Designing a customizable Product Life Cycle Management system for an SME to reach data singularity

Florin Păuşan

EXAMINATION COMMITTEE

Dr.Ir. Jos de Lange

Dr.Ir. Eric Lutters

MSc. Robbert-Jan Torn

COMPANY SUPERVISOR

Wolter Hoekman

UNIVERSITY OF TWENTE.

Faculty of Engineering Technology
Industrial Design Engineering (MoPD)
Date: 10/06/2021
DPM: 1816

Table of Contents

Acknowledgement

This thesis came to life due to the highly appreciated support of many individuals. I would like to extend my acknowledgements to all of them.

I would like to express my gratitude towards my family members who supported my decisions and all my educational progress. My second family, represented by my classmates and friends from The Netherlands, I owe a great respect and appreciation because of their values and inspirational attitude that they reflected on me. Along with my family, I would say that constant support was received from my girlfriend who was patient and encouraged me at every step.

I am highly appreciative of Company X, with special thanks to the CEO Wolter Hoekman, the management staff and employees which provided an exciting, challenging project and facilitated an engaging environment to conduct this assignment. The freedom, guidance, and constant check-ups took me to successfully complete my thesis.

I would like to express my special gratitude and thanks to my thesis advisor Jos de Lange who guided me in an exceptional way, who shared his expertise and knowledge for the accomplishment of my actual professional experience.

Distinguished members of the evaluation committee, headed by Eric Lutters together with Robbert-Jan Torn for the valuable feedback and approval of my work.

My thanks and appreciation to all the other people that are not above mentioned and who have willingly helped me out through different means.

1 INTRODUCTION

1.1 Assignment introduction

The focus point of this thesis is represented by an integrated part of Industry 4.0 (I4.0) that is product lifecycle management (PLM). The PLM core activities are strictly related to data management and are assuring product data singularity in an industrial environment. In this case, the industrial environment is represented by a manufacturing company in The Netherlands. Due to confidential reasons, the name of the company is not mentioned in this thesis. During the process of the thesis, the writer will refer to the company as Company X.

The study aims at designing and developing a software tool that gives the premises to create a full-spectrum view of the product data defined and agreed upon by multidisciplinary teams. The intention is to provide a solution in the form of a proof of concept, that aligns different perspectives, processes, people, and technologies to assure the product data reliability and singularity, and eventually speed up the product-to-market process. Real-time data transfer is an objective that companies are aiming at, thus Company X embarked on studying the potential to achieve data singularity and provide insights into their capabilities by having good control of how the product data is generated.

Company X took the initiative to explore and develop a PLM system tailored to their processes and market. This system is intended to stand as a centralized system that will encompass all data and information across the entire life cycle of the product portfolio. This is also an opportunity for Company X to display its capabilities to the actual customers and suppliers. This process is just at an incipient stage, which leaves space for discovering new opportunities and challenges that the company is currently facing. In a broad sense, the project contributes to clarifying the information flow within Company X and its value chain, data flow which acts as a first step in developing a PLM system. Company X emphasized the fact that it would like to build its own PLM system given the potential market demand and the intention to develop an adjacent business case.

1.2 Background information

1.2.1 Initial background information

The current study is based on the findings from a previous PLM study case offered by Company X to the University of Twente students. Company X aimed at creating an overview of their information and data flow resulting from internal and external processes to allow Company X to determine the bottlenecks in communicating and collaborating with their customers and suppliers. There were two student groups working out the study case. The results of the student groups were tailored in initial data flows as well as a low fidelity front-end and one back-end solution. These results were used as guiding mechanisms in accommodating the scope and intentions of Company X regarding the thesis project.

1.2.2 Current goals

To help address the challenge of creating a centralized system for data management, it is important to understand how Company X collaborates and manages data and information. This will lead to some

potential challenges and requirements for implementing a PLM strategy, implicitly taking a step further towards Industry 4.0 maturity. Consequently, this study is focused on defining the information flow within the actual business ecosystem that Company X takes part of, determining the bottlenecks and good practices in exchanging data with different stakeholders. The goal of the study is to integrate the steps from a problem description and definition towards a proof of concept.

The goal is to contribute to structuring and managing data regarding communication and collaboration between Company X and its customers. In time, this should give clients insight into Company X's capabilities and give the company handles to build knowledge upon their product development process. By determining the bottlenecks and strength, Company X can take faster decisions in addressing all pain points that result during the product lifecycle development.

Another primary step is to optimize the relations and exchange of data between Company X and its customers. Company X wants to continue the research about the PLM possibilities and develop and integrate a PLM interface to centralized data and facilitate a clearer communication with customers and suppliers. Additionally, Company X wants to understand current developments and trends in the market, how the competitors are developing their technological roadmap, and adapt to the new trends. PLM platforms and the vendors offering those services are of high interest in this phase, thus the objective is also to have a brief understanding of what the PLM offer in the market is.

By approaching strategies aiming towards Industry 4.0 and having a better understanding of data flow, Company X wants to maximize its benefits. A preliminary analysis of the current state done together by Company X provides the first preliminary requirements and challenges. Additionally, the challenges proposed by Stark (2015) are translated into requirements and combined with the requirements that Company X defined with as follows:

- Minimize risks of prototyping delay by reducing to a minimum the delivery time.
- Reduce errors; therefore reduce the time of response on request-delivery.
    - Define correctly and in a clear way the product data.
- Predict the supply chain capabilities based on customer demands by a clear overview of the supplier's material.
- Optimize decision-making process at different product development stages.
    - Define standardization in processes.
    - Clear project objectives
- Improve communication and planning between internal and external parties.
    - Reduce knowledge gap
- Give shareholders insights in Company X's capabilities.
    - KPIs definition
- Achieve data singularity
    - data across multiple software.
    - different data definitions
- Design an information management system build around the customers, suppliers and Company X.

- Align the IT applications to reduce manual data entry, errors and data inconsistencies.

- Understand how Company X collaborates and manages data and information

On top of the first preliminary requirements, it is important to highlight potential challenges and bottlenecks:

- Currently, there is not a clear overview of how the existing manufacturing systems can support digital transition towards Industry 4.0.
- The so-called umbrella system that connects all software within Company X is missing, thus a centralized system is required. However, at the moment there is no action plan on understanding how system connectivity can be possible.
- Company culture plays an important role in Company X, thus introducing new technologies might introduce new cultural elements to the existing culture that might seem intrusive and disruptive. Employees working for Company X are settled into a routine and the adoption of new technologies will have direct implications on their working methodology.

The above requirements and problem statements will suffer modifications based on the internal and external analysis and the input that is given by various stakeholders. These will serve to define the aim and the objectives of the study.

1.3 Study setting

Company X, an electronics manufacturing company has been used as the setting of this study. During the process of developing the present study, Company X was subjected to a thorough scan to determine the requirements that stand at the base of the proposed solution.

Company X is a medium-sized high tech company focusing on the production of electronics. Company X supplies prototypes and is, therefore, an important part of the R&D process of its customers. Its core processes are PCB (printed circuit boards) soldering and assembly, final assembly, wire bonding as well as order fulfillment as service manufacturer for different customers. Company X is a reliable subcontractor, which aims for long-term customer relationships, being in the electronics prototyping and development industry for more than 20 years. Given the fact that Company X started as a consulting company in the electronic industry, it gave the company a close impression of what the trends look like in the market.

Company X delivers services to customers from general industry, healthcare, defense, aerospace and analysis systems with current growth in medical and sensoric appliances. Some examples of applications that Company X performs are in the medical area (signalizing responses from the brain), interactive playing tools for outdoor playing grounds, shop pass gates for security, laser application for eye correction, electric wheelchairs, etc.

The company wants to ensure its competitive position through means of new ideas and methods such as “Design for Excellence”. The intention is to remain in a leading position and to provide one of the highest quality on the market.

1.4 Technological trends

The last years are marked by tremendous technological advancement, which offers opportunities in digitization and interconnection of processes, products, value chains, and business models. Geissbauer et al. (2014) researched over 200 companies from multiple industries (e.g. automotive, manufacturing, electric, and electronic systems) and found that the digital transition will generate a considerable change in most of the industries. Companies are facing a considerable performance shift due to the digital revolution and transformation. Geissbauer et al. (2014) predicted that in the upcoming years, the share of investment in Industry 4.0 (I4.0) solutions will account for more than 50% of planned capital investments.

According to Fitz et al. (2019), cyber-physical systems (CPS) are hybrid hardware/software systems that are able to analyze, learn, adapt and communicate through networks and independently decide what steps to follow within the production process. CPS is the technological core of Industry 4.0, where elements such as sensors, enterprise resource planning (ERP) and actuators are emerging in the connection between the digital world with the real one. As stated by Kiel et al. (2017), one of the main objectives in systems interconnectivity is to achieve real time data transfer that provides a singular source of truth of product data. The end goal is to leverage the product system and businesses through new technology adoption. Using technologies that facilitate digitization in manufacturing, allows manufacturers to achieve end-to-end supply chain integration, where all stakeholders can benefit from an efficient and trustworthy collaboration.

For most companies, it has become the leading impulse to innovate, manufacture, sell and in the end service products. Some rationales to invest in Industry 4.0 technologies according to Falk et al. (2015) are as follow:

- Remain competitive in the market,
- Increase efficiency,
- Improve quality,
- Effectively manage the resources and services in the event of reducing the risks that are threatening the core business activities and objectives.

A study by Smit et al. (2016) for the European Parliament's Committee on Industry, Research and Energy (ITRE) showed that with these recent technological developments, most of the companies are recognizing the need to take action and slowly blend into the digitization and connectivity processes. Far fewer, especially among small-medium enterprises (SMEs) are prepared for it.

1.4.1 Technological Challenges

A more digitized industry brings challenges and unforeseen effects for companies that want to transition. Thus, it can happen that the path towards digitization and connectivity of processes cannot be effectively paved or does not live up to the expectations of all the parties involved or affected by the desired changes.

I4.0 engages companies to take action in digitization and connectivity; however, they are not aware of the full benefits, challenges, and requirements. This leads to several complications that are stretched out by Stark (2015) in his book "Product lifecycle management, the 21st-century paradigm of product realization":

- Incorrectly or unclearly defined products.
- Unclearly defined and incorrectly structured data.
- Lack of data singularity.
    - data across multiple software.
    - different data definitions.
- Missing clear definitions of the processes.
- Ineffective application interfaces, unaligned applications leading to manual data re-entry, errors, and data inconsistencies.
- Vague project objectives.
- Machines are underused or not used at all.
- The knowledge gap between employees, no capturing of tacit information and experiences.
- Not a clear overview of the key performance indicators (KPIs).

These challenges aid the thesis study in assessing the current state of Company X and having a clear focus of what to assess during the analysis phase.

1.5 Aim of the study

The focus point of this thesis revolves around the technological enhancement that offers possibilities to manage the portfolio of products across the entire lifecycle in the most effective way. This falls under the so-called Product Life Cycle Management systems. Words like connectivity, interconnectivity, product data singularity, the cohesion of views, data cloud, transparency, traceability, real-time data, and many more are often related to PLM. This will further revolve around the proposed case of this study.

The role of a PLM system in small-medium enterprises (SMEs) is becoming more important because it provides great perspectives on digital continuity across the supply chain. *Company X* aims at creating the digital continuity between manufacturing and engineering departments by developing its own PLM platform that can foster product data and assure data singularity. A need is identified in the designing and conceptualizing of a digital logistic platform/architecture that can monitor and manage the product data and production steps in real-time as well as offering the possibility for optimizing the stakeholders' responsiveness. The goal is to contribute to structuring and managing information and data regarding the communication, collaboration and product development between businesses. In time, this should give the customers insight into Company X's capabilities and give the companies some handles to build

knowledge upon their product development process. The final goal should convey a detailed proof of concept for a PLM platform that will give Company X the right handles to manage the data flow internally as well as externally while the communication and responsiveness of all parties involved in defining the product data is more efficient.

1.5.1 Research questions

Following the aim of the study and the project goals the research questions below serve as guiding points for this project:

1. What data flow is Company X possessing in its environment and across its supply chain?
2. What are the means of centralizing data and offering a singularity of information?
3. How can people, systems and processes be connected to product data to provide a predictable product outcome?
4. How can the demands of the customers be matched faster with the capabilities of the suppliers?
5. What platform functionality can serve Company X in achieving data singularity?

1.6 Thesis Outline

Chapter 1 gives more background information about the research, highlighting elements such as the study setting and company description, goals, mission and vision of Company X, the current challenges that Company X is facing. Additionally the chapter covers also the main goals set by Company X at the beginning of the study as well as the aim of the study.

Chapter 2 The stakeholder analysis is comprised in this chapter. This stage covers internal interviews with Company X employees and external interview with customers of Company X. Additionally, IT architecture and methods of software integration are encapsulated in this chapter.

Chapter 3 covers the theoretical background that incorporates theory regarding Industry 4.0 and trends in manufacturing industry. Moreover, the paper integrates a general research on Product Lifecycle Management (PLM) and enterprise resources planning (ERP) domains and systems. A quick comparison is made to understand what ERP and PLM stand for, and understand their particularities.

Chapter 4 comprises the study on the main market where Company X is active. This mainly comprises the platform analysis, the weaknesses, and strengths at business level of the main competitors over Company X. Additionally it touches on the analysis of PLM vendors and platforms to understand the main functionalities behind a PLM system. Additionally the chapter is represented by the SWOT analysis. This chapter comprises all the strengths, weaknesses, opportunities and threads discovered along the extensive analysis preceding this stage.

Chapter 5 this chapter incorporates the prioritization of all bottlenecks emerged from the analysis phase and integrates an assessment on the initial problem statements to verify if the pain points are obsolete or not. It includes the requirements specifications which are the baseline for developing the PLM concept.

Chapter 6 is the most extensive chapter that includes the solution principle. It is branched in back-end and front-end description, general design principles and features and it covers scenarios based design with the scope of enhancing the main features that address the problem statements and requirements.

Chapter 7 provides the means for testing and evaluating the actual mock-up and prescribing functional adjustments. Moreover the concept solution is further assessed on its applicability regarding PLM characteristics and the possibility of its usage in Company X enterprise.

Chapter 8 - provides the recommendations and the reflection on the research, methodology, outcomes, providing recommendations and advice for further developments and research.

Chapter 9 - provides a concise conclusion on the outcome and the research methodology. During this chapter the author reflects upon the core proposal and assess to what extend the aim of the thesis is achieved.

2 Analysis

2.1 Stakeholders and interview procedure

Before conceptualizing the design of the PLM solution it is important to understand the current performance of the organization in terms of data management, data flow within its own ecosystem so that the company can refine its processes for a more efficient, compliant and secure offer. This analysis focuses on two main areas:

- Internal processes and
- External processes

This current state analysis allows Company X to diagnose current bottlenecks as well as to anticipate future concerns. The analysis procedure aims at addressing the needs of the internal and external stakeholders, the information flow and technological systems that are currently used in data management. The scope is to analyze, evaluate and improve the effectiveness of management procedures and governance processes by providing clear insights and recommendations based on analyses and assessments of data and business processes.

This analysis follows certain steps along the following lines:

- Conduct interviews with internal employees and customers.
- Analyze internal and external documents, workflows, data management methodologies, people, processes, activities and systems to define their role and effectiveness of use in data management.
- Synthesize findings in a list of bottlenecks, observations and recommendations.

Due to confidential reasons the extended findings of the internal and external analysis are listed in the external file called Appendix 14 – Analysis phase. All data with personal character as well as the data that refers to the current procedures, systems, strategies and business objectives of the company are anonymized within this report. The appendix comprises a thorough description of the designed workflows and data maps as well as the bottlenecks, procedures and suggestions for enhancements of internal and external processes.

While proceeding with the analysis of the current state of Company X, it was discovered that there is a need to fully comprehend which are the stakeholders that play a key role in defining the effectiveness of business processes and assure the data flow. A preliminary overview of the internal stakeholders was drawn out by the management team to clearly define the persons that need to be interviewed.

The interviews were conducted with four customers and eleven employees of Company X that have an influence on defining and managing the product data. The description of the main stakeholders can be consulted in Appendix 1 – Stakeholder division.

Together with the management staff it was agreed that the following are the relevant actors that have a consistent impact in internal as well as external processes of Company X:

1. Internal Stakeholders
    a. Management staff - two persons
    b. Account managers - two persons
    c. Component purchasers - two persons
    d. PCB purchasers - one person
    e. Project leader - one person
    f. Production leader - one person
    g. Warehouse worker - two persons
2. External Stakeholders
    a. Customers - four company representatives
    b. Suppliers

Concerning the interviews with the internal stakeholders, there was a number of two semi-structured interviews and several unstructured feedback sessions conducted as follows:

1. First interview integrated discussions about the current situation, tasks, activities, responsibilities, data flows and IT systems within Company X.
2. Second interview consisted of a feedback and revisiting session of the findings from the first interview.
3. During the analysis phase, the maps were created and revisited in close collaboration with the internal stakeholders by having periodical and spontaneous meetings aside from the scheduled one where the maps were defined in the final form.

A similar procedure was followed in the case of external interviews. The only difference is that the second interview was replaced with a written feedback and data validation session. This means that all findings were forwarded to the customers and asked for feedback and validation of the findings in writing.

The interview procedure encompasses open questions for each stakeholder. Open questions are a good way to comprise an in-depth understanding of what each stakeholder is doing, with clear examples while giving them the freedom to express their thoughts with no restrictions. For the researcher it gives the opportunity to approach each interview in a flexible and easy to comprehend way.

The final results of the interviews encompass the internal and external stakeholders perspectives in the shape of data flows and maps. These data flows integrate the main areas of interest in PLM which are the product data, people, processes, IT systems, communication and business processes.

Next subchapters comprise two main categories which represent the overview of the current state and the current IT architecture within the organization.

2.2 Overview current state

By determining how the information flows through the ecosystem of Company X, the staff can precisely determine the urgency, pinpoint bottlenecks, thus can spot possibilities for reshaping different processes and procedures. Further on, the employees can determine the efforts for each task, record best practices, see how the information is structured and captured, and have a holistic overview of the strengths and points of improvement within the Company X ecosystem. The analysis phase aims at determining

potential and existing weaknesses regarding data management. It shows where and how the human and material resources are used as well as the efficiency of its usage.

This research encompasses the most relevant information after applying a filter on the outcomes resulting from the internal and external analysis. The outcomes of the interviews are translated into maps. The maps provide a general overview of the stakeholders interaction within the existing processes of product development, and provide an understanding on how the product data is manipulated within the existing IT infrastructure.

Due to confidential reasons the maps, the procedures and the full overview of the findings that resulted from the analysis phase, are separated from this report. Please refer to Appendix 1 Stakeholder analysis to have a full overview of the analysis.

2.2.1 Internal analysis

During the interviews, the findings were documented in flow charts. Draw.io is a brainstorming tool that allows the users to create interactive flow charts as well as share the results with target groups. This was the tool used in designing the data maps. The purpose of this is to create awareness and gain understanding about processes, procedures, people, systems with the scope of simplifying and improving the overall processes. The intention is to use the findings for further automation of processes, as well as reduce costs and redundant procedures.

The results of each discussion provide a clear description of the process steps, systems in use, how data is managed, followed by a list of pain points and observations. Eventually they show the “who”, “what”, “when”, “where”, and “how” product data is handled during the development cycle.

The analysis incorporated discussions with members from all departments. After determining the main pain points of each discussion there were several similarities that were mentioned during the interview's reason why the pain points followed a categorization procedure. Nine main problem definition categories emerged from the internal analysis. Appendix 17 - Bottlenecks categorization encompasses the categorization process of all bottlenecks that resulted from the discussions with different internal stakeholders.
The internal analysis presents a list of nine problem definition categories as it follows:

1. Inconsistent statuses and updates about product information at different stages. Notification, Customer & Supplier Communication

- Employees request a notification system regarding statuses, updates or any other changes to the product data, respective to the project. Not having a clear notification system in place leads to slow operational response and awareness.
- No real time control of production processes, no notification if there are any updates on the product/process.

2. Manual file manipulation & repetitive work.

- This results in high set-up time and indirect hours because of repetitive work that encompasses manipulation of typically offline (transition offline to online) files by different employees.

- The purchasing time is increasingly high because of the highly increase manual search that needs to be done while purchasing components
- Important changes in the physical products or parts are captured on paper that can result in lag of the virtual counterpart product, additionally in extra human effort, energy, materials and incorrect information.

- Manual production scheduling done in excel with minimum of automation.

3. File format

- Suppliers and customers are providing different file formats that implies for employees a high intensive file formatting work that can lead to loss of information, incorrect data processing, long duration processes.
- The EBOM to MBOM file conversion is a tedious process which takes a lot of time due to different file formats that Company X receives from different customers.
- Open BOM reflecting costs of individual components is missing.
- Component purchasing process requires long processing time due to missing API connectors
- Information exchange (via Email or phone)
- Data exchange presents a low degree of automation and is usually spread across multiple interfaces.
- Exchange of information between employees as well as in the interaction with stakeholders is done verbally, via email or phone which can result in loss or scattered information across multiple systems.

4. Decision rationale, data and product traceability

- Traceability of product data and statuses both internally and externally is inconsistent and where is done is dispersed across multiple systems
- No clear and transparent information/data flow.
- There is no documentation or traceability of decisions/ rationale (because decisions are often made verbally and are therefore not digitally stored)
- There is no traceability of delivery status regarding products or components that are delivered by suppliers.
- There are go-no-go decisions between the shareholders traded verbally or via emails concerning the correctitude of information and data exchanged that are not captured in any of the systems.

5. Testing and development

- Problems during prototyping and production can result from the lack of testing tools (e.g. DFT,DFX), problems that can account for long stand-by periods of the production line, implicitly delays in satisfying the delivery date of the product/service.
- System interconnectivity, interfaces and data storage
- Digital continuity between Company X and its stakeholders is not established.

- Barbone/backbone and ERP are not interconnected thus product data is stored across multiple systems and none of them provide the singular source of truth.
- API connectors are missing for supplier and customer database access.
- ERP system is not used at its entire potential because its features are partially unknown or not well developed and integrated within Company X.

6. Working methodology

- Different working methodologies that are used by Company X employees for the same tasks result in confused customers.
- Experienced employees might fall ill or might leave the company and their work ethics are not captured in a meaningful way so that the next person can accommodate faster to the tasks and responsibilities of the job.

7. KPI Dashboard

- Not sharing KPIs risks alienating and frustrating the company's employees and other stakeholders who are unable to see the direction in which the organization is heading. At the moment the managerial strategy and vision is not fully visible to important stakeholders in Company X's ecosystem.

Based on a first look it is important to point out that Company X encounters most of the complications and challenges pointed out by Stark (2015).

The Company is using three main systems to manage and store data which leads into ineffective application interfaces that are unaligned. These are forcing the employees to work with different file formats as well as to execute manual file manipulation on different systems which translates in repetitive work. It is clear that the current systems, especially the ERP system is underused and employees are not aware of the full range of functionalities that the systems provide. Furthermore there are working methodologies that different from person to person, even though the persons occupy the same position. This points out that there are either missing clear definitions of work processes or another assumption is that the employees are not going through a well defined onboarding process.

