS-02	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	Software needs to work as a Knowledge Management System.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Demand	
Rationale	There has been a lack of information and knowledge transfer between the students, mainly due to the exchange of team members each year.				
Stakeholder requirement code	CFS-03	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	The software should provide the possibility of communication between team members.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Demand	
Rationale	The software should provide the feature of messaging other members and communicate needed information, without the need for a separate external application.				
Stakeholder requirement code	CFS-04	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	Assignment of different roles to team members.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Wish	
Rationale	The possibility of assigning a specific role to a teammember could be beneficial in order to have an overview of the team and each members document access and restrictions.				

Stakeholder requirement code	CFS-05	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	Approval of changes during the project.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Wish	
Rationale	The possibility of approving parts, assemblies and drawings could improve the work output and documentation maintainability. It will also make it more difficult to accidentally change parts and assemblies which should not be changed.				
Stakeholder requirement code	CFS-06	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	Being able to store all types of documents.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Demand	
Rationale	Since CFS uses numerous software during their development efforts, the software needs to be able to store various filetypes.				
Stakeholder requirement code	CFS-07	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	Providing transparency of work.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Demand	
Rationale	In order to make it easier for all members to know what other members are working on and thereby improving the transparency of labour division.				
Stakeholder requirement code	CFS-08	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	Possibility of creating customized folder structure.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Demand	
Rationale	In order to structure the documents according to the needs of CFS, the folder structure needs to be customizable.				

Stakeholder requirement code	CFS-09	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	Possibility to create structured work flows.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Wish	
Rationale	The possibility of creating structured work flows would enable members to always follow a specific path for their development efforts. For example, every part that is deemed complete by a member would automatically be sent to another member for review and/or approval. This could increase the insight in the work efforts as well as providing a natural feedback cycle.				
Stakeholder requirement code	CFS-10	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	Possibility to clone entire projects.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Demand	
Rationale	Since the team is exchanged each year, there is a need for the new team to access the previous years model. The possibility of cloning the entire previous years models would save time and not require a rebuild of assemblies.				
Stakeholder requirement code	CFS-11	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	The software must be able to store and handle CAD files.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Demand	
Rationale	Since the design of components and assemblies is done in CAD (CATIA V5), the software needs to be able to handle both parts, assemblies and drawings generated throughout the development.				
Stakeholder requirement code	CFS-12	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	The software must be able to store additional information regarding documentation, for example when it was changed and why.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Demand	
Rationale	The current data storage lacks the possibility of tracing which team member has done a certain change or created a specific file. By storing metadata, information of this kind would automatically be stored.				

Stakeholder requirement code	CFS-13	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	Version and revision control.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Demand	
Rationale	CAD files and other documents needs to be version and revision controlled to avoid mistakes and keep track of changes.				
Stakeholder requirement code	CFS-14	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	Effective document search capabilities.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Demand	
Rationale	A concern mentioned by multiple interviewees related to difficulties in searching and finding documents they were looking for. To mitigate this issue, the software should be able to provide an effective search for documents.				
Stakeholder requirement code	CFS-15	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	Possibility to add notes to updates and changes of documents.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Wish	
Rationale	The current system does not automatically allow users to add notes to updates and changes of documentation. This increases the likelyhood of users not adding additional thoughts, information and reasoning behind certain changes due to it being complicated or requiring extra time. The possibilty to add notes alongside updates and changes could be benefical as it would create a history for changed documentation.				
Stakeholder requirement code	CFS-16	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	Being able to integrate and keep track of Project Mangement and Project Planning in the software itself.				
Stakeholder requirement type	Primary	Stakeholder requirement priority		Demand	
Rationale	Integration of Project Mangement and Project Planning activities and structure into the software would remove the need of using a separate software.				

Stakeholder requirement code	CFS-17	Stakeholder code	CFS	Stakeholder	Chalmers Formula Student
Stakeholder requirement	Generate Bill of Materials.				
Stakeholder requirement type	Primate	Stakeholder requirement priority		Demand	
Rationale	It is important to keep track of every part that belongs to an assembly, in this case the entire CFS car. The BOM is used to list all of the included parts, hence it is a very important to be able to rely on on it. The current situation requires a lot of manual inputs which is time-consuming and increases the possibility of human errors.				

D

System requirements

This appendix includes the System requirements.

Stakeholder requirement code	CFS-01	System requirement code	S-CFS-01-01
Stakeholder requirement	Standardised data organization aiding backtracking of information.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Demand
System requirement	The software needs to be able to provide a standardized data structure in order to make it easier for users to find sought information.		
Verification method	User test	Verification method code	VM-UT
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-06
System requirement status	In progress	System requirement history	2021-05-06 System requirement and verification written.

Stakeholder requirement code	CFS-02	System requirement code	S-CFS-02-01
Stakeholder requirement	Software needs to work as a Knowledge Management System.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Demand
System requirement	Software needs to work as a Knowledge Management System.		
Verification method	Test	Verification method code	VM-T
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-06
System requirement status	In progress	System requirement history	2021-05-06 System requirement and verification written.

Stakeholder requirement code	CFS-03	System requirement code	S-CFS-03-01
Stakeholder requirement	The software should provide the possibility of communication between team members.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	VM-T
System requirement	Software need to work as an Effective communication system, allowing for communication between members without the need of using a separate software.		
Verification method	Test	Verification method code	VM-T
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-06
System requirement status	In progress	System requirement history	2021-05-06 System requirement and verification written.

Stakeholder requirement code	CFS-04	System requirement code	S-CFS-04-01
Stakeholder requirement	Assignment of different roles to team members.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Wish
System requirement	It should be possible to assign specific roles to individuals of the team.		
Verification method	Test	Verification method code	VM-T
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-06
System requirement status	In progress	System requirement history	2021-05-06 System requirement and verification written.