Because the data is exchanged through different means of communication additionally to the existing systems, product data rationale is barely captured, while Company X is not able to create the product data as a singular source of truth. This results in incorrectly or unclearly defined products because of unclearly and incorrectly structured data.

2.2.3 External analysis – customer interviews

The external analysis encompasses four customer interviews. There can be multiple approaches to create quantitative and qualitative customer research, however, this research followed the narrative from the internal analysis. The method agreed upon during the customer research was again in the shape of interviews. Together with Fraunhofer IPT, it was agreed on clear guiding questions that helped different

company representatives to freely express their thoughts during discussion and provided the chance for researchers to react to the customer statements.

To comprehend all the procedures and have a full overview of the interview outcomes please consult Appendix 14 – Analysis phase. Due to confidential reasons, the names of companies interviewed are anonymously presented.

As represented in Figure 1 the interview integrated five main topics:

1. Cooperation
2. Service offer
3. Communication
4. Interfaces
5. Technological Roadmap

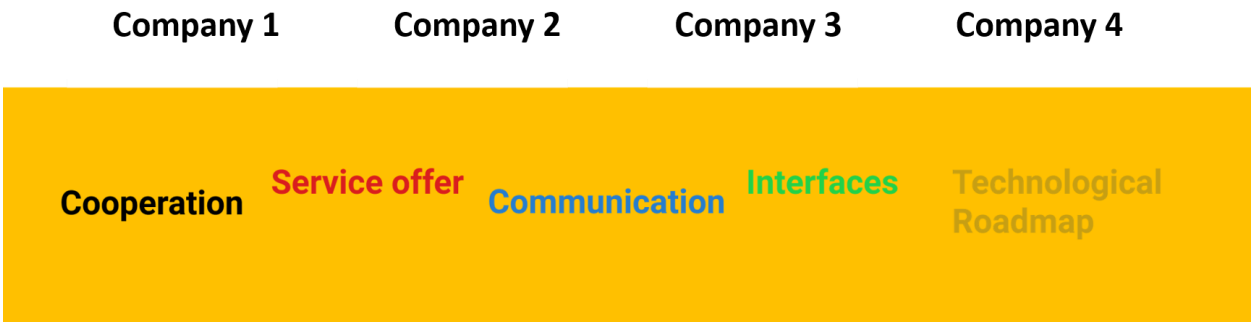


Figure 1 External analysis topics

The aim of these interviews was to assess the current state for each topic and determine the wants and needs as a potential future state. This procedure included the following two steps:

- The interview – one hour where each representative answered the open questions related to the proposed topics.
- Outcome data validation – the results of discussions were compressed into a report that was sent back to the company representatives to validate the findings prior to transmitting the information to the Company X management team.

Following the results of the analysis are summarized under the categories of discussion mentioned earlier.

Cooperation

Current state:

All clients mentioned that the cooperation between Company X and their company is based **on high quality, high flexibility in services. The communication and cooperation between the enterprises are well organized** and are focused on long-term collaboration. One of the customers mentioned that being

located in the same area offers the possibility for quick, on-site discussions while another customer mentioned that cooperation is defined as proactive from both sides.

Future state:

Almost all electronic manufacturing services (EMS) companies in the region provide the same level of services and products. This aspect was pointed out by two of the companies during the interviews**.** They continued by mentioning that the other collaborators who differentiate from the companies in the region also provide extended testing capabilities such as DFX, DFM, DFT, etc. A third company phrased its response in this direction. As a continuation of cooperation companies mentioned that transparency is key as well as establishing structured feedback for parts improvements. On top of that, direct and clear communication is desired at all points. One company specifically mentioned that the cost structure in the quotation process should be more transparent.

Service offer

Current state:

Most companies interviewed benefit from similar services. However, this is highly dependent on the product as well as on the type of prototype that companies request from Company X.

Future state:

During interviews it became clear that the focus and suggestions lay on developing further testing capabilities that are full range and customizable. One customer stretched out that repairing capabilities are of high importance in the future, a fact that also Company X intends to work on.

Customers would also desire that Company X would expand the assembly capabilities and other manufacturing services that they offer just because they would like to opt for the same supplier to execute most of the manufacturing operations, instead of accessing services from multiple suppliers. The customers trust the quality and collaboration with Company X, however they desire that Company X will expand its testing capabilities as well as the service offer. Early stage prototyping is inevitable in the product development cycle, thus customers mentioned that they see the need for Company X to step earlier in this stage in order to prevent at a later step errors and any other inconvenience that might appear while executing the prototyping. Two customers suggested that this aspect can be tackled by appointing block schematic meetings and establishing regular collaborations on technology development.

Communication

Current state:

Data provided to Company X in most of the cases is the same from all customers. In case of special requests from Company X, customers are also providing logistic data such as monthly forecasts, quality dashboards. Same applies when customers request data from Company X. Usually at the start of each project, the same information is exchanged between the two parties. The response time varies from product to product and the clients are overall satisfied with the timeframe allocated from Company X to form a quotation. During the internal interviews, employees mentioned that at the moment BOM

conversion process is time consuming and if this aspect is improved the customer response time can be diminished considerably, thus there is a change here to improve the customer satisfaction if an appropriate solution is found in this case.

Future state:

One client mentioned that as Company X is mainly supplying prototypes thus the traceability is not applicable in case of prototypes because it involves a lot of trial and error.

When it comes to communication, traceability, updates and notifications are some of the mentions that customers pointed out that might be a future solution in improving all the communication process. This can lead to less time spent on updating parties on different changes, it can provide to customers the assurance and the comfort of being able to see what is happening at every moment in time with the product. Another critical element is having an open BOM reflecting costs of individual components. This could help both sides in coming earlier on an agreement regarding quotation, moreover it can facilitate an easier transition between engineering BOM and manufacturing BOM with minimum of effort and errors.

Interfaces

Current state:

Momentarily all orders and data exchange are done via file transfer protocols or email.

Future state:

One customer mentioned that the interface for ordering is not desired because the customer already has a supplier portal from where Company X can exchange and access files. The same customer mentioned that when it comes to updates about product development a personal discussion is preferred. However, if the statement is analyzed it can be observed that in this particular case is just a one way solution that the customer is providing while for Company X the problem will still persist. The exchange of product data is possible by having the IT infrastructure integrated with one of the customers. On top of that, the other three companies mentioned that digitization and automation of data exchange is generally seen as good while the digital continuity between them and suppliers is one of their main goals. One important aspect mentioned by all customers as well as during the internal interviews is related to the personal contact between the aforementioned parties which is still desired no matter the degree of automation. Overall, the conclusion is that companies adopting a tool/platform that facilitates better traceability of data, updates, and data quality checks are more appreciated than the ones that are not.

Technological roadmap

Current state:

All four companies mentioned that currently the technological roadmap is not shared with Company X.

Future state:

All four companies are at least willing to frequently exchange information regarding which technologies are required in the future while three companies mentioned that they are willing to discuss the possibility of exchanging the technological roadmap that addresses the industry where Company X is active.
One of the companies mentioned that they are willing to share also Industry 4.0 vision to see the potential for further collaborations.

Outcomes external analysis – customer interviews

The findings regarding customer wishes in terms of product traceability, extended testing capabilities such as DFT,DFM, product data availability and accessibility, and project statuses and updates are confirmed and backed-up by the internal analysis where employees mentioned in their discussions similar remarks that they received from different customers.

As a summary of the external analysis the following mentions are standing out:

1. Digital continuity between Company X and its customers is a requirement from customers for future collaborations.
2. Data automation - There is a specific need in improving the level of automation in terms of data exchange and processing.
3. Companies with a centralized platform to conduct data exchange and trace each project are perceived as being more qualified.
4. Transparency and traceability - Customers desire full traceability regarding each project in each phase (quotation, preparing, production and delivery). There is no clear data transparency and product traceability.
5. Customers require notifications, status and updates at each product/process development step for better transparency.
6. Cost structure - The cost structure should be clear and concise and when there are changes, the customer should be notified.
7. Open BOM reflecting costs of individual components
8. Developing testing capabilities without engineering by the customer and developing technical capabilities such as DFT, DFM, DFL, DFC, etc.
9. Advising service for customers to conduct functional tests
10. Extending services capabilities such as assembly, wire-bonding and introducing repairing services.

IT architecture and software integration analysis

This section emerged from the internal interviews with stakeholders.

Figure 2 showcases the current state of the IT infrastructure that Company X is making use of.

As Figure 2 displays, when the customer gets in contact with Company X usually this happens through email or phone. The outcome of the conversation is represented by the preliminary product data and customer details. This data is usually sent via email and stored in the local server while the customer details are entered into an excel spreadsheet. The production employees which are represented by the purchasers, production leaders and planner are handling the data and creating a quotation for the customer. The quotation is stored in the server as well. The moment the customer issues a purchase order the product data information enters the ERP system. Until then the product data is still placed in the

server. As soon as the purchase order is confirmed, there is a parallel activity that integrates the creation of product workflow through production processes. This data is usually created in the server and during the execution of the production processes the data related to the product is introduced in barbone and backbone.

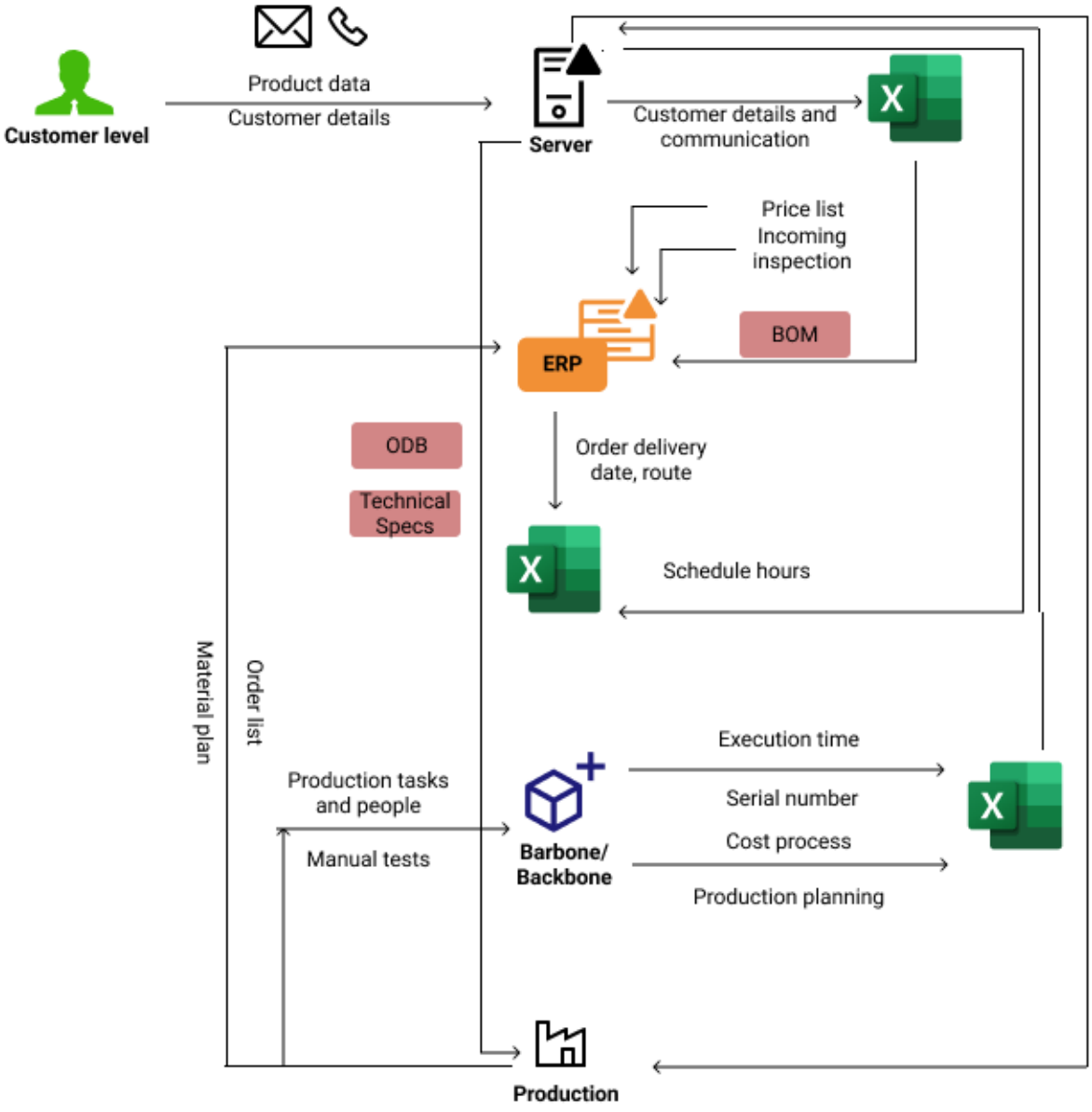


Figure 2 Current IT architecture

The software exploration was done with the aim of clearly understanding the IT infrastructure and how the systems are connected within Company X while the data flows offer an in-depth understanding on

how the existing infrastructure is used to manage the product data. Following, the next systems are currently used by Company X to capture and manage product data:

ERP system

The main use of this system is to streamline processes and to improve the decision-making process regarding finance and supply chain tasks. Currently it is used to manage and monitor all materials used for diverse products. The range of data captured in the system is not reaching out to manufacturing and project management related information. Now it is unknown what are the full capabilities and features of the system and if the systems can fulfill Company X's needs. It is desired to make use of its entire potential and include extended functionality that will allow the system to capture information that is essential. More importantly, exchanging data between the internal systems as well as external ones of the customers and suppliers is necessary for future developments.

Backbone and barbone

The two systems are internal project management systems used to help employees with the production tasks, and help leading staff to monitor the progress of different projects. The user can check quantities, syntaxes, tasks, people assigned to tasks, the status (unconcluded) and various production remarks made by production employees when a change, error or a faulty product (process) happens.

The main difference between the two systems is that Barbone is capable of generating barcodes that are useful for PCB traceability during production processes. Aside from that aspect, it is important to mention that the systems are having a high degree of functionality overlapping and are interconnected. Backbone has the capability to register more production steps than Barbone, however none of the two systems is capturing the full range of production processes and providing a full overview of the production processes, statuses, people and activities done.

Momentarily, Company X is looking into merging the two systems and creating the possibility to connect it to the ERP system. It is important to notice that Barbone has an integrated functionality that indicates that the connection to ERP systems is possible, however this function was never used or any connection between Barbone and ERP was never attempted.

Company X needs a further assessment of the IT infrastructure because it is noticed that at least one system is redundant while the others are either not used properly or at its full potential.

Data Server

The server in Company X is used to backup and store data. The server consists of drives that are mapped to the desktop units within Company X. However, often it happens that the data is transferred at first over the internet. When the network is down the Company X is still able to access the data. Company X is responsible for the maintenance of the server.

The main observation regarding this scheme is that the systems are not interconnected and information about the business environment, financial results, tracking of people, tasks, and machine data are dispersed across multiple interfaces. This was also pointed out by Stark (2015).

2.3 Conclusion

The internal and external analysis stand as the backbone of this research. The research started with the intention of bringing clarity over how people, processes, systems and data are interlinked. This aids Company X in further defining the level of automation that requires implementation as well as be able to plan for further investigation concerning the functionalities of a PLM platform.

There were a set of 15 stakeholders interviewed to determine the current state of data management and IT infrastructure.

Within the internal analysis, the main goal was to capture the perspectives of different key players on defining the product data. The result displays a map for each specific process within the product development process. By interviewing the account managers, purchasing and production planning employees it was possible to determine the points of improvement, and provide recommendations based on the stakeholders needs. Eventually this offers a great insight on the efficiency of using resources such as data, material and human ones.

The weaknesses and bottlenecks resulting from the internal analysis are shaped into nine main categories.

The intention of this categorization is to encompass the main perspectives on the challenges that Company X faces when it comes to PLM principles and the effectiveness of business procedures. To mention that each category contains a list of bottlenecks that are related to the category description or name. To consult the whole categorization please refer to the internal analysis subchapter. Additionally, Appendix 11 Data centralization compiles the information overview for each stakeholder. This entails the interaction between product data and stakeholders.

The internal analysis also touched upon the IT infrastructure that Company X possesses. One of the biggest challenges that Company X is facing is the lack of interconnected systems and data exchange between them. Data that contains information about finances, processes, tasks, people, suppliers and customers are dispersed across multiple interfaces that are not linked between them. Thus, it does not facilitate the singular sources of truth, which means that Company X has great challenges of understanding the full overview of the product data and being capable of learning from it.

Customer interviews come into play to exclude a biased perspective on the data mapping process. The external analysis encompasses four customer interviews that tackled five main topics of discussion.

The interviews were designed to capture the current and the future state of each topic of discussion. Thus, it is important to mention that according to the customers, Company X stands for high quality, reliability and trustworthy cooperation. For the future, Company X should increase the transparency and traceability of projects and products as well as extending their collaboration by extending their service offer. The internal stakeholders point out this element also during the interviews. Momentarily Company X offers a wide range of services, from prototyping to assembly of PCBs however, customers would desire extended capabilities in testing, repairing and assembling. When it comes to the exchange of data, the data provided or received by and for Company X is similar in most of the cases, with small exceptions when it comes to

logistic data such as monthly forecasts or quality dashboards. However, data and especially the rationale is usually communicated verbally, or via email, and the essence of the design rationale is not captured at its fullest. Traceability, updates and notifications are the main elements that Company X should improve according to the internal and external stakeholders. Another critical element is having open BOM reflecting costs of individual components. This could help both sides in coming earlier on an agreement regarding quotation; moreover, it can facilitate an easier transition between engineering BOM and manufacturing BOM with minimum of effort and errors.

Digital continuity through system interfaces and data automation are necessary when it comes to improving the collaboration with customers.

Further on the findings from the analysis are used in prioritization of the bottlenecks, assessing and benchmarking the technological trends in the market as well as defining the main functionalities of the PLM system.

Additionally the information maps resulted from the interviews bring opportunities at different levels:

- In educating employees, creating an employee culture revolving around knowledge creation and management. Working methodologies can be standardized by mapping out an optimal working guideline.
- At enterprise level, the information mapping brings clarity and standardized standpoints in relation with the other stakeholders within the end-to-end supply chain. It boosts efficiency at the operational management level, by clearly being able to define the KPIs based on the customer needs.
- Determines the tacit and explicit knowledge created at enterprise and production level.
- It brings a short exemplification on the knowledge of the employee and their working methodology.
- It provides an overview and an in-depth understanding of the bottlenecks that result from data management processes.
- Is highly important in recognizing and engaging key stakeholders who can have tremendous impact in adjusting and defining new business strategies as well as technology roadmaps according to their wishes and needs.
- It creates understanding of the main IT systems and how they are used to capture and manage data.

3 Theoretical Background

Within this chapter, the intention is to build new knowledge and understanding of the PLM and ERP technologies. Additionally the chapter provides an overview of the key variables that influence the PLM principles as well as an understanding of how Company X stands against these principles.

3.1 Product LifeCycle Management

Company X discovered on the way the benefits and the potential of PLM systems and now they want to continue investigating and developing their own PLM software, however it is never easy to adopt a new enterprise system that can imply a great disruption in internal and external processes. It is important to understand enterprise applications, the value that it brings for the enterprise as a whole and to each department involved in the product development phase. Software applications that work hand in hand like PLM and ERP might be the way to build an integrated, centralized environment for data management, while engineering, manufacturing and sales teams can have the full perspective of product data in one view. This might enlarge the competitive edge that Company X has by reaching more efficiency in product development.

To start creating an understanding of the PLM systems it is important to see how industry and experts in PLM domain are defining this technology and methodology:

- "A strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise from concept to end of life – integrating people, processes, business systems, and information." – CIMdata
- "PLM stands for Product Lifecycle Management, which is a blanket term for a group of software applications used by engineering, purchasing, marketing, manufacturing, R&D, and others that work on NPD&I" – AMR Research
- "A strategic business approach for the effective management and use of corporate intellectual capital" – National Institute of Science and Technology Fenves et al., (2003).
- Product Lifecycle Management (PLM) is an integrated, information-driven approach consisting of people, processes/practices, and technology, to all aspects of a product's life, from its design through manufacture, deployment and maintenance—culminating in the product's removal from service and final disposal. By trading product information for wasted time, energy, and material across the entire organization and into the supply chain, PLM drives the next generation of lean thinking. Grieves, M (2005)

Product lifecycle management systems are designed to manage the information and data within an enterprise. According to Grieves, M (2005) the major benefits that PLM brings to enterprises is that it improves efficiency of the design, manufacturing, support, repairing and eventually disposal processes of a product by creating a manageable digital twin in the shape of data. Parametric Technology Corporation (PTC)(PLM (Product Lifecycle Management), n.d.), a global technology company defines PLM software as a tool where multidisciplinary teams, dispersed across multiple locations can strategically collaborate with

partners and customers enabling up-to-date product data. Thus, a PLM system is implicitly designed to manage data throughout the product life cycle.

Such a system is essential during the R&D phase, where designers, engineers, and salespersons need access to product data, including requirements and specifications, engineering parameters and documentation. As the analysis conducted on Company X indicates, some of the main needs of the stakeholders are related to improving the designing and engineering processes by having employees of Company X involved in earlier stages of product development. Additionally manufacturing and support services are considered good, however as several customers mentioned in the interviews, the companies that stand out offer a wider range of services, including repairing. In order to facilitate an earlier engagement of Company X, there is a need to offer to the multidisciplinary teams a tool where product data is revisited and aggregated until it reaches the desired form and complexity.

According to the research (*PLM Software - The Complete Guide*. (n.d.)), a PLM strategy is applicable to any type of technology and it does not have limitations regarding the type of a product.

Stark (2013) claims that PLM can bring an increase in productivity, maximize product value and enable cost reduction in an organization. Additionally, it enhances a better decision making process between multidisciplinary departments when issuing out complex products and acts as a centralized system for all the resources Stark (2013). PLM applications can bring improvements to all stages of a product development cycle, including design and research, communications, while reducing risks and potential problems Maropoulos, P., & Ceglarek, D. (2010).

As also the analysis shows, a high number of errors comes from a scattered decision making process, where data is captured across multiple systems. Company X should aim at having a centralized data management system where all products can take the form of a digital twin.

3.1.1 Benefits and features of PLM systems

As a summary of the above mentioned resources, the main benefits of a PLM tool/system are as follows:

- It provides a place where all product data and information is centralized.
- The systems can provide a centralized record-keeping of all decisions and data changes conducted by departments and employees.
- Team members together with stakeholders are able to access real time data.
- The system can track and manage data, BOMs, product documentation, engineering changes and revisions, as well as compliance data. *PLM (Product Lifecycle Management)*. (n.d.).
- Provides a place to integrate the iterations of different designs.
- It can maximize efficiency of processes and reduce redundant steps and processes. *PLM Software - The Complete Guide*. (n.d.).

All these benefits can have a contribution to solving the problems that Company X faces when it comes to managing product data. By having a centralized data system, where the decision making process as well as the data changes are visible, Company X can analyze and make faster decisions than with the current IT architecture, concerning changes and the final shape of the product data. Additionally the PLM

system can reduce the workload of employees, manual manipulation of data as well as eliminate redundant steps and processes.

3.1.2 PLM characteristics

According to Grieves, M (2005), PLM approach is defined as an "information driven approach". This implies that physical products and their parts are created in a virtual environment that is governed by data and information. The intention of these virtual products is to mirror with accuracy their physical counterparts. Grieves, M. W., & Tanniru, M. (2008). In order to do so, Grieves defined six essential characteristics that underlay at the base of each PLM system:

1. **Singularity –** Also defined as the singular source of truth, it refers to the version of the product data that is agreed by everyone who is participating in the development process. It is highly important to monitor and track changes from one version to another version of product data, so that it increases the efficiency of different processes.
2. **Correspondence –** represents the connection between a physical product and the data that describes the product. This process is highly connected to the process of data extraction that implies the development of a methodology and technology able to concisely describe code or catalogue a physical product. Tomovic, M., & Wang, S. (2010)
3. **Cohesion –** Describes the capacity to match and align different perspectives (e.g. engineering, sales, and manufacturing), views and/or representations of product information. The main important aspect in this case is to be able to display the potential impact that one view may have on another.
4. **Traceability -** follow back the path of product information seamlessly back to its origin. By having a virtual model in a shape of data, which is described over time, engineers may be able to run tests and conduct analysis that may save time, energy and materials.
5. **Reflectiveness –** this characteristic gives the answer to the question "How fast does the PLM solution capture a change to the physical product?" This stage encompasses the product changes through its lifecycle, and the rapidity with which the virtual counterpart can capture those changes.
6. **Cued availability –** This characteristic describes the usefulness of the product data and information. It simply describes the capacity of the system to have the right information, at the right time, for the right people. Grieves, M (2005)

As the theory indicates, the singular source of truth should allow companies to track changes applied to a version of the product data and allow different perspectives to agree on it. This is an ideal phase where Company X wants to be. Currently, Company X is not able to provide a singular source of truth when it comes to defining product data. There is no system in Company X that facilitates the product data singularity. Additionally the current systems are not interlinked thus it is difficult to create the singular source of truth. The traceability of product information is partially executed within Company X. It does not provide a fluent flow of information that can be traced back to its origin.

In case the enterprises are not able to keep these characteristics intact, data can be compromised and most likely any ambition in adopting a PLM system will result in a failure. PLM can be effective only if the

data reflects the real product, and that the real product is continuously recorded in the core system Tomovic, M., & Wang, S. (2010). These elements are considered during the development of the PLM system.

3.2 ERP SYSTEM

According to the article written by Oracle (*What is ERP? Definition of Enterprise Resource Planning (ERP)*. (n.d.)), one of the leading computer technology corporations, an Enterprise Resource Planning (ERP) system is a software that its core usage is to direct companies towards more effective activities such as accounting, procurement, project management, risk management and compliance, and supply chain operations. Additional specifications of an EPR system can also contribute to the enhancement of human resource management, customer service and manufacturing. The software can help an enterprise to plan, budget, predict and report on the financial results Cimalore, C. (2012).

It is developed to support and boost the activity of diverse departments by automating and eventually improving processes such as order fulfilment, providing a single location for financial data, thus providing consistency for different processes and standardizing the information generated by various personnel.

It is questionable if an ERP can provide a single source of truth, considering that the purpose of an ERP system is mainly designated for manufacturing activities, excluding engineering Cimalore, C. (2012). Relevant information and data that drive the design process, information such as component specification, designs, inspection and tests notes, and supplier documentation are usually not captured in the ERP system. Another important aspect that an ERP is omitting is that it does not always provide the capacity to enable collaboration with external users to directly access product data and take part in the product development process.

Complex operations require not only manufacturing systems that deal with those operations, but it requires a coverage beyond manufacturing which also incorporates complex engineering data processing which is mainly addressed by PLM systems. That is why companies are looking into ways on how a system integration can boost and facilitate a more efficient block of operations.

Company X intends to expand their product portfolio as well as penetrate new markets, thus the intention to expand its technological and collaboration capabilities. The current ERP system might facilitate now the functionalities that fulfill most of the requirements regarding the execution of product development stages, however it does not capture the rationale and engineering data plus it does not give the handles for collaboration with external parties.

3.3 PLM vs ERP

Figure 3 puts in perspective the information that is presented in the above sections, and presents in a clear overview of the usage of PLM and ERP systems.

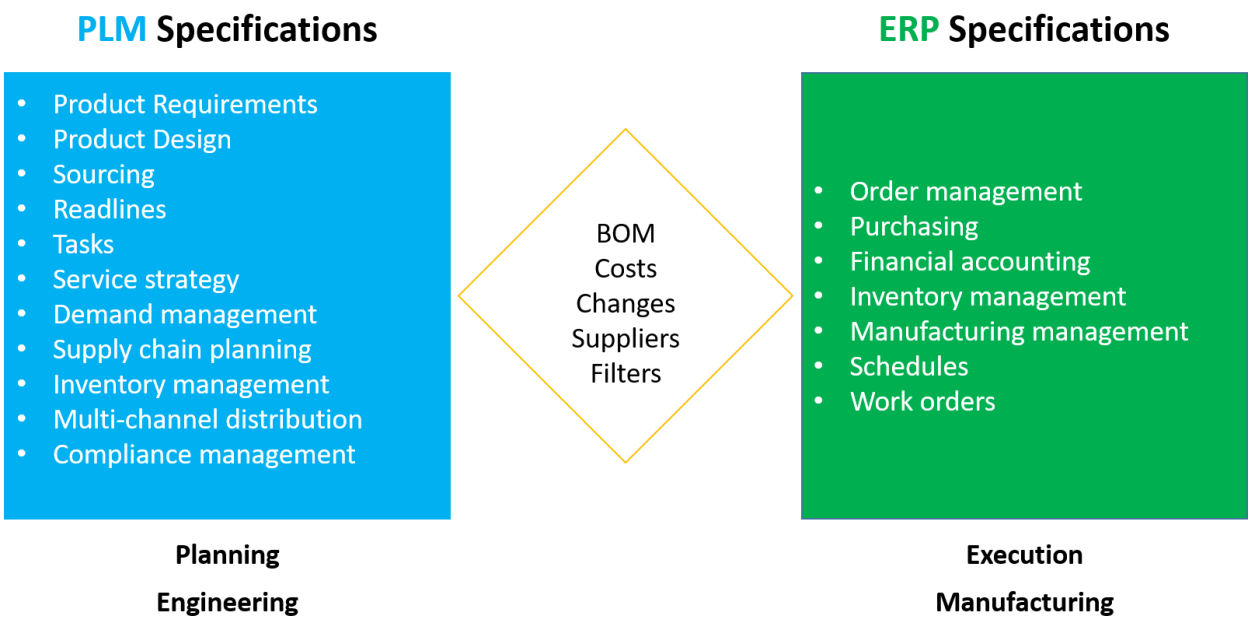


Figure 3 PLM vs ERP

To define the need for one or both of the systems it is important to understand the differences between PLM and ERP systems. After all, both PLM and ERP software are able to manage the Bill of Material (BOM) , cost changes, suppliers and files. A simple way to differentiate these systems is to look at the way they are used. PLM is a collaborative planning tool for product development that has as main users engineers, researchers and designers who need to collaborate on defining what the product looks like, how it functions, and what it is made of. ERP, on the other hand, is focusing on the manufacturing and the activities that lead to the execution of the product while the primary user is the personnel involved in manufacturing operations. PLM is about planning the activities and data around the product, it provides specifications and capabilities around managing product requirements and designs, related services, tracking and tracing all versions of the product design, defining the engineering BOM, it confers task management solutions and the list can continue. Moreover, since ERP is about execution and fulfilment, it focuses on capturing information around order management, providing the execution of the manufacturing BOM, purchasing, inventory, manufacturing management and others.

In short, looking at the benefits and capabilities of both systems, it is important to observe that both solutions are meaningful for a company to develop and make products. At the moment there are multiple systems in use such as ERP, two product management internal systems called backbone and barbone, and systems under the shape of spreadsheets and local server, used to manage product development phases

and implicitly product data. However, the present systems are not facilitating a full supply chain management where the biggest challenges might come from engineering changes.

According to a study conducted by Jackson et al. (2008) from Aberdeen Group, that 59% of the companies that responded in the research communicated that in their intention to define product data the starting point is the ERP and PLM integration. To go further, Aberdeen Group specifies that the "best in class" companies are starting with the ERP and PLM integration while the companies that are not as successful started with the integration of other systems such as Customer Relationship Management (CRM), Supply Chain Management (SCM).

Figure 4 places in perspective a quick overview on how ERP and PLM systems can work together. PLM can help Company X define, design and plan a product and it can be followed by an integration with the ERP, where the engineering team can feed the engineering BOM, so that it is transformed into a manufacturing BOM so that the manufacturing team can order, produce and deliver products.

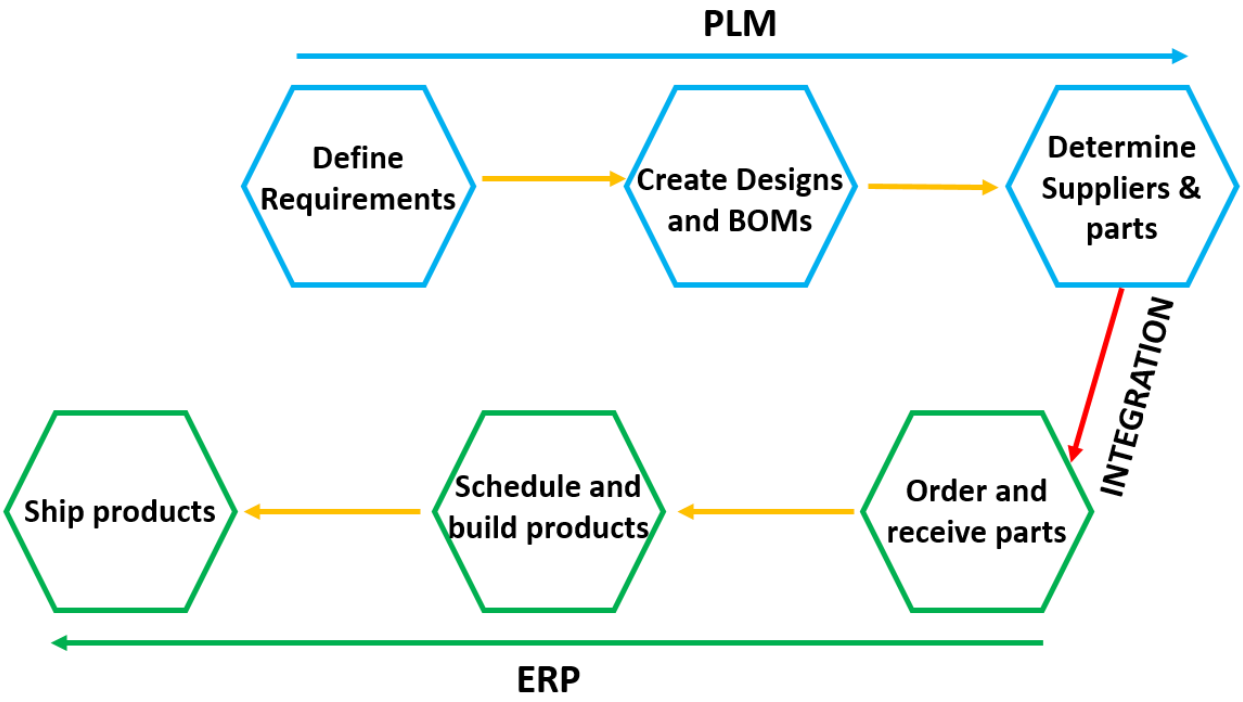


Figure 4 PLM interlinked with ERP

The end goals of this integration is the synchronization of information that is highly relevant for engineering and manufacturing teams. This can lead to less errors regarding data manipulation that results in data integrity across systems. It is assured the final result shapes accurately the product data.

Moreover, through the synchronization of ERP and PLM systems, Company X and the management team can generate business-relevant data, which incorporates the needs and the faults of stakeholders across the entire supply chain, therefore it give the opportunity to support better design and manufacturing processes.

3.4 CONCLUSION

The intention of this chapter is to bring better understanding on how PLM and ERP systems can complement each other in the context presented by Company X. Both ERP and PLM are already existing and are mature technologies, however small-medium enterprises are not fully familiar with them. Thus it was important to define the contribution of each system in defining the product data. With just an ERP system in place, Company X has a blind spot in defining the singular source of truth of product data. Having an additional system like PLM will allow the multidisciplinary teams that actively participate in the product development process to agree on the final form of product data. These two systems play a key role in enhancing product development and achieving bottom line operational benefits. The engineering and manufacturing performance can be enhanced by adopting a PLM system to work in conjunction with an ERP system. The result is the potential to bring products to market faster, deliver higher quality products and be able to avoid errors and task repetitions that can lead to higher competitive advantage Cimalore (2009)

The current state of Company X is disconnected from the PLM characteristics that indicates that the enterprise is just at the beginning of the journey regarding PLM adoption and implementation. The problem categories and statements identified during the analysis can be overcome by the PLM characteristics and its potential benefits, thus it is essential for Company X to consider a further integration of the PLM system within the current IT infrastructure. Of course, the system functionalities should be defined in order to accommodate a fitting solution.

4 Market research

4.1 Introduction

Company X realized the importance of the PLM system in the overall enterprise growth. Based on a preliminary study of the electronic market, the enterprise noticed that the complexity of the products is increasing thus this will bring challenges for manufacturing and engineering the products aimed at this market. In order to face those challenges, the company aligned its strategy towards the implementation and possible development of a PLM system. Additionally Company X is seizing a business opportunity in the electronics manufacturing market where the technology and the integration of various production systems are still at an early stage. Thus, by having prior knowledge about competitors and their needs, Company X suggested researching the possibility of generating a new business model that brings benefits to the market itself.

However this research is not focusing on creating and validating the business model due to time limitations, but the focus is on determining the PLM functionality that suits the market where Company X is active.

Throughout the various discussions with the management board, and based on the previous market knowledge that Company X pointed out that other electronic manufacturing service (EMS) companies in the region expressed the wish to innovate and further adopt a PLM system. This knowledge was built during several collaborations and strategy meetings with EMS companies in the region. Thus Company X would like to learn about the possibility of facilitating those services to EMS companies.

During the research ten main vendors in the PLM world were analyzed in order to determine the main functionalities that a PLM system can integrate as well as point out functionalities that differentiate the vendors from each other. Additionally this research addresses the needs that the PLM vendors are covering and it provides a list of limitations on the current systems. Additionally, the chapter integrates a preliminary list of requirements in terms of systems development as well as a SWOT analysis that provides an overview of the strengths, weaknesses, opportunities, and threats that Company X should take into account when developing the tool.

4.2 PLM challenges

Several research papers point out that PLM vendors still do not fulfill the needs of SMEs in terms of PLM implementation and adoption. Thus, it is essential to answer the following question:

Why is PLM complex for SME companies?

According to a research conducted by Koomen, B. (2018) some of the main motives when it comes to the adoption and implementation of PLM systems are as follows:

- High costs of implementation
- Lack of skilled resources

- Limited understanding of PLM
- Network dependencies
- Unstructured information flow
- PLM complexity Cimalore, C. (n.d.)

Also Shilovitsky, O. (2017), a PLM expert and the co-founder of OpenBOM software, points out that small and medium enterprises struggle with understanding what PLM is and the value that it brings to the overall business and processes. To continue the rationale, according to Oleg there are three main inhibitors that stand in front of a successful implementation of a PLM system for SMEs:

1. Limited financial resources
2. Lack of IT support
3. A diverse set of requirements

As indicated in the research conducted by Koomen, B. (2018), the complexity of the existing PLM platforms is really high while Shilovitsky, O. (2017) continues the same rationale by indicating that the complexity of the existing PLM systems results in high implementation costs. Silventoinen et al. (2009) pointed out that the main challenges in SMEs when it comes to PLM implementation are related to their limited financial and human resources. This train of thought is continued by Antonelli D et al. (2012) that point out the fact that SMEs adopted a more semi-informal organizational structure thus this conflicts with the scope of PLM of adopting standard methodologies. The research continues by saying that SMEs do not see the benefits of a PLM system because most of the solutions are designed for large companies, thus those do not fit the needs of SMEs Silventoinen et al. (2009).

Reflecting also on the internal analysis it is visible that Company X is on its journey to standardize their internal methodologies. The first step is to create awareness of the aspects that need standardization. Additionally, through the interviews with the management team, Company X. faces some of the problems and challenges pointed out in the research. The management team suggested that some of the main reasons why they consider developing an internal PLM system are because of the following reasons:

1. Implementation costs are high
2. Costs related to training the users are high
3. There is an extended learning curve
4. With the implementation of the existing ERP systems Company X noticed that there is an increased dependency on the ERP vendor services thus it assumes that the PLM systems will behave the same way.

Aside from these problems, during the interviews and discussions, it became clear that Company X lacks skilled human resources and knowledge about PLM. Usually, large companies have designated departments that work on innovations and strategies, while SMEs are focusing first on their core competencies and only after that are focusing on innovating internal and external operations and strategies. This is also the case of Company X, that assigns time for innovation, however not enough to produce fast and efficient changes.

The fact that existing PLM vendors are not fulfilling the needs of SMEs is an aspect though that still needs to be considered for further research. Now the study captures the capabilities of ten PLM vendors, however many more other solutions might fit Company X, thus it releases the pressure of taking the responsibility of developing a PLM system. This is highly depended also on the market needs.

The next part of the research gives a more in-depth analysis of the PLM vendors, the features of the PLM systems as well as several limitations that the systems have.

4.3 PLM platform analysis.

The analysis integrated general business elements and general functionalities and features that the existing PLM vendors are offering. A number of ten PLM vendors are included in this research. To consult the list of the PLM vendors and the analysis please refer to Appendix 2 Platform analysis. The aim of the research is to build an understanding of the prices that the vendors are having, the main target groups, as well as the main features that are common or differentiating the PLM vendors from each other.

1. **Price**: The traditional PLM vendors like Teamcenter, PTC Windchill, SAP, Oracle, or Arena PLM have the pricing model based on quotation; these usually also differentiate between them by having packages for small, medium, and large enterprises. Some other PLM vendors are more transparent in terms of pricing. Autodesk Vault % Fusion offers packages that vary from 500 euros to about 2000 euros over the period of three years. Odoo for instance has a pricing model based on the app that the users purchases. The user will pay for one app integrated into the PLM system. However it often happens that the app comes in a combo package. For instance the PLM app comes as a combo with the Inventory and manufacturing app which implies additional and increased costs.
2. **Target groups**: Eight out of ten vendors pointed out that their services are targeted to all three categories of companies: small, medium, and large. One company took the niche of small and medium while another pointed out that medium and large companies represent the target group.
3. **Deployment method**: Even though in the past it was only possible to have systems deployed on premise, nowadays the majority of the PLM vendors provide at least a cloud deployment solution while four of them are also providing on premise deployment. The cloud brings better scalability, and reduced costs due to lack of maintenance compared to on premise solutions (*The Rise of Cloud Computing Extends to PLM*. (2012)). Oleg from Open BOM points out that so far there were several innovations in the market such as transitioning from on premise deployment to cloud-based solutions, however those innovations did not consistently contribute to lowering the costs of implementation Shilovitskyy, O. (2014).
4. Key features: When it comes to the key features of the platform the following are the most common:
    - BOM management
    - Revisions and history of changes
    - Change management

- Quality management
- Manufacturing and process management
- Product data management
- Collaboration
- Governance and workflow management
- Requirements and test management
- Service process management
- Environment compliance
- Project and reporting management
- Analytics

The solutions are offering a wide range of features that aid their customers to collaborate on engineering and design processes as well as manufacturing, maintenance, and service across the entire supply chain. The PLM solutions integrate cloud deployment, build-in workflow management, and governance, BOM management as well as environmental compliance management. These kinds of platforms allow users to access reports on the performance of product development activities. Additionally, it allows users to access catalogs and get in contact with suppliers that facilitates an easier decision-making process when choosing the right supplier. Some other features are related to product and project management. Users can monitor in real-time the progress of a product, visualize the activities, statuses and get updates whenever a change is happening to the product or project.

While most of the vendors are offering the same range of services and features, some of them provide features that differentiate from the general ones. Some of the distinctive features are as follows:

- Document coding and control - several vendors are standing out by allowing users to edit files directly in the system and simultaneously with other users in the system.
- Data extraction - this feature is necessary when it comes to different file formats. For instance, OpenBOM offers data extraction from Excel files while Oracle Agile PLM does not support data extraction of different file formats. This feature is missing in most of the PLM solutions.
- Integrations of third parties – Some companies are supporting integration with certain vendors from ERP, CRM, etc. while others are able to integrate with most of the other solutions on the market.
- Microsoft integrations - The new adaptation of the Microsoft office package that can be accessed in the cloud systems, it can have great implications on increasing collaboration between different departments and stakeholders and collaborating in formatting files.
- Communication integration - email and phone - Just a part of the companies are offering the chance to customers to capture and search the information that is connected to the communication streams.
- Defect and complaint tracking - The systems are able to register defects of products, create complaints and track them to the moment they are solved.
- Product data shared outside the system - Just a part of the systems are allowing users to share product information outside the system through external links or other methods.

- Training management - Vendors like Odoo are offering training offline and online while Autodesk Fusion is offering basic training offline while the rest of the training is accessible on their internal platform. This aspect is of high importance due to the increased learning curve that users need to follow.
- Open-source - PLM vendors that entered the market at a later stage provided also open-source solutions that facilitate free access to the main functionality of the platform. This model is usually easier to implement due to its lower complexity. Thus, it tends to be adopted by a high number of users.
- Inventory management system – the inventory management system and the ability of the system to connect to the database of the suppliers is a differentiating factor in picking up a PLM vendor.

4.4 Limitations

The companies offer a high range of functionalities that increase the complexity of the systems. Due to the extensive functionalities, SMEs might be intimidated by adopting such systems because there are functionalities that are redundant and the customer needs to pay for them. The reviews from three main websites specialized in software analysis show that the existing systems require a high degree of customization to accommodate a company process. Thus it results in a lengthy and complicated process. G2. (n.d.), Trustradius. (n.d.), Comparecamp (n.d.).

One issue pointed out by the customers in the reviews is that the vendor's interface and the user experience are not intuitive which increases the complexity of implementation and adaptation to the new system. The user interfaces are usually robust, old-fashioned, and provide an increased amount of functionalities without guaranteeing that the user knows what it means and how to use it.

Additionally the main limitations are related to the training of the employees as well as filters and search capabilities. The learning curve for users is high, thus it requires extensive training and costs that relate to the training. The main problems in the review section are related to the lack of support and assistance in accommodating the users with the PLM systems. Just small parts of the vendors are offering in-depth training and constant support, while some vendors are offering just online training through their training programs and platforms. Filters and search options are limited in some cases and are not offering precise results.