Stakeholder requirement code	CFS-05	System requirement code	S-CFS-05-01
Stakeholder requirement	Being able to approve parts and assemblies during the project.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Wish
System requirement	The software should allow for approval of parts and assemblies.		
Verification method	Test	Verification method code	VM-T
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-06
System requirement status	In progress	System requirement history	2021-05-06 System requirement and verification written.

Stakeholder requirement code	CFS-06	System requirement code	S-CFS-06-01
Stakeholder requirement	Being able to store all types of documents.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Demand
System requirement	The software needs to be able to store all types of documents which are used for the current needs of CFS. This includes Excel, Word and other types of documents.		
Verification method	Software capability	Verification method code	VM-SC
	Verification method description	Software capability	
System requirement writer	RK	System requirement date	2021-05-06
System requirement status	In progress	System requirement history	2021-05-06 System requirement and verification written.

Stakeholder requirement code	CFS-07	System requirement code	S-CFS-07-01
Stakeholder requirement	Providing transparency of work.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Demand
System requirement	The software must provide the possibility of assignming work tasks to individual team members.		
Verification method	Test	Verification method code	VM-T
	Verification method description		
System requirement writer	RK	System requirement date	2021-05-06
System requirement status	In progress	System requirement history	2021-05-06 System requirement and verification written.

Stakeholder requirement code	CFS-08	System requirement code	S-CFS-08-01
Stakeholder requirement	Possibility of creating customized folder structure.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Demand
System requirement	The software needs to provide the possibility of creating a customizable folder structure.		
Verification method	Test	Verification method code	VM-T
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-06
System requirement status	In progress	System requirement history	2021-05-06 System requirement and verification written.

Stakeholder requirement code	CFS-09	System requirement code	S-CFS-09-01
Stakeholder requirement	Possibility to create structured work flows.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Demand
System requirement	The software should provide the possibility of creating structured work flows. The flows should be able to structure the work efforts into a common way of working.		
Verification method	Test	Verification method code	VM-T
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-06
System requirement status	In progress	System requirement history	2021-05-06 System requirement and verification written.

Stakeholder requirement code	CFS-10	System requirement code	S-CFS-10-01
Stakeholder requirement	Possibility to clone entire projects.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Demand
System requirement	The software should be able to clone entire projects without losing any data related to assemblies and their structure.		
Verification method	Test	Verification method code	VM-T
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-06
System requirement status	In progress	System requirement history	2021-05-06 System requirement and verification written.

Stakeholder requirement code	CFS-11	System requirement code	S-CFS-11-01
Stakeholder requirement	The software must be able to store and handle CAD files.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Demnd
System requirement	The software must be able to store and handle CAD files. It needs to be manage parts and drawings as well as assemblies.		
Verification method	Test	Verification method code	VM-T
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-06
System requirement status	In progress	System requirement history	2021-05-06 System requirement and verification written.

Stakeholder requirement code	CFS-12	System requirement code	S-CFS-12-01
Stakeholder requirement	The software must be able to store additional information regarding documentation, for example when it was changed and why.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Demand
System requirement	The software must be able to store metadata.		
Verification method	Test	Verification method code	VM-T
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-06
System requirement status	In progress	System requirement history	2021-05-06 System requirement and verification written.

Stakeholder requirement code	CFS-13	System requirement code	S-CFS-13-01
Stakeholder requirement	Version and revision control.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Demand
System requirement	The software needs to be able to manage version and revisions of documents.		
Verification method	Test	Verification method code	VM-T
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-07
System requirement status	In progress	System requirement history	2021-05-07 System requirement and verification written.

Stakeholder requirement code	CFS-14	System requirement code	S-CFS-14-01
Stakeholder requirement	Effective document search capabilities.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Demand
System requirement	The software needs to provide an effective search feature.		
Verification method	Test	Verification method code	VM-T
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-07
System requirement status	In progress	System requirement history	2021-05-07 System requirement and verification written.

Stakeholder requirement code	CFS-15	System requirement code	S-CFS-15-01
Stakeholder requirement	Possibility to add notes to updates and changes of documents.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Wish
System requirement	The software should be able to to have notes attached to updates and changes for documentation.		
Verification method	Test	Verification method code	VM-T
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-07
System requirement status	In progress	System requirement history	2021-05-07 System requirement and verification written.

Stakeholder requirement code	CFS-16	System requirement code	S-CFS-16-01
Stakeholder requirement	Being able to integrate and keep track of Project Mangement and Project Planning in the software itself.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Demand
System requirement	The software should provide management of project and project planning.		
Verification method	Test	Verification method code	VM-T
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-07
System requirement status	In progress	System requirement history	2021-05-07 System requirement and verification written.

Stakeholder requirement code	CFS-17	System requirement code	S-CFS-17-01
Stakeholder requirement	Generate Bill of Materials.		
Stakeholder requirement type	Primary	Stakeholder requirement priority	Demand
System requirement	The software needs to be able to generate Bill of Materials.		
Verification method	Test	Verification method code	VM-T
	Verification method description	Verified through testing the software.	
System requirement writer	RK	System requirement date	2021-05-07
System requirement status	In progress	System requirement history	2021-05-07 System requirement and verification written.

Verification method	Definition	Verification method code
Test	Capability and functionality tested by the authors of the thesis.	VM-T
User test	Capability and functionality shown or tested by initiated stakeholder.	VM-UT
Software capability	Capability and functionality evaluated based on information gathered about the software, through tutorials or other documentation.	VM-SC

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