4.5 Software Benefits and Requirements

4.5.1 Benefits

Based on the vendor analysis as well as based on the findings in the internal and external analysis it is obvious that Company X can benefit from adopting or creating a PLM system. It is normal that SMEs can be skeptical when it comes to the adoption of new IT systems that will disrupt the services. The benefits

are not always clear and visible and not easily transferred to monetary benefits Silventoinen et al. (2009). Some of the main benefits for Company X can be as follows:

- Automation of file formatting
- Reduce the product development time by increasing automation at the BOM level
- Reduce repetitive work
- Standardization of processes in manufacturing, service, maintenance, and support
- Standardization in data management
- Faster time of product development thus faster product to market
- Reduce costs with repetitive work and focus on improving internal and external processes.
- Filters and search options - Companies that stand out are Odoo, Aras and propel. They offer a customizable filter tool that can be adapted based on the window that the user is in. Due to links between product data, the search option in these platforms is really exact and easy to use.
- It boosts productivity
- Allows the business to scale up

Additionally it is essential to point out that developing an internal PLM system can be still feasible considering that a great amount of SMEs are still afraid of disruption or are accommodating with the idea of adopting a PLM system.

4.5.2 Requirements

The system that Company X intends to develop should consist of the core features that the actual vendors are offering, such as BOM management, change management, quality management, planning of workflows, product data management, etc. Additionally, below several requirements are defined, requirements that aid the process in defining the functionality of the proposed solution:

- User friendly - the interface should be easy to use and intuitive to navigate. This will offer a competitive advantage over the existing systems.
- API and systems integrations - the interface should be able to integrate easily with the existing ERP systems and allow easy integrations of other systems and tools.
- Data coding and data extraction - the system should be able to allow users to edit and modify files directly in the platform. Additionally, the system should be able to recognize different file formats and translate the file formats in the desired format.
- System configuration - the system should be easy to configure to meet the needs of the market.
- Speed of implementation - the systems should be able to offer faster installation and implementation processes than the existing ones. This should offer easy integration with other systems and incorporate processes and data.
- Customizable filters and search options - the systems should be able to offer a customizable filtering tool that allows users to set filters based on the screen they are active in. The search tool should be fast and concise.
- Integrated training – The system should be able to host a knowledge transfer platform that allows users to capture, share and discover PLM related knowledge.

The requirement list will serve the research in the later stage when the solution is designed, tested and evaluated.

4.6 SWOT analysis

As it derives from the abbreviation "SWOT", this business technique defines a compilation of internal and external strengths, weaknesses, opportunities and threats that define and evaluate a company's competitive advantage Kenton, W., & Scott, G. (2021). According to Schooley, S. (2019) the primary goal of a SWOT analysis is to guide companies in creating awareness of different business factors when intending to proceed to new initiatives.

The SWOT analysis provides an overview of the strengths, weaknesses, opportunities, and threats that Company X should take into account when developing the tool. This analysis is important to determine the

Following the SWOT analysis is applied on the findings from the internal, external and market analysis. Additionally Appendix 2 Platform analysis consists of the PLM vendors and competitor analysis. The analysis intended to capture the essence of technological strategies and capabilities of the competitors, however little information is found about that. Thus, the analysis provides a short overview of the business capabilities and website functionalities of competitors that can offer to Company X an initial understanding of the market needs and trends while the PLM platform analysis offers more an understanding of the main features and possibilities in optimizing PLM software infrastructure.

The result is the compilation of the most important strengths, weaknesses, opportunities and threats as it follows below:

Strengths

1. Manufacturing capability for complex PCBs
2. Flexibility in production
3. Reliable and focus on long term- partnerships
4. High quality orientation
5. Good cooperation
6. Qualified employees for manufacturing purposes

Weaknesses

1. Internal analysis
    - No knowledge in software development
    - Inconsistent statuses and updates about product information at different stages. Notification, Customer & Supplier Communication
    - Manual file manipulation & repetitive work
    - File format
    - Information exchange (via Email or phone)
    - Decision rationale, data and product traceability

- Testing and development
- System interconnectivity, interfaces and data storage
- Working methodology
- KPI Dashboard

2. External analysis
    - Digital continuity between Company X and stakeholders
    - Data automation
    - Transparency and traceability
    - Product notifications, status and updates
    - Clear cost structure
    - Open BOM reflecting costs
    - Developing testing capabilities
    - Advising service
    - Extending services capabilities
3. Market analysis
    - Low branding visibility
    - Low marketing promotion
    - Low technology adoption compared to the some of the main competitors
    - Company X is biased regarding the competitive advantage in the market.

Opportunities

1. Real time data
2. Platform as a new media to attract customers
3. Website that allows a better and more reliable marketing engagement
4. Digital continuity between Company X and its stakeholders
5. Consistent, trustworthy and standardized storage data
6. Capturing and optimizing decision making process (go-no-go decisions)
7. Data availability and accessibility
8. Fast responsiveness to changes occurring at the enterprise and market level.
9. Enlarging the business scope by providing new services such as repairing and testing
10. Predict the supply capabilities based on customer demands by having a clear overview of the offer-supply capacity.
11. Improving communication and planning between internal and external parties
12. Build knowledge upon the external collaborations and internal processes.
13. Increase brand visibility
14. Create a PLM software that is tailored to the needs of the electronic manufacturing market.
15. Create a business plan for the electronic manufacturing companies
16. Decrease PLM functionalities and focus only on the necessary ones

Threads

1. A wide range of PLM vendors on the market
2. High demand for product traceability due to trend for repair services.
3. Regional, national and international competition.
4. Increasing customer requirements for real time production information.
5. New knowledge and skills for digital transformation, which can disrupt the company culture.

The SWOT overview is used as a reference for the prioritization of the bottlenecks that were found in the research. Identification of SWOT serves this research for later steps in achieving the objective of designing a PLM system that suits both internal and external needs. Next step in line is represented by the prioritization of the pain points.

4.7 Conclusion

PLM vendors that intend to address the needs of small to medium enterprises still are in the process of puzzling out a fitting solution.

The existing solutions might offer the functionalities that a small to medium company needs, however the elements that prohibit the adoption of such solutions are related to high implementation costs, the high price tag of systems as well as increased complexity. Companies are seen as having an overall stiffness regarding scaling down the functionality to fit the unique needs of an SME. Due to the high costs of PLM vendors and the dependency that is created the moment the systems are integrated into the IT Infrastructure, Company X intends to continue further with the research and development of the internal systems that offer the functionality that fits their needs. The SWOT analysis gives now an understanding and aggregation of the market strengths, opportunities, weaknesses and threads. This reinforces the current position that Company X has in the spectrum of PLM which is that of an early adopter of PLM knowledge that tries to understand the full potential that PLM can bring to the enterprise.

5 Bottlenecks Prioritization

The outcome of the previous stages that is defined by the internal, external analysis as well as the platform analysis is a list of problems and observations that each one of them has a certain degree of importance and influence in the current process. The factors are an emerging part of the first analysis stage, and it resembles the points of attention that need to be addressed.

The stakeholders involved in the actual collaboration have to decide what the most critical interference in the ecosystem is. This process encompasses the prioritization method. Prioritization is important in any project development stage where critical decisions need to be taken. The prioritization was verified with the management team.

5.1 Prioritization methodology

Table 1 incorporates the prioritized problems that resulted from the internal, external stakeholder analysis and market analysis. All problems are categorized under a general problem definition that is highlighted with the green color. Moreover, the problems that fall under each category are differentiated as follows:

- Green highlight – Represents the category of the problem definition
- No highlight – Represents all problems resulting from the internal stakeholder analysis.
- Yellow highlight – Represents all problems resulting from the external stakeholder analysis.
- Blue highlight – Represents all problems resulting from the market analysis.

As the aim of the study indicates, the following are the initial objectives of the study:

- Designing and conceptualizing of a digital logistic platform/architecture that can monitor and manage the product data and production steps in real-time
- Optimizing the stakeholders' responsiveness
- Structuring and managing information and data regarding the communication, collaboration and product development between businesses
- Give the customers insight into Company X's capabilities and give the companies some handles to build knowledge upon their product development process
- Collaboration between parties involved in defining the product data

The objectives guide the bottlenecks prioritization rationale. Additionally the for each bottleneck the following questions are answered:

1. What is the priority to solve this?

The table includes the level of prioritization in the left column, while the prioritization is established based on the following methodology:

- **Level 1** indicates the highest priority where the researcher will consciously and explicitly address the topic and suggest solutions. Usually Level 1 includes topics that are falling directly under the objectives of the project, thus are directly connected to the PLM system.
- **Level 2** indicates medium priority. That means that suggestions regarding those topics are desired and the researcher will try to address them. It happens that some of the Level 2 topics are not directly connected to the PLM or automation, but it is believed that their improvement, as a side effect, could highly influence first level topics. This section incorporates also relevant problems that arose at business level and have an influence on the PLM characteristics.
- **Level 3** topics are low priority topics. This means that the topics falling under this category are not addressed, unless there is an opportunity to do so through the development of a solution for a first or second level topic. That does not indicate that level 3 topics could not be as equally important as level 1 or 2 topics. However, their level could indicate that they are either deemed out of scope, or their current state is already adequate.

2. How urgent is it?

- Urgent – has a big impact on the overall data management and automation.
- Partially urgent – has a moderate impact on the overall data management and automation
- Not urgent – this topic does not require urgency.

Appendix 13 bottleneck prioritization includes the full rationale of the problem prioritization process. The main and most important problems that fall under level 1 priority are prioritized according to the methodology earlier explained. The rationale behind the prioritization is placed in the column called "rationale".

Table 1 Bottlenecks Prioritization

Po.	No.	Problem definition	Rationale
	1	Inconsistent Status & updates about product information at different stages. Minimum of notifications Customer & Supplier Communication	
1	a	Employees request a notification system regarding statuses, updates or any other changes to the product data, respective to the project. Not having a clear notification system in place leads to slow operational response and awareness.	Partially urgent. This aspect is important because it addresses the speed of operational response in product data. By addressing this element Company X as well as the stakeholders can

			benefit from a clearer collaboration.
1	b	No real time control of production processes, no notification if there are any updates on the product/process.	Partially urgent. This aspect is highly important for stakeholders and customers because it often provides traceability and transparency which is highly desired by them.
1	c	Customers require notifications, status and updates at each product/process development step for better transparency.	Partially urgent. This aspect is highly important for stakeholders and customers because it often provides traceability and transparency which is highly desired by them
1	d	The cost structure sometimes is not clear and concise and when there are changes, it happens that customers are not notified about those changes.	Urgent. The cost structure is highly important because the customers are becoming frustrating if extra costs are added without being notified.
	2	Manual file manipulation & repetitive work	
1	a	High set-up time and indirect hours because of repetitive work that encompasses manipulation of typically offline (transition offline to online) files by different employees.	Urgent This results in high costs for the company. It is because of poor data management.
1	b	The purchasing time is increasingly high because of the highly increase manual search that needs to be done while purchasing components	Urgent Currently the supplier database connection is missing which results in increased manual search for components.

1	c	Important changes in the physical products or parts are captured on paper that can result in lag of the virtual counterpart product, additionally in extra human effort, energy, materials and incorrect information.	Urgent. The process should be as much as possible paperless and capture information in one system
	3	File format	
1	b	Suppliers and customers are providing different file formats that implies for employees a high intensive file formatting work that can lead to loss of information, incorrect data processing, and long duration processes.	Urgent This has an influence on the outcome of product data and now is one of the main pain points that exist in the Company ecosystem.
1	c	The EBOM to MBOM file conversion is a tedious process that takes a lot of time due to different file formats that Company X receives from different customers.	Urgent This has an influence on the outcome of product data and now is one of the main pain points that exist in the Company ecosystem. Long conversion process.
1	d	File computation and editing is missing from a wide range of PLM vendors	Urgent This aspect directly impacts the performance of product data thus it is highly relevant
	4	*Information exchange (via Email or phone)*	
1	a	Data exchange presents a low degree of automation and is usually spread across multiple interfaces.	Urgent This will prevent the manual manipulation of data thus will lead to less errors. Systems are not interconnected at the moment.
1	b	The exchange of information between internal employees and stakeholders is done verbally, via email or phone which can result in loss of information while the decision making process is not captured at its essence.	Not urgent

			This aspect is not urgent but it influences how product data is defined.
1	c	**Data automation** - There is a specific need in improving the level of automation in terms of data exchange and processing.	Urgent This will prevent the manual manipulation of data thus will lead to less errors.
	5	***Decision rationale, data and product traceability***	
1	a	Traceability of product data and statuses both internally and externally is inconsistent and where is done is dispersed across multiple systems	Urgent At the moment the statuses of product data are not displayed in any platform and are not coherent
1	b	No clear and transparent information/data flow internally	Urgent Employees would
1	c	There is no documentation or traceability of decisions/ rationale (because decisions are often made verbally and are therefore not digitally stored) There is no traceability of delivery status regarding products or components that are delivered by suppliers.	Urgent This might lead to production delays thus it is essential to tackle it.
1	d	Customers desire full traceability regarding each project in each phase (quotation, preparing, production and delivery). There is no clear data transparency and product traceability.	Urgent Project traceability aside from product and component traceability is a requirement often mentioned by customers.
1	e	Customer platform and product traceability is used by the most competitive companies, while Company X lacks these features	Urgent Company X should keep their customers involved and offer them tools that facilitate an easy communication
	6	Testing and development	

1	a	Due to lack of testing tools and capabilities there are problems that arise during prototyping and production (e.g. DFT,DFX), problems that can account for long stand-by periods of the production line, implicitly delays in satisfying the delivery date of the product/service.	Urgent Company X and customers need early engagement of both parties in the early stage of product development.
	7	*System interconnectivity, interfaces and data storage*	
1	b	Barbone/backbone and ERP are not connected thus product data is stored across multiple systems and none of them provide the singular source of truth.	Urgent This is addressed because it directly influences the outcome of product data.
1	c	API connectors are missing for supplier and customer data base access.	Urgent This also influences the outcome of product data. Aside from that it can bring more accuracy in terms of BOM conversion and component data.
1	d	Component purchasing process requires long processing time due to missing API connectors	Urgent This also influences the outcome of product data. Aside from that it can bring more accuracy in terms of BOM conversion and component data.
1	f	Companies with a centralized platform to conduct data exchange and trace each project are perceived as being more qualified.	Partially urgent Build customer trust by showing initiative in improving collaboration
1	g	Missing open BOM reflecting costs of individual components	Urgent Missing Open BOM structure results in biggest bottlenecks in the existing process

5.2 Conclusion

In order to address the features of the PLM platform it is highly important to understand the main bottlenecks that stand in front of Company X.

The PLM interface needs to be built around the needs of the main users which are the employees and customers. In this case the prioritization offers an overview of the most important needs of the target groups and the rationale to first tackle level 1 bottlenecks.

This categorization relates also to the research questions by addressing the main needs of the target groups, thus it provides a clearer direction towards the functionality that the PLM interface needs to foster in order to achieve digital continuity across Company X supply chain. In order to address the root problems that are highly related to product data management, communication and system integration it is important to link these problem categories to the requirement functionality of the platform. Thus the following chapter elaborates further on the requirements definition.

5.3 Requirements specifications

The actual problem definition and prioritization gives the incentives to clear out the new current state of Company X regarding data management and PLM maturity.

The current status presents and extended list of bottlenecks that refer to the following categories:

- File formatting
- Manual file manipulation
- Repetitive work
- System interconnectivity
- Ebom to Mbom transition
- Testing and development implications
- Communication and collaboration issues

All the above mentioned issues have an impact on the product data and how at the end of the cycle this is defined.

As in case of any other software, it is smart to consider a methodical approach in the creation and implementation of a PLM system. For the next phase it is important to reframe the goals and objectives that this project entails according to the findings from the analysis phase.

The main goal of this project is to provide a proof of concept that displays how to capture and manage data according to PLM principles. Thus, the solution should provide a clear understanding on how stakeholders can collaborate and contribute to the achievement of product data singularity. This represents the desired status in Company X. Additionally the intention is to reduce the number of systems and have an interconnected IT architecture that allows data to be transferred from one system to another.

The following areas are identified as the main focus points and goals for this project:

- Build a PLM system around customers and employees at
- Optimization of the decision making process at Company X.
- Identify areas where automation can increase efficiency, reduce errors and manual manipulation of data.
- Reduce repetitive work by increasing automation of file formatting.
- Provide an open BOM structure that facilitates collaboration and transparency in costs.
- Predict the supply capabilities based on customer demands by a clear overview of the supplier's material.
- Provide means of collaboration that allow employees from Company X to interfere in earlier product development stages.
- Identify the product data that is required to be digitally converted.
- Convey solutions that reduces the product development cycle
- Removing or reducing spreadsheets and siloed information from internal and external processes.
- Convey a quality dashboard that gives insights into processes, products and people.
- System interconnectivity and centralization of data.

The focus of the proposed system is to foster at its best the PLM characteristics so that the digital version of a product can be captured integrally into the system. Moreover, a second objective is to showcase how manipulation of hard copies can be drastically reduced by cross-connecting platforms. The open BOM version is one of the most time-consuming tasks and the one labeled with high priority by all stakeholders, therefore a special attention is addressed to this aspect during the development process. Workflow management is another important aspect that needs special attention given that an important amount of product data is generated during the definition of workflow stages. System integration is essential in this context. The solution should provide understanding on how the systems can integrate and facilitate centralized product data. Additionally, the stakeholder communication and decision making process is another important step that needs to be addressed in the desired state.

Eventually the solution should be designed to work as a central hub for all product data within Company X and its supply chain.

5.3.1 Functional requirements

According to Miedema, J. et al. (2007) product development integrates the activities that translate the customer or the marketplace needs into a product that satisfies those needs. Here, the aspect of requirements specification is defined in terms of software constraints, demands and wishes. Throughout this research the requirements specifications serve as a benchmarking tool for the entire development process to support all the required decisions.

Based upon the initial analysis the key findings are synthesized in a list of functional requirements that correspond with the stakeholders wishes and that combat the bottlenecks of the current situation. This stage reflects the transition from the current state to the desired state.

Purchasing process:

- The platform should allow the purchasers to make decisions based on insights about relevant information retrieved from supplier databases.
- The system should be able to provide tracking and scheduling capabilities, which enable the company to manage product development along with resource allocation in real time.

Traceability

- The PLM system should allow for backtracking the decision making process by employees who have the authority to perform the check.
- PLM systems should allow tracking and tracing of the decision making process and document all decisions emerging during the development process.
- The system should be able to provide an overview of the current status of the order, which is updated in real-time and can be viewed by all stakeholders.
- The PLM solution should be able to track and trace quality checks
- The PLM solution should be able to allow tracking and tracing of employee activities.
- The solution should be able to manage changes to product configurations while maintaining the functional and physical attributes of a product throughout its lifecycle (digital twin).
- The system should be able to notify and update the authorized users when a change is made
- The PLM solution should provide a clear overview on the product data version history and a clear guideline on which product data version the latest edit was performed.

Collaboration

- The PLM software should be able to align different perspectives of product information (e.g. the financial, engineering, manufacturing, etc.)
- The PLM solution should be able to manage, visualize and share up-to-date BOM information across the organization in real time.
- The system should be able to provide means for validation of product data.
- The system should be able to provide means for planning and validation of manufacturing processes.
- The system should allow collaboration of stakeholders with the aim of defining the product data

Usability

- The PLM solution should facilitate an easy to use, straightforward interface. Buttons and icons should be self-explanatory.
- The platform should allow the users to maintain task relevant data within the sight while the users navigate through the interface.
- The platform should allow the users to undo or redo previous activities
- The system should be intuitive and leave space for establishing the best practices in handling data.
- The PLM solution should be able to provide the possibility to compare business statistics within a specific timeframe
- The solution should be able to allow users to set access levels to sensitive library information items based on specific roles or group hierarchy.

KPI Dashboard

- The PLM solution should be able to aggregate the **customer** overview, performance, satisfaction
- The PLM solution should be able to aggregate **suppliers** overview, quality, performance, satisfaction
- The PLM solution should be able to store, analyze and arrange the product data in an understandable manner.
- The system should be able to identify risks within the project portfolio
- The platform should compile and aggregate all the findings from customer feedback and complaints into a clear dashboard
- The platform should automatically define the KPIs and shape them into form of analyzed data, and dashboard.
- The platform should allow Company X to extract the quality dashboard.
- The PLM system should be able to perform analytics and provide low and high level KPIs for all stakeholders

Customer and supplier analysis

- The platform should integrate a customer satisfaction questionnaire that can be easily accessible for companies.
- The platform should be able to store and analyze the customer complaints
- The platform should be able to automatically store and analyze the supplier complaints
- The platform should be able to allow rating the suppliers based on delivery time,

File format

- The system should be able to comply with file formats used within Company X
- The system should be able to comply with file formats used by customers and suppliers.
- The system should be able to extract data from different file formats and compile it in the desired format.
- The system should allow users to edit and program file formats within the system
- The system should be able to transcript file formats into the desired format.
- The system should be able to read different file formats.
- The PLM system should allow users to edit, view files based on their administration rights
- The PLM system should allow users to standardize formats.
- The system should be able to fill in forms automatically with preliminary information.

System interface and integration

- The PLM solution should be able to offer cross-functional collaboration between stakeholders.
- The PLM solution should be able to provide open BOM reflecting costs of individual components.
- The PLM solution should be able to notify users about any changes in the solution system
- The PLM solution should be able to integrate with the ERP system and allow direct and automated sharing of engineering and manufacturing information

- The PLM solution should be able to integrate part of the functionality of Barbone/backbone internal systems (workflow stage, hour registration, task registration)
- The solution should give the flexibility to integrate different CAD systems and communication systems (emails, calls)
- The system should be able to capture the decision rationale
- The system should convey supplier connectivity through API connectors that provide information for quotation, procurement. Using API, it can access stocking information, price breaks, lead times, minimum order quantities and much more information. It will automatically give information about the price, stock and the delivery date, plus information related to the quality of the products and suppliers.
- The system should integrate the internal inventory management system
- The system should integrate external inventory management system
- The solution should work on all operating systems
- The systems should be able to provide an open source framework.
- The system should capture data that is in relation to other entries
- The PLM solution should be able to function in browser, desktop, tablet or app interface.
- The system should be able to allow API integration for data sharing.

Training

- The system should integrate a knowledge transfer platform

6 Solution/Design principle

6.1 Concept description

Currently, the enterprise resource planning system, the local servers, and Barbone/backbone serve Company X in managing product data. These systems represent the central point where data is sourced. This role is changing with the introduction of the PLM cloud-based solution. The PLM aims at being the overarching enterprise application that serves Company X to tackle the current challenges in capturing the product data into one system.

The solution that is proposed incorporates an IT architecture consisting of a PLM system and the existing ERP systems. The major change proposed to the existing IT infrastructure is the replacement of Barbone and Backbone internal systems with integrated applications within the proposed PLM solution.

Company X is able to facilitate a collaborative environment for the entire product life cycle development. Thus the proof of concept shows how internal and external users are able to collaborate, define and agree upon the final form of the product data.

The PLM system together with the ERP system, are capturing data in a cloud-based hosting environment. The suggestion is to transition to a cloud hosting service because of the scalability potential, as well as the lack of hardware maintenance. Thus the cloud exists to store and capture data generated by the collaboration between different stakeholders. The cloud will also capture the information and decision-making process that results from email and phone calls, by having an interlinked system with the communication one. To understand more the benefits of a cloud solution please refer to Appendix 4 Back-end technical solutions.

The PLM acts as the master system that integrates data, processes, activities, business analytics as well as project management-related data. In the case of duplicate information in both systems, the PLM is considered the dominant system that will facilitate centralization of product data. The system proposes a scalable design where a centralized platform hosts multiple applications that have different roles. The following are the main applications of the systems

1. Project management
2. PLM platform
3. Management Dashboard

Project Management and the dashboard functionalities are further explained and displayed in the external Appendixes 18 and 19.

The focus of this proof of concept is on the PLM application thus the following section will go into detail on the backend solution, and the general interface to give an overview of what functionalities consist of. Lastly it goes in-depth explaining the PLM application and its functionalities based on contextualized scenarios.

6.2 Back end

Figure 5 displays the holistic back-end and IT infrastructure solution that consists of two main systems and a cloud server connection. The PLM and the ERP system are the main systems that are interconnected and permit the users to exchange data. However, the PLM system is expected to be the master system that captures the singular source of truth while the ERP system is an adjacent software that contributes to the singular source of truth while capturing manufacturing data. It can happen that the duplicate information is on both systems, however, the PLM system and the data captured within the system is the dominant one.

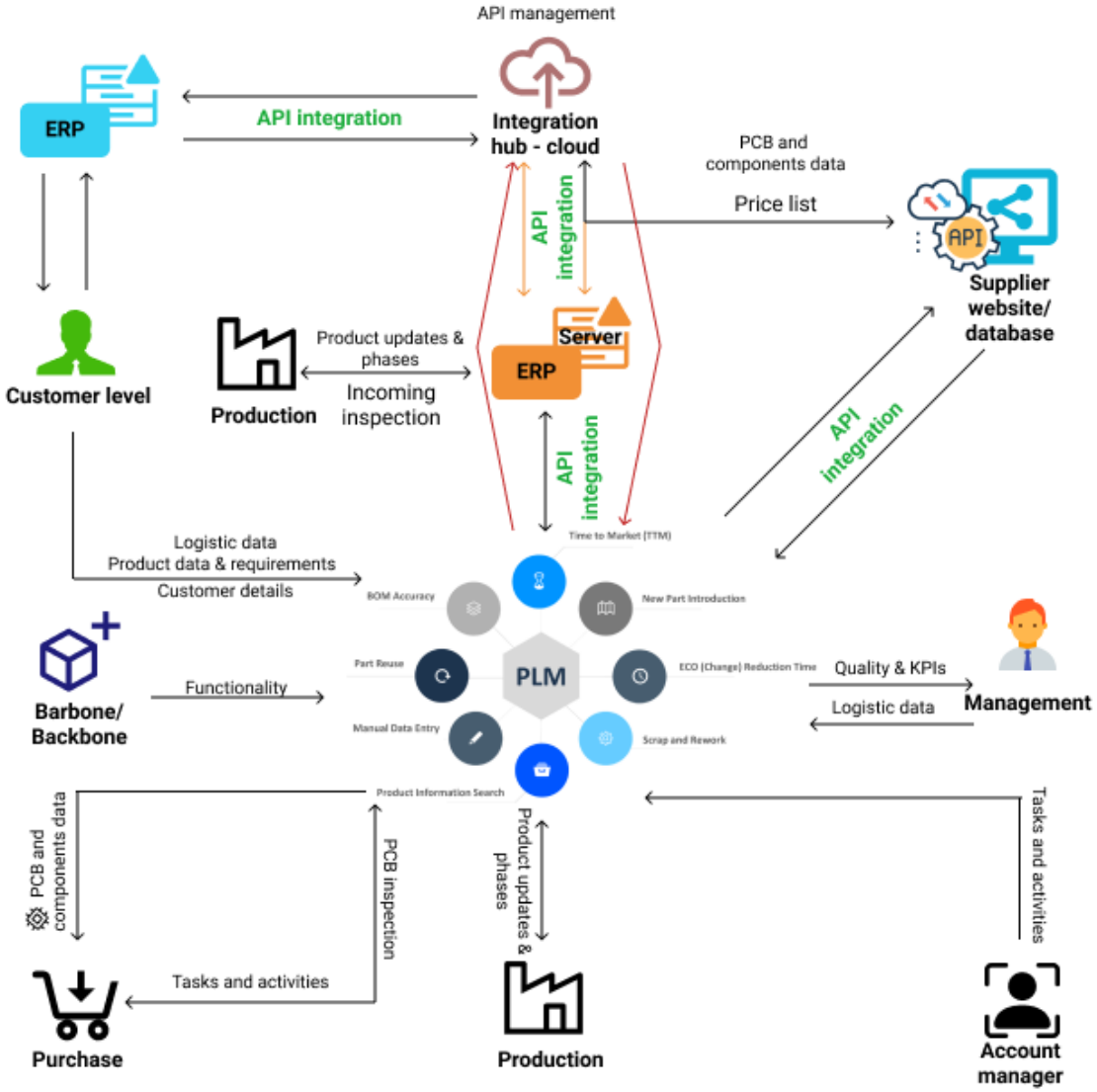


Figure 5 Proposed IT infrastructure

Ensuring connectivity and interoperability of systems is an essential step in creating beneficial engineering and manufacturing processes, thus minimizing errors along with the product lifecycle development. The intention of this solution is to close the loop between PLM and ERP systems, thus enhancing product data exchange between engineering and manufacturing teams.

The solution proposes that all stakeholders within the supply chain, from customers, suppliers to Company X employees, are connected to the PLM system. The PLM platform serves as a master system that captures all product data and decision-making processes in one view. The product data including tasks, people, processes revolves around the list of product requirements and the BOM with the scope of achieving the final version of the product data agreed by everyone.

The PLM system integrates the possibility to achieve BOM accuracy giving Company X the chance to interfere in the early prototyping phase to reduce later operational and manufacturing risks. The proposed solution aims to automatically populate the ERP system with the BOM information directly from the PLM system. This ensures the synchronization of both systems. Furthermore, this reduces the manual processing time and minimizes human processing errors that are some of the biggest pain points that Company X encounters while manipulating BOM files. The PLM software should interface with the ERP system in real-time for all the core business processes, prices, and logistics based on an API connector. This means that BOMs, customer-specific prices, order costs, delivery time, product specifications, and payment methods are some of the elements that are exchanged between the platforms.

Within this arrangement, the ERP system serves the same functionality as it does in the current state. All manufacturing-related data, component inventory, and financial data are still connected and stored in the ERP system. Company X relies on the existing ERP infrastructure, thus there is no intention to eliminate the system from the desired IT infrastructure. However, this aspect is a research point that Company X should consider for further development. By implementing the PLM system, Company X needs to determine the redundancy of the other systems, especially software packages offered by the ERP vendor.

System interconnectivity raises an important question regarding the coherence of the system architecture:

How does the PLM and ERP system communicate and exchange data given that the proposed PLM solution is a cloud-based system, thus it does not rely on local servers as the ERP does?

Alumio integration platform as a service (iPaaS) comes with an extensive range of features that allows companies to create, maintain and monitor diverse system integration including ERP and PLM systems that have local and/or online storage space Alumio. (n.d.). This allows two systems to interconnect and automatically exchange relevant data with each other. Thus, a similar solution principle is considered when taking into account the exchange of data between the ERP and PLM system. In case Company X decides to keep its local server the proposed solution is able to accommodate a server to cloud connection with the observation that the cloud stores all the product data while the server stores only the ERP related data.

All exchange of data has at its base an API infrastructure. The API infrastructure allows the PLM system to automatically extract all component and financial information that is highly relevant for ERP procedures and manufacturing processes. It can happen that the financial data is built in the PLM system therefore immediately as the users validate the product data in the PLM system the ERP retrieves the information automatically from the PLM system. Hence, data from the ERP server can be synchronized to the cloud storage and mashed up with product data extracted from other product development phases.

An important change compared to the existing situation is the proposal to integrate Barbone/backbone functionality in the PLM system. The two software of which main focus is capturing (pre)production processes and activities of employees are used redundantly within the existing IT infrastructure and none of them are providing a clear connection to the ERP system.

This decision is based on discussions with different internal stakeholders who are keen to use only one system instead of multiple systems. The data singularity is another motivation that underlies this decision. By keeping a third system that has project management core functionality, it will increase the complexity of system integration. Thus the PLM systems have inbuilt applications (project management and PLM applications) that integrate several functionalities from Barbone and backbone systems. This includes tasks, activities, PCB component data along with production processes, and updates. However, this is just illustrative, thus for further development Company X should research more into the possibility to fully implement Barbone, respectively backbone functionality into one PLM interface.

One of the aims of this solution is to have the product data flowing from the PLM to the ERP system and vice-versa through cloud storage. The integration and exchange points include requirements, items, BOMs, product data revisions, and engineering change orders (EOC). Moreover, the intention of the PLM system is to source data from ERP regarding costs, suppliers, and provide an understanding of the existing processes and previous product lifecycle developments. This allows the PLM system to learn from previous product versions and adapt the product revisions according to the already existing data. Cost information is highly important for customers, thus the solution proposes a different use of PLM about costing, where costs can be identified and partly defined in the engineering phase as opposed to or in addition to the manufacturing phase where the ERP system is capturing this specific data. The cost management in this situation appears much earlier in the product lifecycle.

The PLM platform is the system that facilitates the connection between customers and Company X. According to some of the needs identified in the external analysis, Company X should take more responsibility in the engineering phase, to help customers to define the single source of truth of product data. This PLM solution comes in handy to satisfy this need by allowing customers and Company X employees to collaborate, moderate, and shape data at an earlier stage in the product data development. This implies that the PLM system is the primary system for data recording. The engineering department is the place where the PLM system starts being populated with product data. The customer is able to initiate the exchange of product data and build a list of requirements in addition to the engineering BOM.

Additionally, customers and Company X can share logistic data, dashboards, quality plans, and technological roadmaps within the system to facilitate better collaboration between parties. Currently,

the exchange of data is done via email of FPT files. On top of that, PLM allows users to execute all the scrap and rework of product data, product information search, and initiate new part introduction. This is essential for the risk management that involves product development.

The solution proposes an API plug-in system that allows direct access to information from a diverse range of vendors. In order for an API to provide the required information, there is a need for a connector that links the systems, which in this case are the ERP and PLM systems connected to the interface of the APIs. The connector is just the tool that facilitates the data stream. The final result is an integrated application that captures and monitors all data in one place. The PLM is meant to encode all business processes, manufacturing and engineering processes, component data, and eventually all information related to project and people management.

This context can contribute to streamlining the exchange of data with minimum errors and effort between Company X and diverse vendors. Additionally, the employees and external users of the platform can considerably reduce the unnecessary work through automation. For example, the component purchaser can directly access the prices and technical details in the PLM platform and compare components, while the existing methodology requires checking the prices and technical data manually on vendors' websites, which represents a tedious process.

Communication tools integration

One of the main goals of the platform is achieving the singular source of truth. This means that also the decision making process needs to be captured in the interface, a process that is mainly executed through means of calling and emailing.

Thus, a few opportunities for integration are listed below:

- **Email** - Integration with the email system allows the user to build a reliable information structure with very little effort. To accomplish this, the PLM platform should be able to integrate with the email interface as intuitively as possible.
- **Phone calls -** Considering that Company X is already using cordless phones to communicate internally, the same equipment can be re-routed and connected to the PLM platform.

These integrations can provide functionalities for phone, email, chat and as well as for social media for marketing purposes. However, the technical aspect of the integration does not fall under the scope of this research thus it is recommended to further study how such integrations can happen.

Appendix 3 Communication Integration captures the research on communication tools integration that provides an initial understanding of how the communication tools are connected to various interfaces.

6.2.1 System functionality

Apart from connectivity and interoperability, there is the need to make the distinction between the functionality of each system.

PLM – The PLM system will serve as the master system in Company X which means that it encompasses the existing product data from all systems into one. It is intended to record product data across all

development stages, from when the engineering teams of different customers start the concept designs to the moment the customer is releasing the product into the market. The PLM system can aid Company X in managing the product data across its lifecycle, which includes bill of materials (engineering and manufacturing) engineering change orders, approved manufacturer lists as well as product data revisions. PLM can help Company X to document and manage product data while being revised and eventually released for production. The ERP system can use the product data from the PLM system (single source of truth data) to determine and manage production resources and additional finances among other business activities. Like this Company X and the customer can be confident that the product data is accurate and the employees can perform production processes with effective data. The PLM system will also contribute to a better BOM manipulation. Now, Company X is using the ERP system to create the manufacturing BOM for transactional purposes only. PLM will cover the change history documentation of BOM to understand which change has emerged, at what stage and by who was made. This will help the engineering and manufacturing teams who constantly require accurate change history information to track design and prototyping changes and collaborate around product data. This will result also in a direct population of BOM data from PLM to ERP system.

To have an in-depth understanding of the ERP and PLM interconnectivity as well as how the systems can function through API connectors please refer to Appendix 4 Back-end technical solution.

6.2.2 PLM system key benefits

The PLM system is designed with the scope of improving the overall processes that deal with the management of product data. Below are defined several key benefits that Company X can obtain from PLM integration:

1. It provides a clear overview of data analytics and gives insights into product data, processes, and people performance. Moreover, it provides a good understanding of customer satisfaction due to integrated survey functionality. Supplier performance is also one of the elements captured and analyzed by the platform. This will allow Company X to make more informed business decisions as well as improving customer collaboration.

2. The platform is designed to reduce the workload and provides a paperless process in engineering and manufacturing. The solution will give the possibility to users to focus on the most important tasks and focus less on manipulating data manually. Currently, this problem translates to high costs and increased time input from employees.

3. The system integrates multiple perspectives of different stakeholders and permits collaboration between parties. This allows engineering and manufacturing departments to collaborate and validate data with the aim of creating the desired set of data.

4. Through API integration the system will facilitate a faster quotation process and BOM management that will allow Company X to speed up the internal processes related to purchasing, quality assurance production planning.

5. Give the opportunity to capture the decision-making process and the main elements that are highly related to the product data through direct integration of email and phone calls.

6.3 Front-end solution

6.3.1 General indications

By accessing the link-PLM application the reader can view and navigate the functionalities of the proposed prototype. Additionally the link-PLM additional features includes an overview of supplementary features that can contribute to Company X in achieving its PLM goals. In order to understand the functionality of the system the reader should consult subchapter 6.4 PLM application. The tool that was used in the designing and prototyping phase is Figma, which is a web-based tool.

The next section of the chapter incorporates the proposed solutions that address the problem definitions.

6.3.2 Interface design

The main input for the interface design is based on the requirement specifications and bottlenecks prioritization that provides an understanding of the most important needs that Company X and its customers have. This is the ground base for the entire prototyping phase. The visual prototype that will be further explained, attempts to display all features that correspond to the list of requirements. The result should highlight how the PLM system is addressing specific needs related to PLM specifications and data management that are stated in the analysis phase.

The design proposes a central interface that aims to be intuitive, flexible, yet guiding users to adopt a rigid and structured working methodology. The interface presents a modern design that differentiates from most of the existing solutions by providing more intuitive buttons, graphics and colors. The colors are resembling the brand identity of Company X. After defining the colors, not too much attention was paid to the design elements as much as it was paid to the functionality of the platform.

The new PLM system is meant to contribute to the entire data infrastructure and be the main system where the singular source of truth is captured. The objective is to use the system internally by Company X employees and externally by other parties involved in the life cycle development of products.

The system is supposed to have a direct connectivity with the existing ERP system and have an open framework that allows the integration of API interfaces and applications. The open framework suggests that the platform is also an open source platform, thus other developers or stakeholders can contribute to the development of the platform.

Aside from its characteristic features that help at capturing data across the entire product lifecycle, the PLM system presents several features that are overlapping with the ones in the ERP system. Both systems can assure functionalities in the direction of financing and accounting to ensure that the products are manufactured in a timely and financially controlled manner. Another relevant example is the use of BOM. In this case, the proposed solution is able to manage eBOMs and mBOMs that can be directly populated

in the ERP system. Additionally the PLM system as well as the ERP system deal with the purchasing orders and operations as well as with the inventory management.

Some of the main differences between the two systems is that the ERP system captures only the manufacturing data, as it does in the current IT architecture, while the PLM system captures the design, engineering and manufacturing data. Additionally, the PLM system allows cross collaboration between customers, employees and suppliers and facilitates communication functionality through means of phone calls, emails, and chat.

Another distinguishing characteristic of the PLM is that it integrates the project management functionality that barbone and backbone used to capture. Like this, the management staff can capture and analyze projects, products, people and processes performance and can create logistic data that can be further used in the collaboration with external stakeholders.

6.3.3 General introduction

The PLM application is the tool in the platform that allows capturing and validation of product data during the interaction of engineering and manufacturing teams.

The prototype is designed as an overarching interface that captures activities executed by Company X employees and customers. It does not present a fluent and individual solution principle for one particular user, yet it incorporates an overview of activities that external and internal stakeholders can execute in the platform. Thus the product data in the PLM system is viewable in a way that fits the users that need to view, edit or perform any data manipulation.

Further, the concept is placed in context by presenting different scenarios that the users might follow while using the platform. This helps to understand how certain requirements are met.

The core focus of the thesis is to create a PLM platform that addresses data management, the following section explains the main functionality that covers PLM principles and features. The dashboard and project management features are elaborated within Appendix 15 Dashboard management and Appendix 16 platform management.

When creating the main features of the platform the main elements considered were the scenarios and the user persona. Appendix 6 – User persona refers to the main user of the platform and their characterizations and needs while the scenarios are embedded in the description of each subsection of the platform.

6.3.4 Scenarios

In order to test the functional and technical specifications, scenario based activities are defined. Scenarios are hypothetical events in which the product behavior is described in a certain environment. A scenario can indicate how the platform will interact as opposed to technical and functional requirements. Scenarios are an integrated part of the functionality demonstration.

6.4 PLM application

6.4.1 Login page

It usually starts with the login page of which the main purpose is to monitor the user activity and the administration rights for each employee or any other user that is previously registered in the platform. Aside from Company X employees, customers with already set-up accounts have the permission to access the interface. Company X is the company that will create and manage all PLM accounts, thus if a client would like to register and benefit from the PLM platform Company X will handle all the administration policies that come with the creation of an account.

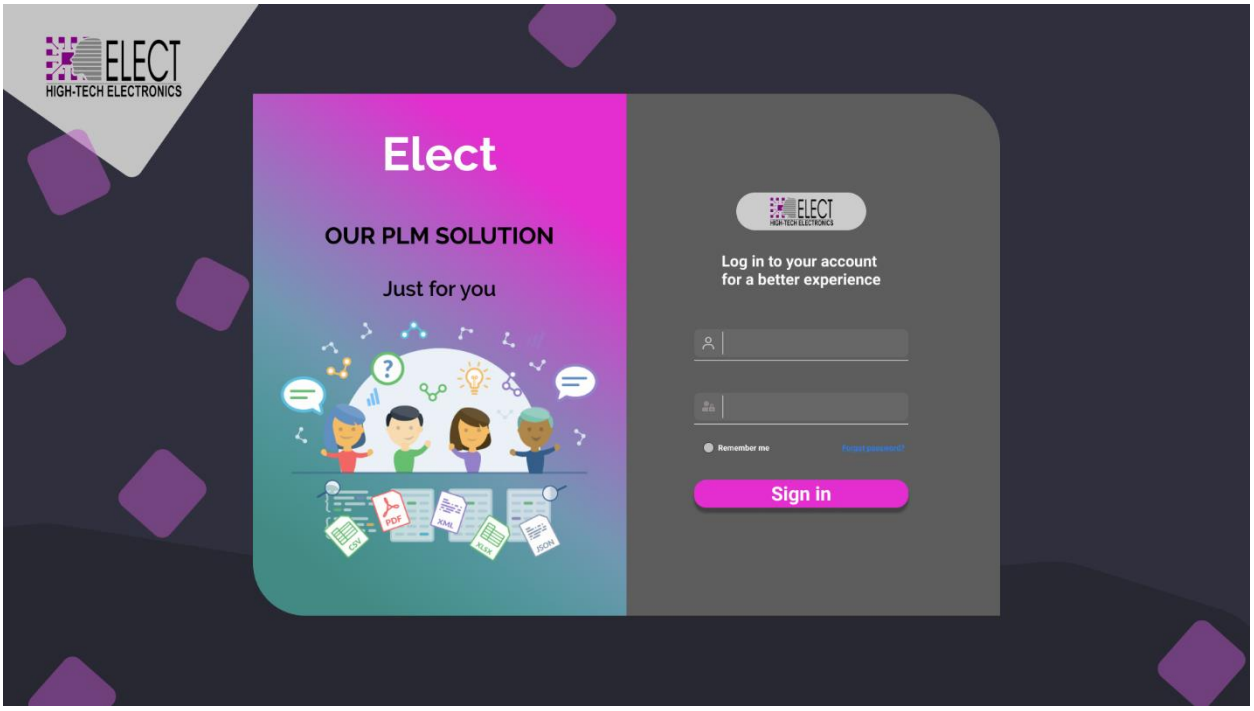


Figure 6 System Login

6.4.2 Landing page

The user interface displays three main applications as seen in Figure 7. This is because of the possibility for the IT specialists to customize and build different functionalities into the platform under the shape of applications. This is highly similar with the existing PLM solutions. Additionally the other software vendors are able to customize and build plug-ins and connect them through API to extend the functionality of the platform. For this specific project, there was a need for three main applications as follows:

Project management – is the general interface that gives the overview of the running projects with its corresponding data and assigned personnel. This app incorporates the project data. The app can be used to administrate, edit and view any project data and employee activity. Additionally this application contributes also to the change management, human resources planning and management activities.

PLM platform – provides the overview of the product data and intends to automate the product design. Another aim is to reduce engineering steps and allow Company X employees to have an early involvement

into the development phase of each product. It comprises all the engineering change orders, BOM revisions and product workflow revisions.

Management Dashboard – represents the user interface that provides the analytics and all the key performance indicators relevant to the business objective and process. Like that, the management team will be able to access, download and share analytics and logistic data with any stakeholder. Product and project insights will be easily accessible and Company X will be able to rapidly understand and spot different pain points and take fast measures to counteract red flags.

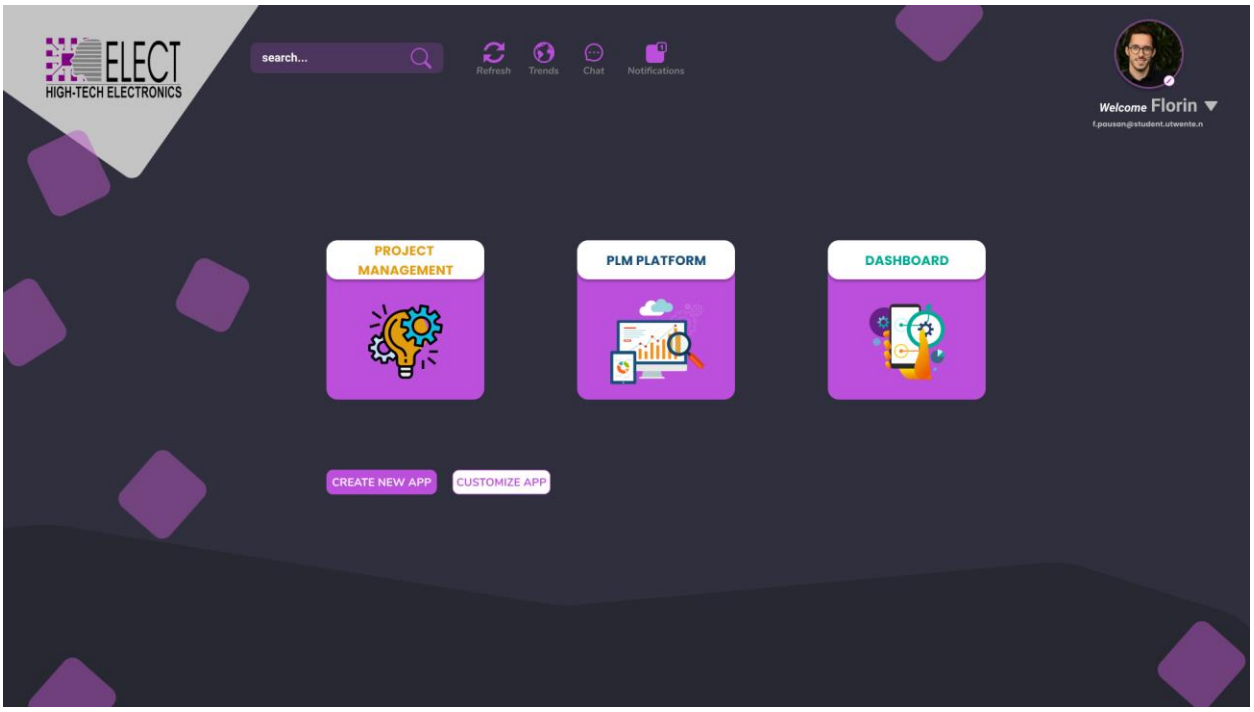


Figure 7 Landing page application overview

The screen captured in Figure 7 provides access to the already existing applications that are developed for the platform. In the top center of the screen the search feature together with chat, notifications, refresh and trends buttons are displayed. These are general features explained in the next steps that will allow users to rapidly access some of the general features in the platform.

6.4.3 General features

The platform facilitates easy access to different features and the customization level that the platform provides through the following tools:

Filtering tool - The interface can tailor made a concise filtering and grouping tool (Figure 8). The filtering tool offers the ability to filter through any information that is wired up to the product data. In case of a missing filter, the user is capable of tailoring the filter according to data that is required. The tool is customizable depending on the view the user is in, locating product data like BOM, manufacturing order, sales order.

Grouping tool - Also grouping has similar features as the filtering tool. The user is able to customize the product data groups depending on the view the user is in. These tools can offer an easy, straight forward and efficient possibility to locate, structure and categorize the product data according to the user's needs, thus it can adapt to a diverse range of engineering and manufacturing companies.

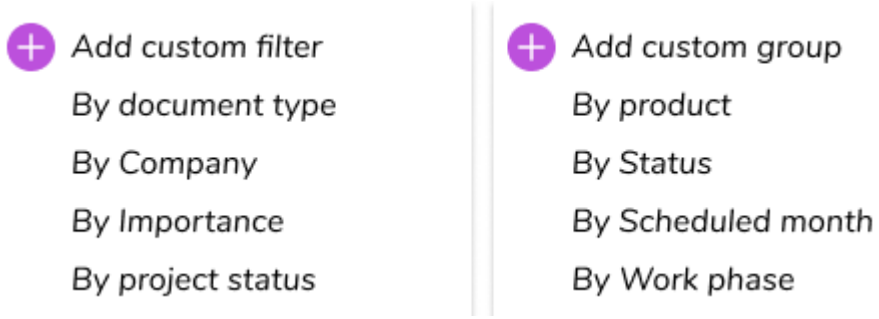


Figure 8 Filtering and grouping

Chat feature – this feature can be used for internal and external communication or in the communication with different stakeholders. Due to large possibilities of API integration, this tool can present a great extension and act as any other communication tool used for project management. It allows the user to have full traceability of any change that is happening in the PLM process. This way the majority of the making decision process is kept within the platform and linked to the project and product information.

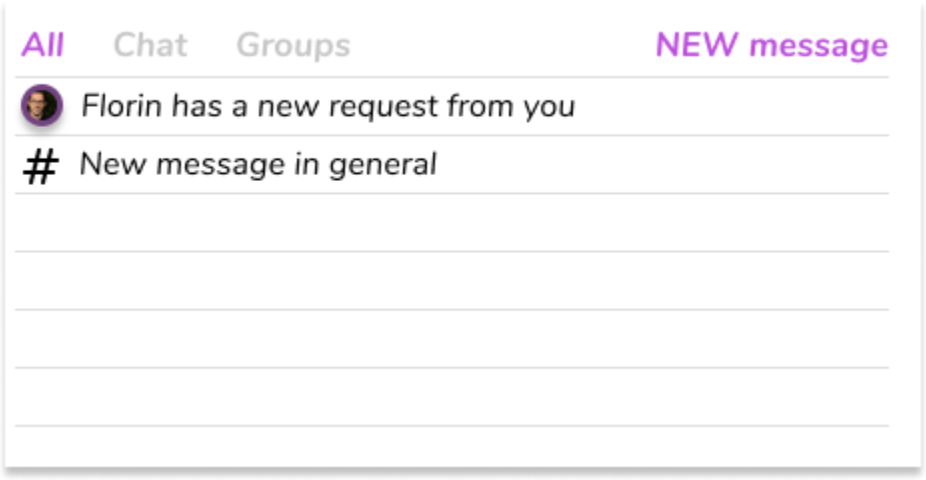


Figure 9 Chat feature

Notification feature – The user can find here all activities related to a particular module or stage of the product. Additionally the user can see the latest activity, the present and future activities. By clicking on one of those it will direct the user to the activity charter.

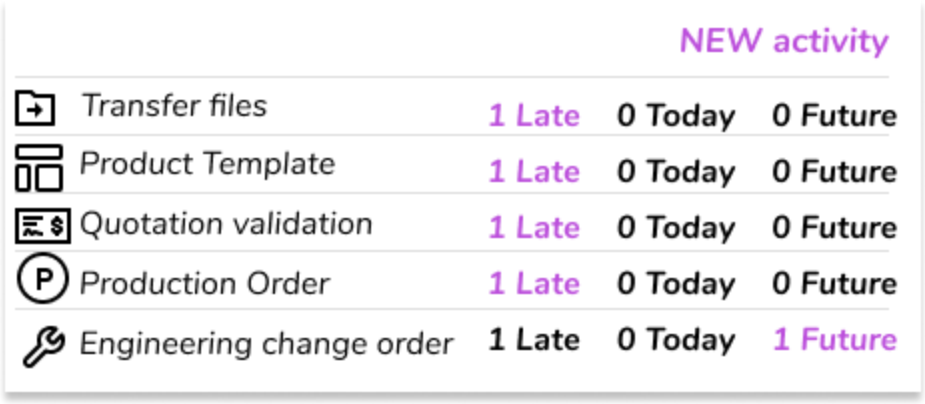


Figure 10 Notification feature

6.4.4 Vaults

A data vault is an application folder that fosters different settings. It works like an usual data folder where other subfolders or documents can be linked or stored to it.

Scenario 1: The customer logs in into the PLM platform and intends to create a new product vault.

By clicking on the PLM application in the landing page the user is sent to the product vault view where all existing products are displayed. The products belong only to one customer. To enter a vault of another customer, the user has to enter the customer's page and enter the vaults page. The home screen interface provides a general view of the PLM application that incorporates data vaults that can be created within the platform by clicking the "New Vault" button. Additionally, in case of an existing product vault stored outside the system, the user is able to import the vault from the local source into the system. A data vault modeling is a method that provides a clear, customizable storage of data coming from different inputs. It functions as a folder where the user is capable of arranging and setting up all product data.

The three data vaults already displayed below in Figure 11 provide preliminary information regarding the product data. Each vault represents and integrates a product and the data that revolves around it. All data, processes and people are easily accessible and customizable in the data vault, thus it provides a clear, fast overview of what data is handled, by who and at what stage in the development.

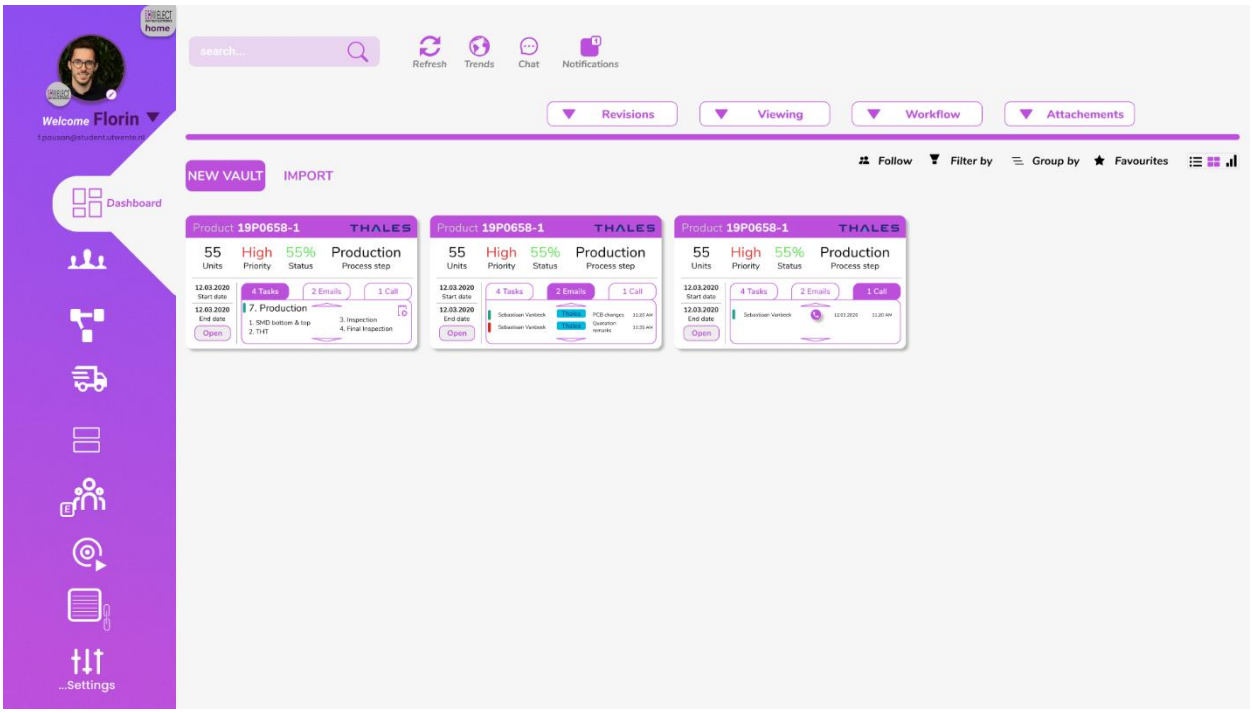


Figure 11 Product Data Vaults

Process: As seen in the figure 11 when clicking “New vault”, a window pops up and it requires the user to fill in the project details and customer information. The left side of the screen that includes the project details can be filled in by the customer or in case there is a recurring project, the screen will be automatically filled in and the user will just have to change the outdated information. By filling in the online form, the customer will notify Company X that intends to create a new product and implicitly intends to request a quotation.

When clicking the edit button the customer can add extra text boxes, as well as connect other people. Currently each Account Manager within Company X is responsible for several customers. When the customer fills in the form, the details of the account manager responsible with the administration of that specific customer can be connected to the vault. In case the account manager is out of office due to unforeseen circumstances, the platform notifies the customer about it, and directs the client towards another account manager. To select one account manager the client has to click the drop down arrow in the right of the account manager and select the one that is indicated as being available. As soon as the form is filled in, the user can save the form and immediately after that will have access to the vault.

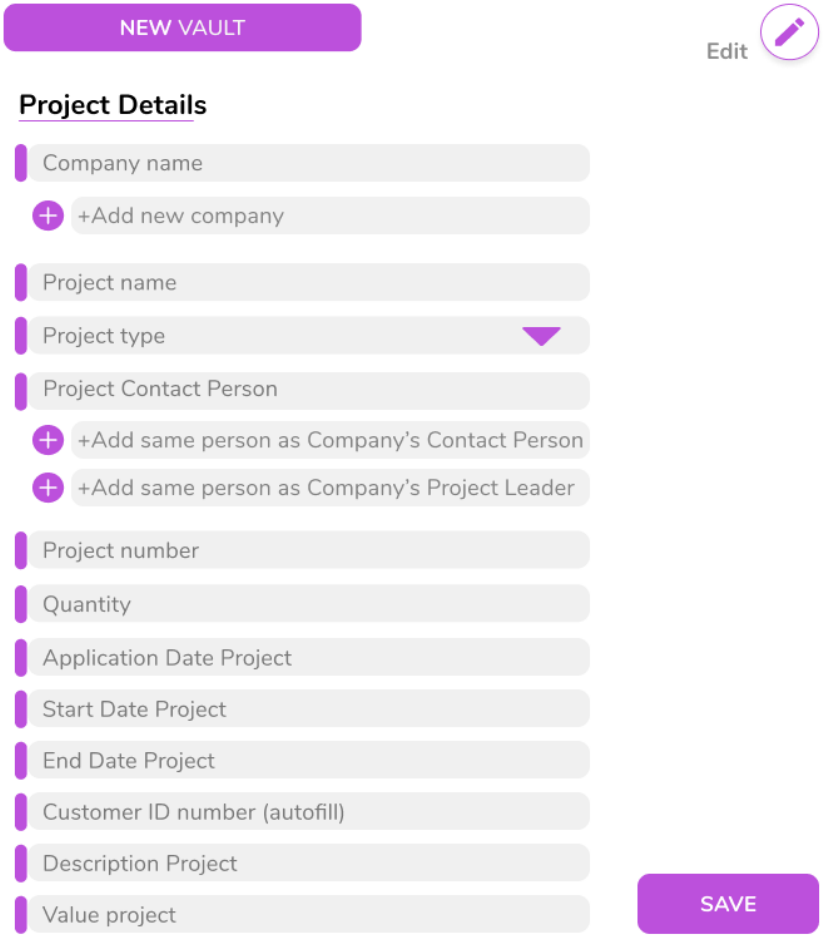


Figure 12 Generate new vault

The right part of the screen in figure 11 displays the people or departments that need to be connected to this specific project. This is usually done internally, by Company X and by the account manager. If the AM selects one department or any employee, they will be immediately connected to the product data vault and made aware of the possibility of having a new project on the pipeline. By connecting employees at this level, they are constantly notified about future updates and changes happening to the product vault,

however the authorization to manipulate data can also be assigned at a later stage when revisions are done.

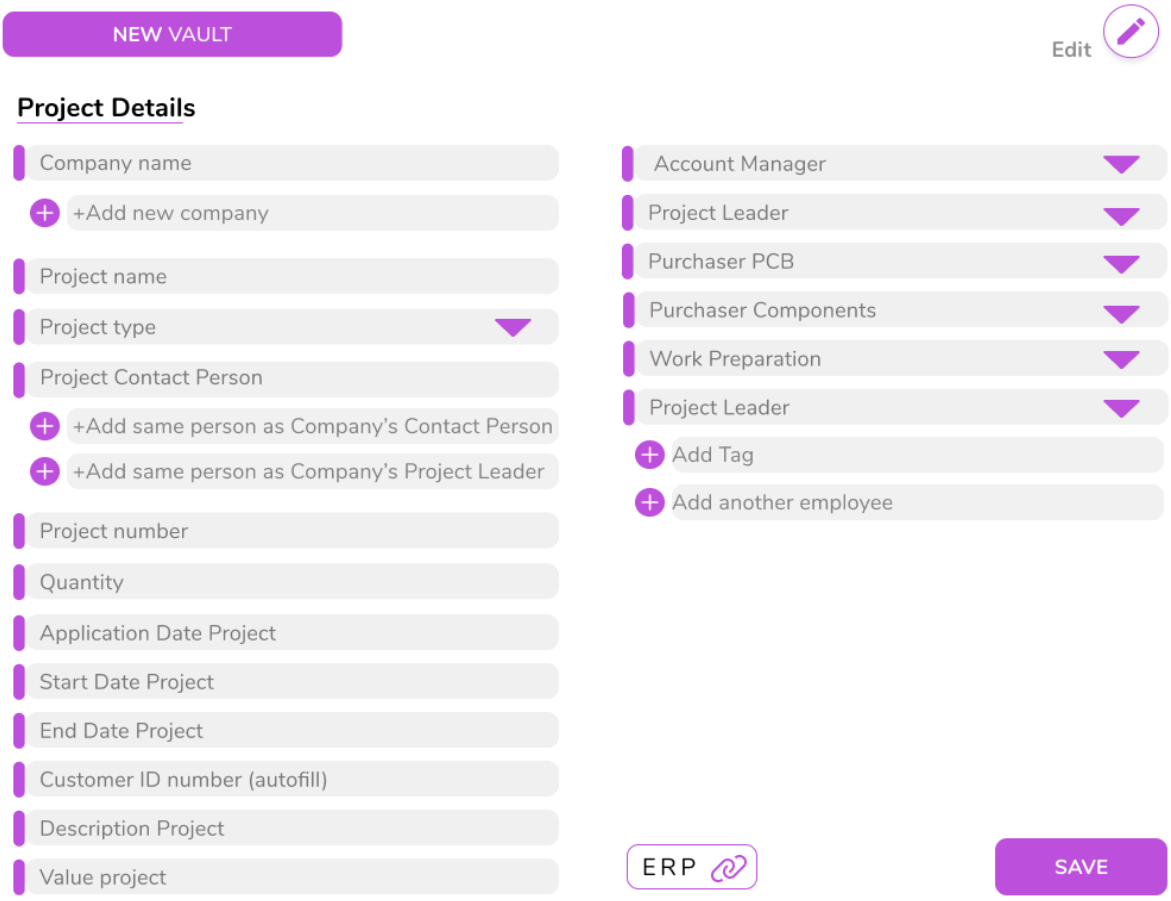


Figure 13 Generate new vault 2

The ERP icon reveals the connection and automatic synchronization between the ERP and the PLM systems. In case the link appears as broken, the system signals that the ERP-PLM synchronization is not available. The icon usually appears only for Company X employees. This icon does not appear in case of the customer, only when the ERP from the customer is connected to the PLM system. This is just a safe mechanism to make sure that the relevant data from the ERP is retrieved at the right time so that the PLM system can follow its purpose of providing the singular source of truth. This button is mainly used when a product request is repetitive and is with the same customer.

When the user fills in all the information and clicks save, the new vault appears in the platform as displayed in figure 14. The text at the top of the vault indicates that it is newly created.

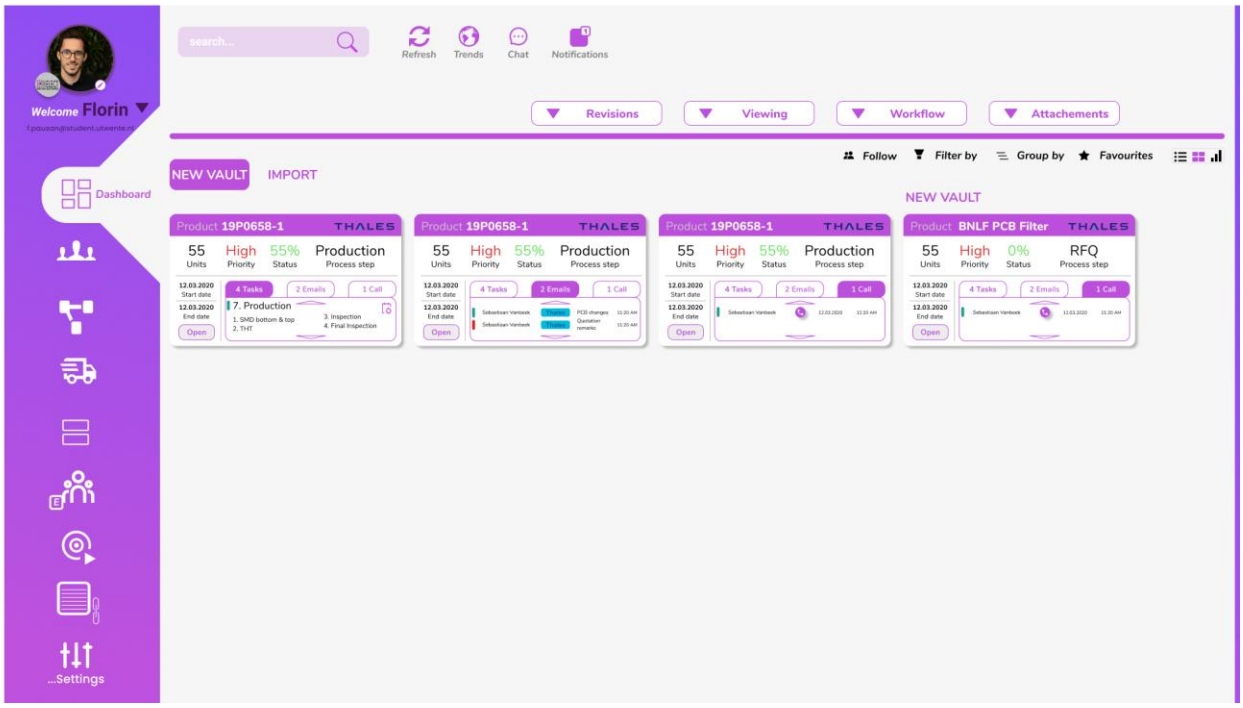


Figure 14 Vault generated

6.4.5 Action folders

The PLM vault contains several boxes as seen in Figure 15 depending on the manufacturer or the user. These boxes resemble action folders where different product data, actions, processes, people and activities are captured, automated, and stored. It is important to say that the boxes and content of each feature can be configured in different ways.

Within each of these boxes is its own kanban view or its own structure which can be customized for different purposes. This is highly dependent on the tasks at hand for each specific activity. In addition the approval steps can be set up depending on the needs of different users. All the changes are managed with different teams, different groups of people that are in charge at each phase of the project and are approving the product data across the development phase.

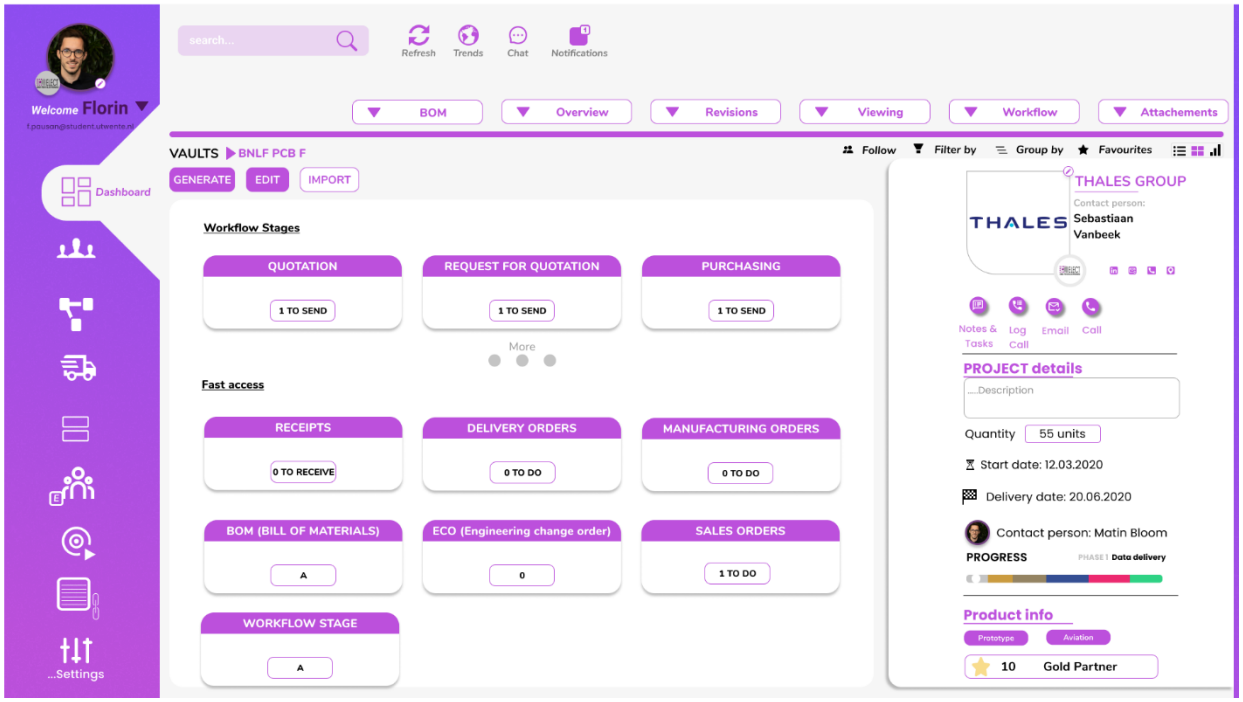


Figure 15 Action folders

6.4.6 Create new revision

To simplify the understanding and highlight how the PLM characteristics are actually implemented in the PLM concept, the next part of the report introduces the revision of an existing product within Company X. This means that the right data needs to be approved by the right people at the right time.

Scenario: How does the user make changes to the BOM and the workflow that is related to an existing product? It is assumed that one customer within Company X wants a similar product with slightly different components which require the refinement of the manufacturing processes and the BOM. Thus a new engineering order is made

Process: Some of the possible changes that the BOM or the workflow stage are encountering are as follows:

- The prototype changes over time.
- The prototype enters series production.
- The delivery date might change.
- One of the vendors goes out of business and Company X needs to order a new item from another vendor.
- The new component plays a critical role in the overall performance of the product thus it requires high quality and reliability.
- The product requires an additional production step due to new product quality requirements.

All aforementioned aspects imply that there might be changes to the actual BOM and manufacturing process, changes that reflect also on the inventory management system.

The next steps will detail how some of these changes can be traced and validated by different users and how the PLM characteristics are assured by the solution principle.

By diving into the PLM platform and accessing the revision of the BOM the platform displays a kanban view that proposes simple stages to track progress of the changes that are happening at the product level. Within this unit, the user can set up priority levels, authorization levels, product labels to indicate the urgency and a wide variety of changes that are required for the product.

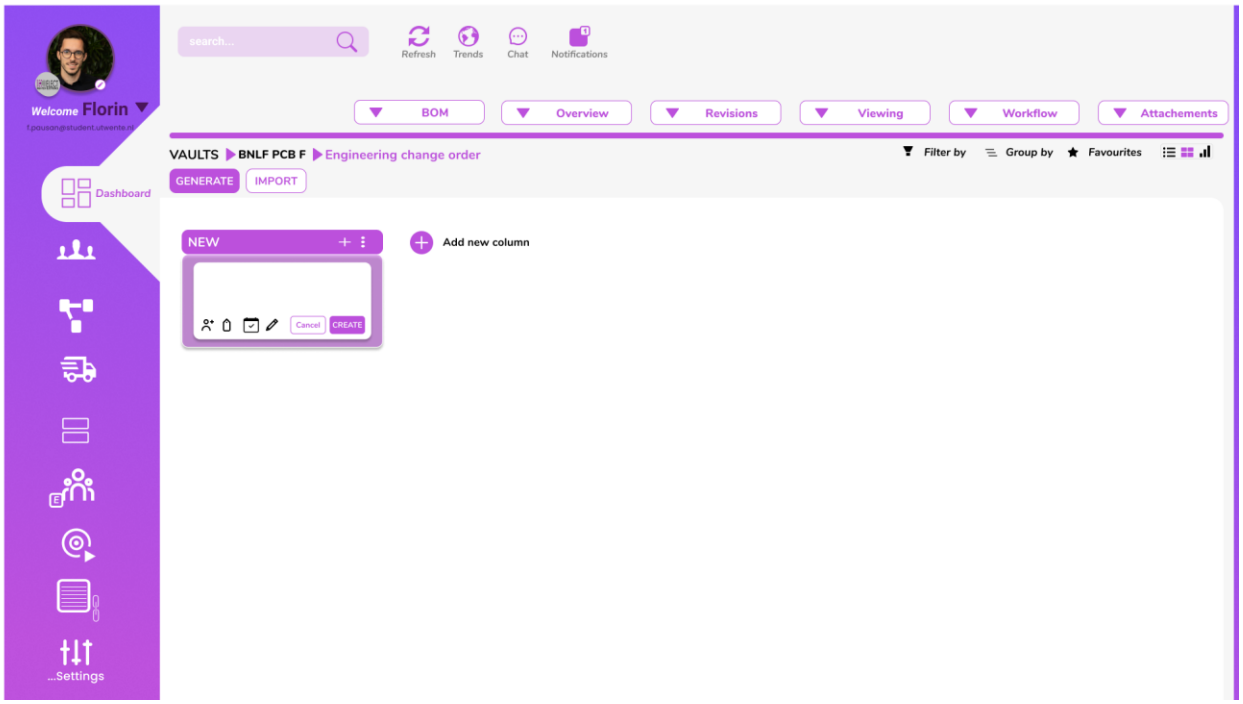


Figure 16 Engineering change order - kanban view

The new engineering order starts with the set-up of the kanban view. This is easily customizable according to the needs of the user and the product complexity. Figure 16 already integrates a phase in kanban view called “new” which indicates that a new engineering order has been created. The next step is to create the next process steps that will help engineering and manufacturing teams to collaborate and validate the product data.

Thus Figure 17 displays 4 main stages that the revisited product data should follow:

- New
- In progress
- Confirmed
- Effective

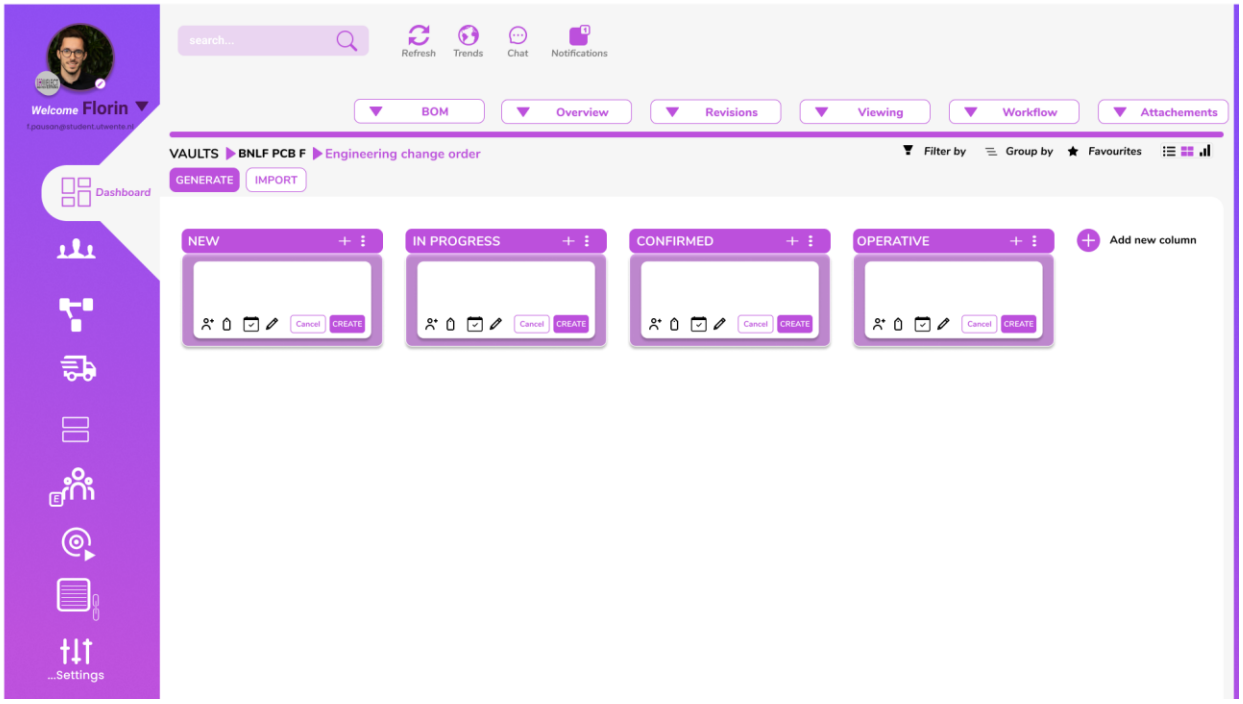


Figure 17 Engineering change order - kanban view - 4 stages

Each stage can be configured separately to act according to the needs of the users. Each stage presents several buttons as it follows:

The following buttons are the main elements that are used to set up each stage:

- Button member approval
- Add labels
- Date schedule
- Edit stage

6.4.7 Member approval

Figure 18 highlights how the member approval works. Each engineering order requires expert approval at each different stage. The solution allows the user to set up the stages, control and give authorization to the right people to follow, edit or comment on the product data aligned with that each stage. The user should question in this stage the following:

- Who needs to approve this step?
- What type of approval the step needs?

The members that are invited for each stage should already have an account, otherwise the person setting the stage can invite external users by clicking on the “invite team” button which will provide a collaboration link.

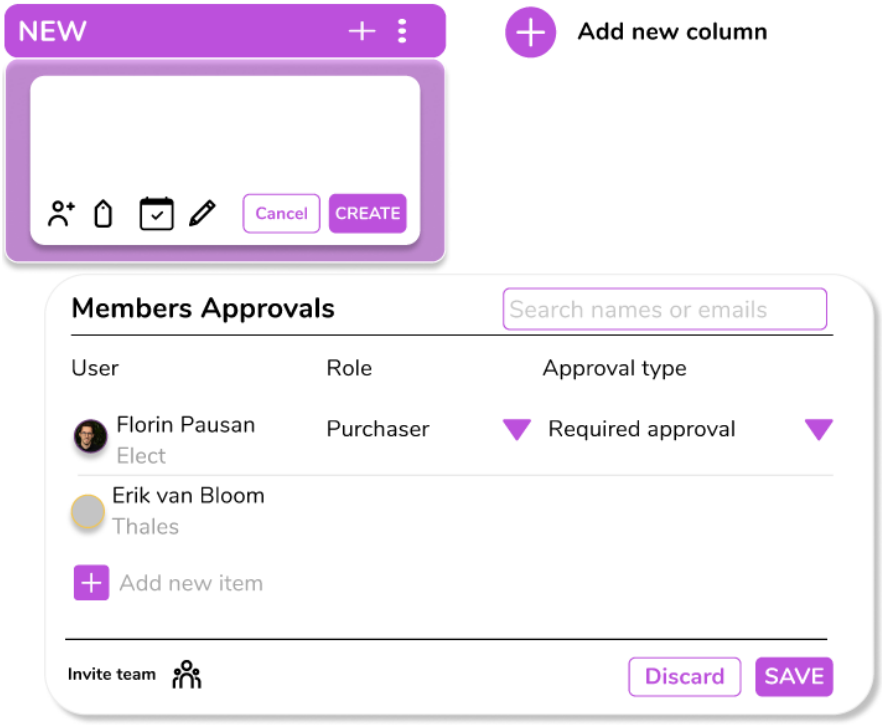


Figure 18 Members approval

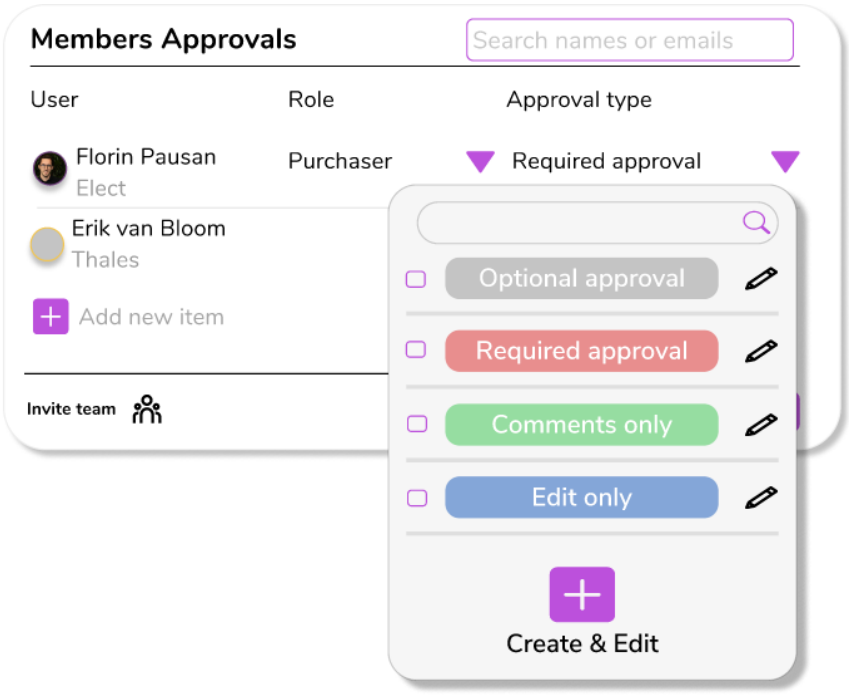
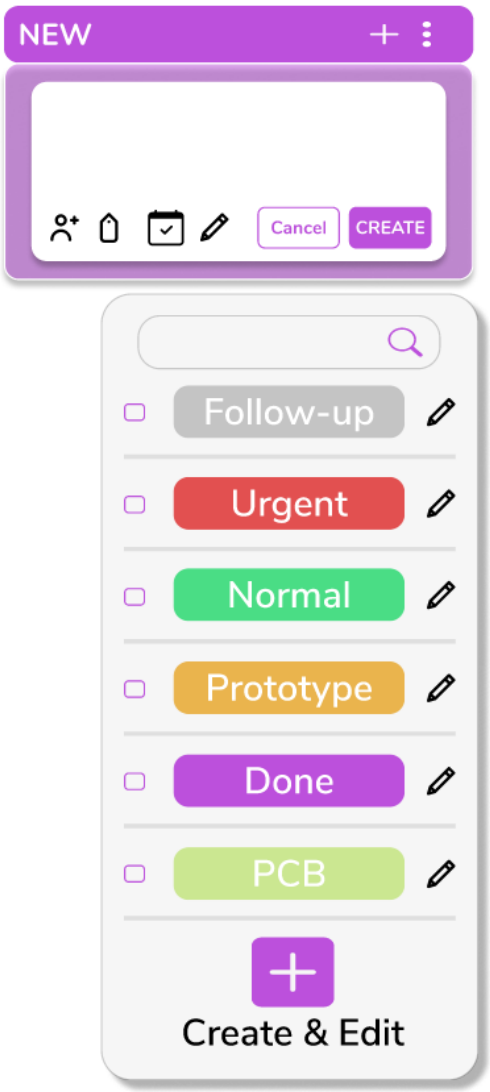


Figure 19 Members approval - type of request approval

6.4.8 Add labels

Figure 20 displays the possibility of the user to assign labels to each stage. This is important because when the member who was connected to the stage gets the notification about a new engineering order, the label will also indicate the importance and the status of the stage and also might indicate what still needs to be done to complete the stage.



6.4.9 Date schedule

For a precise execution of the project, each stage can also be scheduled by setting up a start and an end date to the stage.

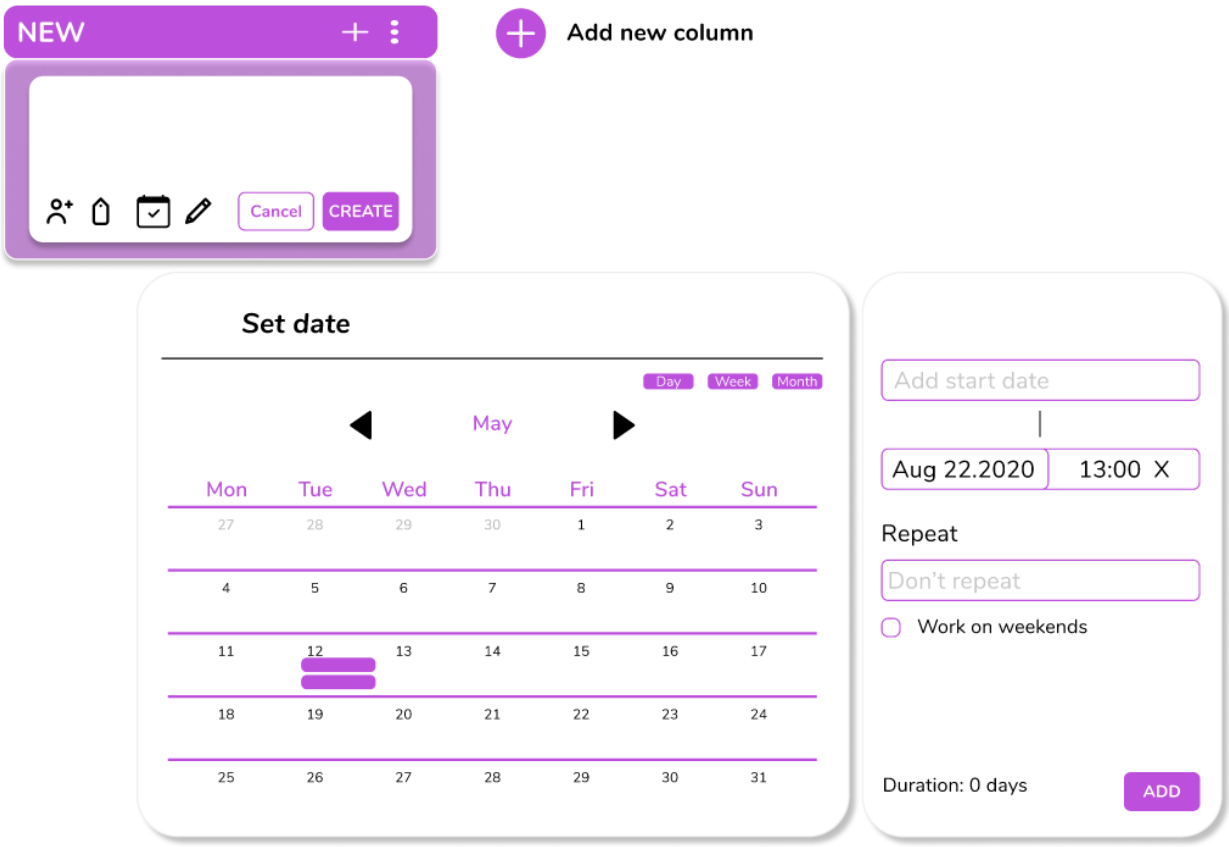


Figure 21 Date schedule

6.4.10 Edit stage

Each stage presents a setting button where different edits are applied. When clicking the edit button the following are displayed as shown in Figure 22.

- The name of the stage - it presents a drop button to select the stage that requires editing.
- The group that is edited
    - change related to BOM or
    - change related to the workflow/routing.
- The track of the stage which
    - inactive card lists - this usually refers to inactive stages and tasks within the stages such as “Done” or “Cancelled”
    - allow to apply changes - by selecting this the stage allows users to apply changes to the product data.
    - final stage - by selecting this the stage will indicate that the product data is in the last version of it. It marks the end of engineering order changes.

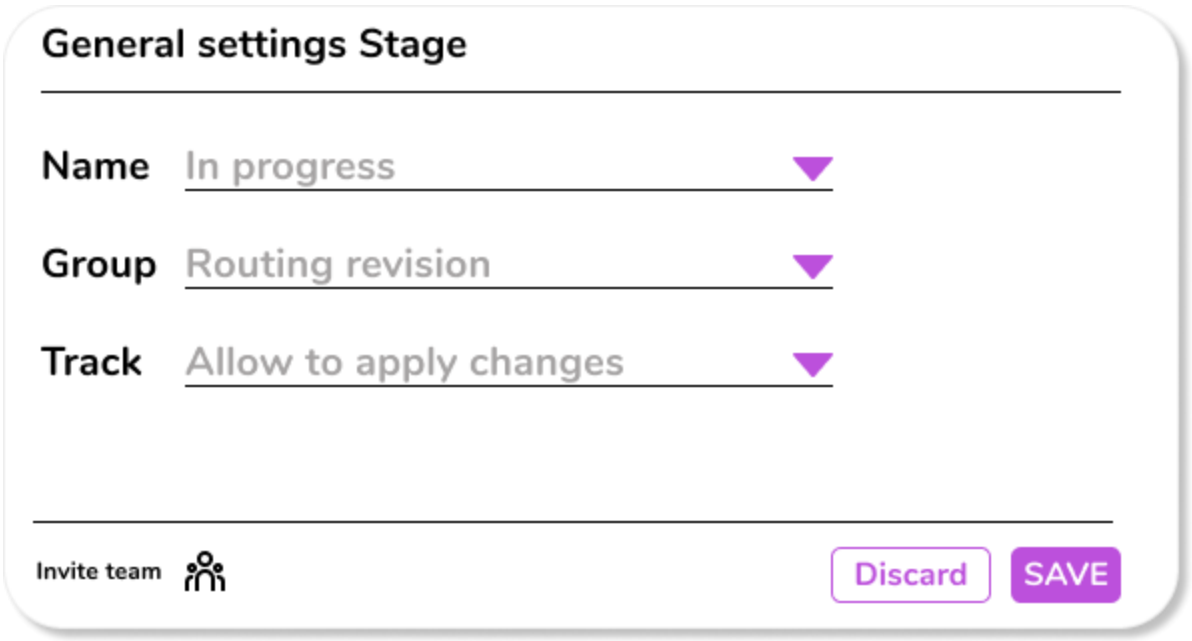


Figure 22 Settings stage

Thus the stages are set up as follows:

- **New** - inactive card list view - in this stage none of the active tasks are listed there. This is a series of tasks that are inactive and are in the backlog for processing.
- **In progress** - inactive card list view - is the stage where the product data suffers modifications, thus it is required that the user requires approval from the right people. However this stage is labeled as being in the inactive view, which means that changes can emerge at the product data level. However none of the changes are applied to the product data, because it requires approval and validation in the next stage.
- **Confirmed** - apply changes - After the changes to the product data will be made in the "In progress" stage, the next stage it is represented by the actual approval and validation of the data. This stage also implies that if there is any other feedback or modification to the product data before being effective, it can be pointed out in the application and request it from the team members responsible for the specific product data.
- **Operative** - final stage - it is marked as the final stage of the product data change, thus the moment the engineering order reaches this stage it means that it passed through all the other stages, the data is validated and no other changes are requested.

6.4.11 BOM revision

The assumption is that the change is done on an existing product; however, in case of a new product the customer should request a quotation. To understand how the request for quotation is done in the platform please refer to Appendix 7 Request for quotation . Given that this is an existing product, it means that it already has a BOM and workflow assigned to it. To comprehend how this is created in the first place please refer to the Appendix 8 BOM management.

Now that the stages for the revisions are set, the user can start the product data revision and apply the desired changes. By clicking on the “create” button the user will enter the screen where the revision will start.

6.4.12 Set new Engineering order

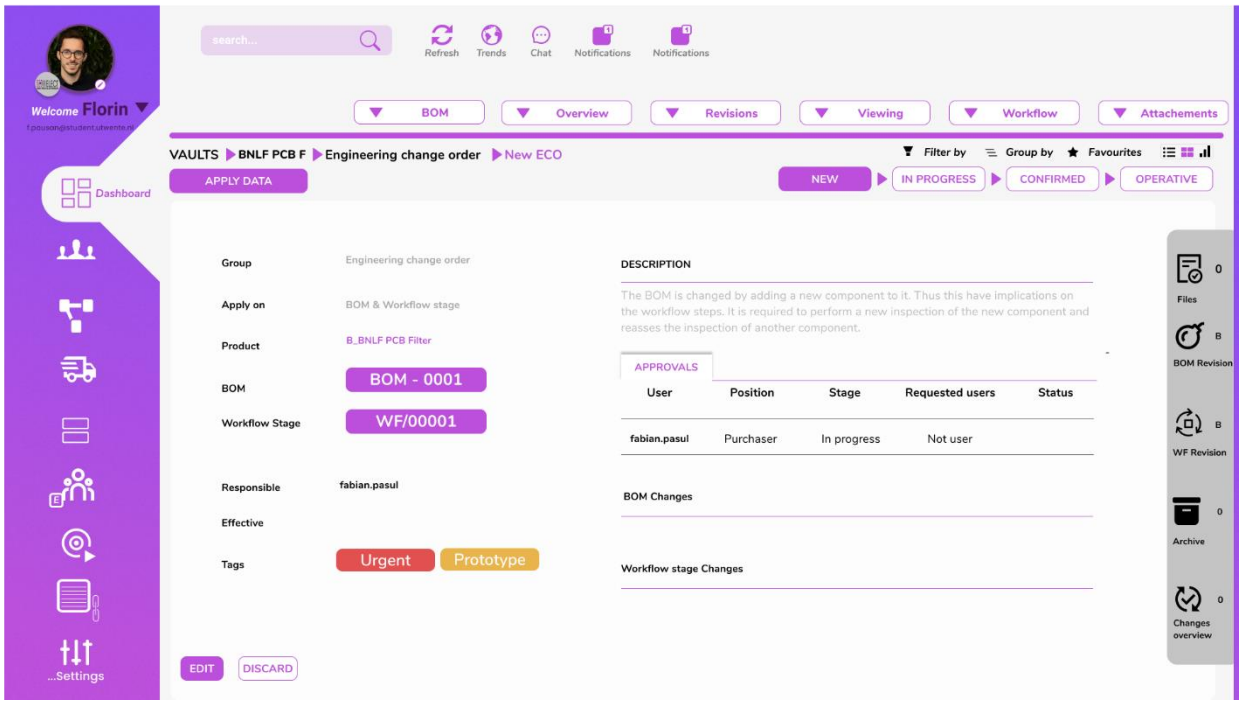


Figure 23 Set New Eco

Scenario: the product suffered design changes within the engineering department. The client contacts Company X regarding a RFQ about an existing product that incorporates new components that also require a new means of production processes.

Process: Thus the user who is requesting the revision of BOM and workflow writes a message with the instructions for the engineering change order in the description section as seen in Figure 23.

The revision is applied to product *B_BNFL PCB Filter that is linked to its BOM-OOO1 and workflow stage WF/OOOO1*. The revision window also displays the person responsible for the change and allows the responsible person to set an effective date for this particular task. Additionally the user can tag the change (see figure 23 for tag list) and indicate the type of the product (in this case is a prototype) or the urgency of the change. In some cases, a product can have multiple BOMs or workflows thus the system can provide a customizable and flexible structure to add multiple BOMs and workflows to a revision. However, the simplified version is chosen for highlighting the PLM characteristics.

Aside from the description section, there is also an approval section where different stakeholders can see who needs to approve this change. Momentarily there is no-one assigned to approve this change because the revision was just created. Also in this window the user will have an overview of the BOM and workflow changes.

The top right side of the screen displays the stages earlier created in the kanban view and provides a focal point on the stage that is active . As the revision is in the **NEW stage** and is set to go, the user has the option to save (bottom left side of the scree) the revision for later use, discard the revision or press the top button “start new revision” which will take the user in the next phase called “In progress”. Within this preliminary stage there are no changes addressed to the product data.

In progress stage:

Now that the user jumps into the next stage, the user can notice at the **right part of the screen** that there are four new buttons and icons as seen in Figure 23.

- Files
- BOM revision **B**
- Workflow revision **B**
- Archive

The BOM and workflow transitioned from revision A to revision B. This transition indicates that all changes and the most updated data is linked to the latest revision and no changes are applied to revision A. By clicking one of BOM or workflow revision buttons, the user is able to enter the window where changes to the BOM, respectively to the workflow (WF) are performed. All changes that emerge from BOM and WF are documented in the right side of the screen (BOM changes and Workflow changes). If there are any old documents that are not useful to the product, the user is able to transfer them to the archive, while any other technical documentation and product data that is still relevant to the new product can be stored in files by clicking the button next to “BOM rev B” button.

6.4.13 BOM change

Scenario: The hypothesis is that the BOM needs a new component to the list of components.

Process: To edit the bill of materials the user needs to click the “BOM REV B” button that will lead to Figure 24 where a simplified version of BOM is displayed.

The user clicks the Edit button and now changes can be applied to the open BOM structure. A new button appears in display and the user is able to add a new component.

To add a new component to the final list the user can click the button “add new item” at the bottom of the BOM and this will direct the user to the open source inventory page that allows the user to choose a new component.

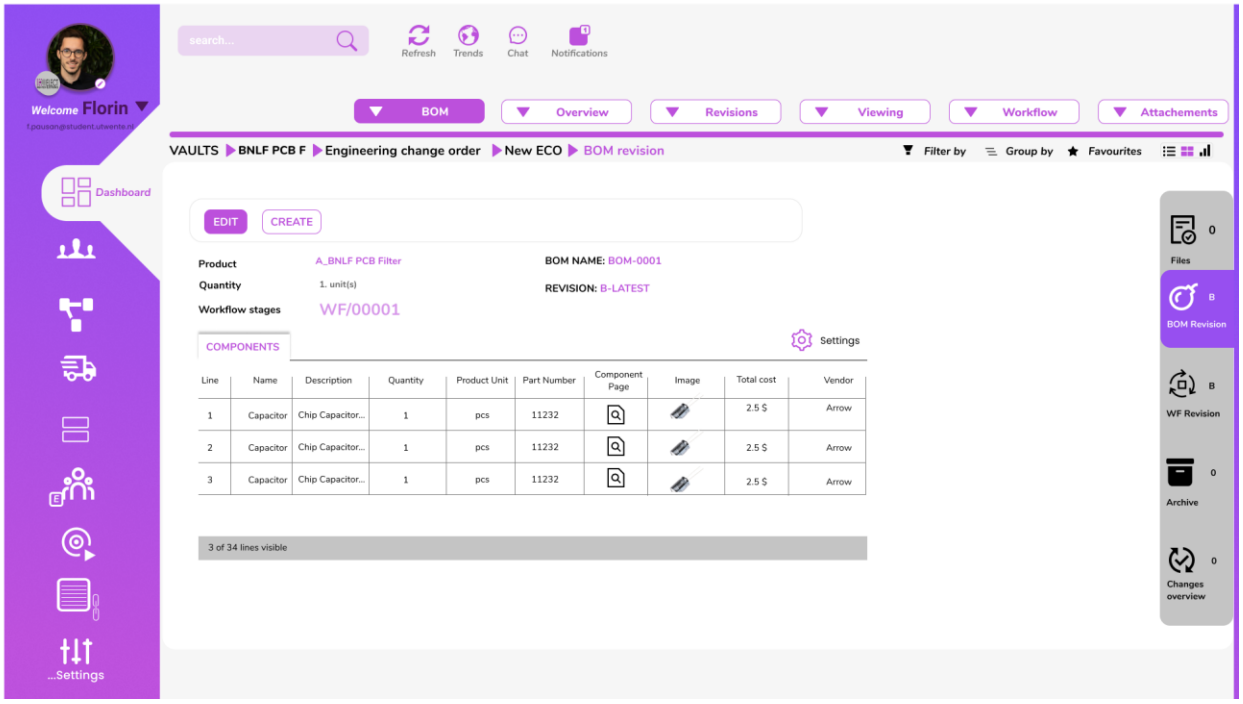


Figure 24 BOM Edit view

6.4.14 Component purchasing process

Scenario 3: The purchaser would like to avoid sourcing components manually from each supplier website or database to save time and focus on executing other tasks. The purchaser is sourcing new components for the manufacturing BOM through the inventory management system within the PLM platform.

Process: By automating this process, Company X can benefit from increased responsiveness towards clients when it comes to product quotations, while the customer is not confused about the costs associated with the BOM. The customer and Company X are aiming for transparency and clear communication.

This is executed by the component purchaser who in a normal situation conveys the information from different supplier websites into the ERP that eventually reflects the cost of each individual component. This step is not required anymore due to the API connectors to the supplier database. Here, the purchaser is able to:

- Check pricing and availability of components by having direct insights into the inventory management system as well as having quick access to the component market availability and pricing. The information is sourced from major distributors such as Digi-Key, Mouser, Arrow, and other suppliers and the ERP that serves as the main inventory system within Company X. Both the ERP and the supplier database are connected to the PLM system.
- Check datasheets that integrate the technical specifications of each component and connect the data to the BOM.

- Identify the most reliable supplier based on compliance information, factory lead-time, availability and pricing, elements that guide the purchaser towards the right decision. This leads to a quick risk identification and the possibility to adapt and opt for part alternatives.
- The possibility to determine automatically the most reliable product based on the user input that involves the rating of the supplier.

Overall, the open BOM captures all component data around it while it confers the possibility to determine how different products impact the stock.

Figure 25 exemplifies how a new item that has the desired specifications can be selected by the purchaser. By entering once again the BOM edit mode the purchaser determines that a new capacitor is required, a capacitor that has improved specifications, and higher reliability. By clicking the button " add item" in the BOM view the platform displays a component management page that allows the purchaser to search a component in the database of multiple suppliers as well as in the local inventory management system. In the image below the capacitor 'C0805C105K3RACTU' is displayed based on the search that the user performed. The supply chain data is directly and real time displayed from the suppliers database and the ERP system thanks to the API connectors that facilitate this exchange of information.

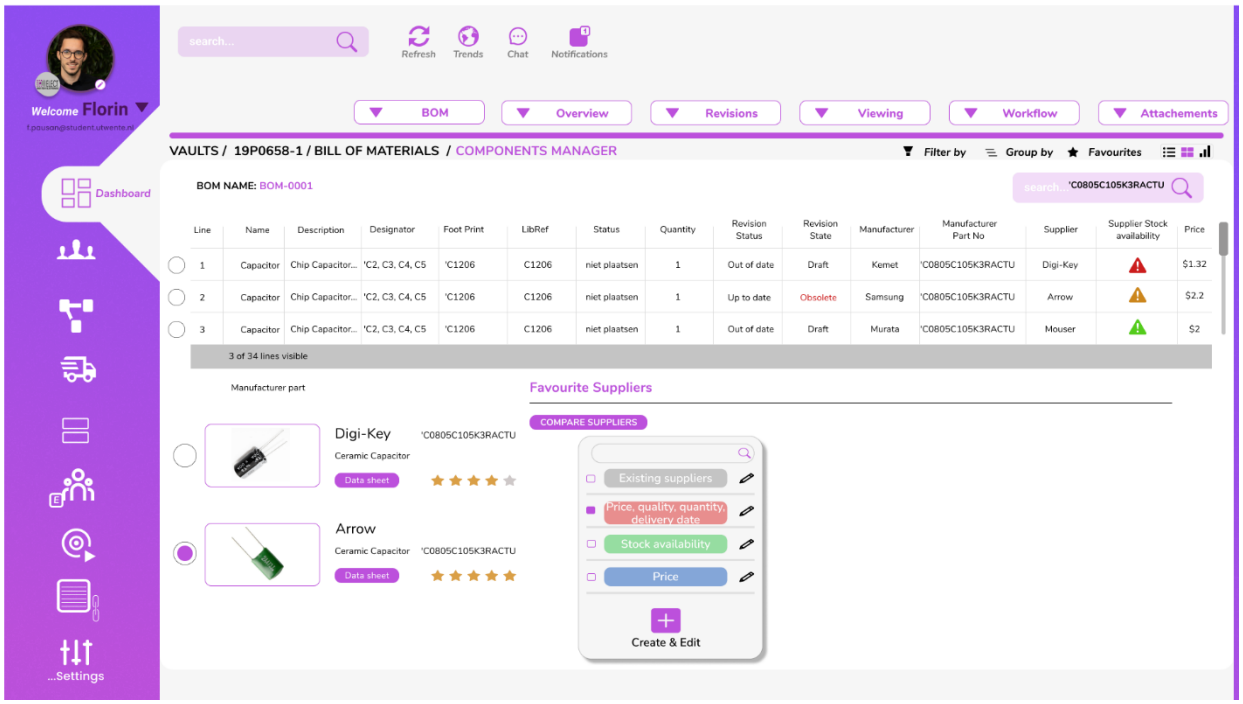


Figure 25 Inventory management system

The purchaser in this case can have at a glance an overview of the component quality, price, availability, supplier reliability, elements that determine the final component selection. The reliability and trust of the supplier is built up based on constant data input and capturing previous experiences in the PLM system. If a product breaks down the customer can point out which component is faulty and Company X can

register it the BOM and on the supplier page that the component broke down. This can notify the supplier further and improve the quality of their services while also offering a full traceability of materials.

Compare suppliers

Below the table the purchaser can create an overview of the favorite suppliers that already collaborated with Company X in different projects and usually stock the required product. When comparing the suppliers the user can click the button “compare suppliers” and a drop down menu appears on the screen. The user selects the comparison criteria or can create new filtering criteria. The main objective of the purchaser is to have an overview of the price, quantity, quality, delivery date and stock availability thus the user selects those items and the platform displays four main suppliers as shown in Figure 26

The suppliers are labeled based on a color scheme. The system has at its base a traffic light methodology that points out if the requirements are fully met, partially met or not met at all. This enhances a faster decision making process for the purchaser.

Therefore it can be noticed that the preferred supplier is “Arrow” because it provides a lower price than the other, it provides on-time delivery and the right quantity.

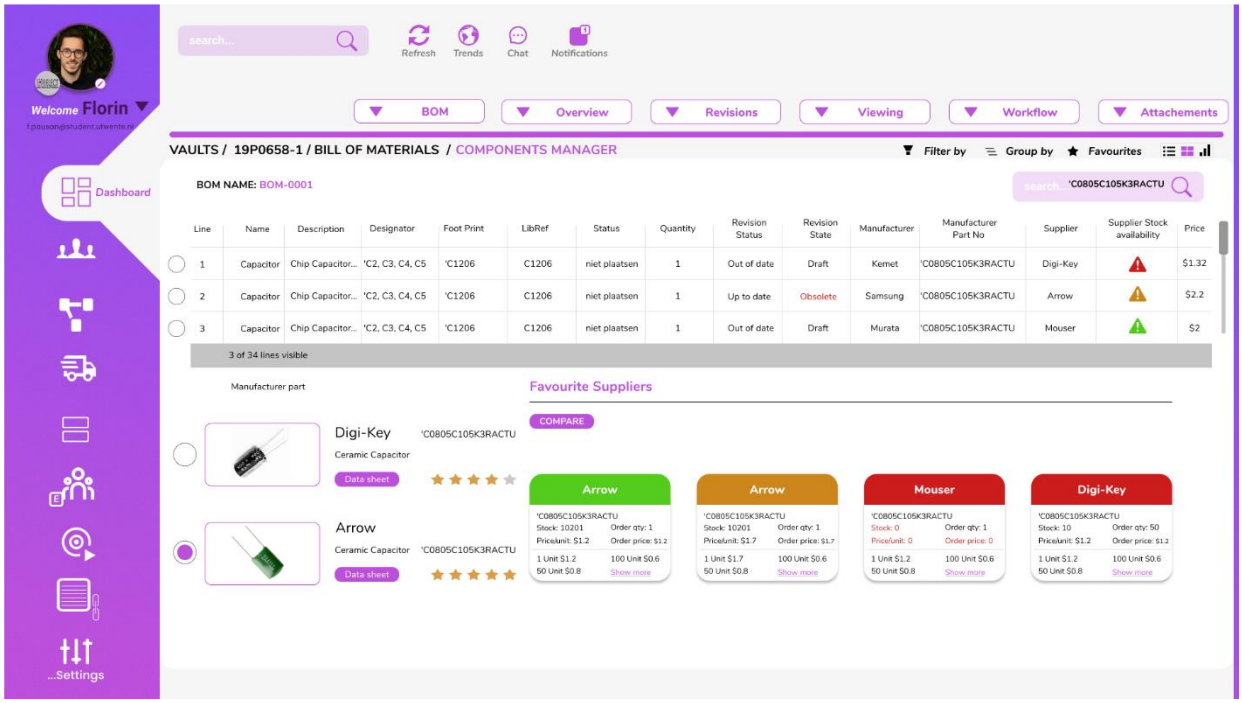


Figure 26 Inventory management system - comparison

Aside from the three quantifiable variables, the purchaser is choosing a product also based on the quality of the component. Compared to the price and on-time delivery information that can be directly deducted from the supplier database, the quality aspect needs constant input from the purchasers based on previous experiences so that the system can learn to precisely indicate the right vendor to supply goods. Thus the purchaser can rate the supplier through a 1 to 5 stars rating system where 1 means that the products have poor quality and 5 means that the products are fully satisfactory. It is to be noticed that

the image above already indicates the quality of the suppliers, where Arrow is rated with 5 stars and Digi-Key is rated with 4 stars. This is the result of the previous evaluation of suppliers' performance. The PLM system should in the end be able to scan through the information and automatically suggest based on the parameters (price, quality, delivery date, reliability) which are the most reliable suppliers. However, the system will not automatically choose the components and the suppliers. The purchaser does this manually only after a clear checkup of the selection. This leads to a concise validation process of the suppliers within the PLM system. Additionally this information is useful for the time when Company X will consider analyzing the supplier performance in the dashboard.

Further on, to increase the chance of choosing the right supplier that meets the requirements, the purchaser can also select suppliers and have a head-to-head comparison between them. This decision is also facilitated by having quick access to the technical data of the components. As soon as the component is determined, the purchaser can just click on the component to select it and place it in the BOM.

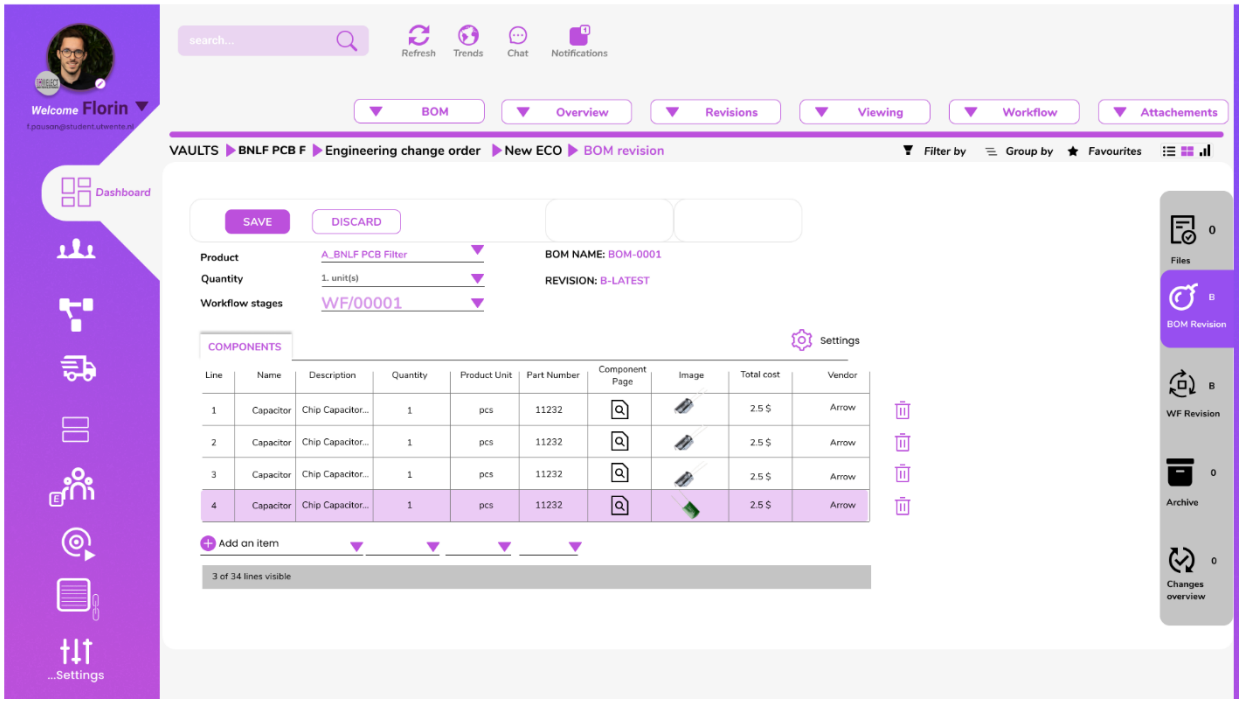


Figure 27 BOM view - edit mode

The moment the component is selected, it will appear in the BOM (Figure 27) and its technical data sheet will also be linked to the BOM. This example resembles the addition of a new component to the bill of materials, however it does not provide an overview on how this addition can be made from the local inventory management system which in Company X's case is the ERP system. This example highlights the way the system is linked to the supplier database from where the engineering and manufacturing team can decide on the best components.

Jumping back to the engineering change order screen (Figure 28) that is displayed in the "in progress" stage, the user now can notice that the change that was just made to the bill of materials is displayed in

the BOM changes panel. This will allow the users to track and trace as well as capture all the changes that are happening to the product data, thus providing the singularity of the product data

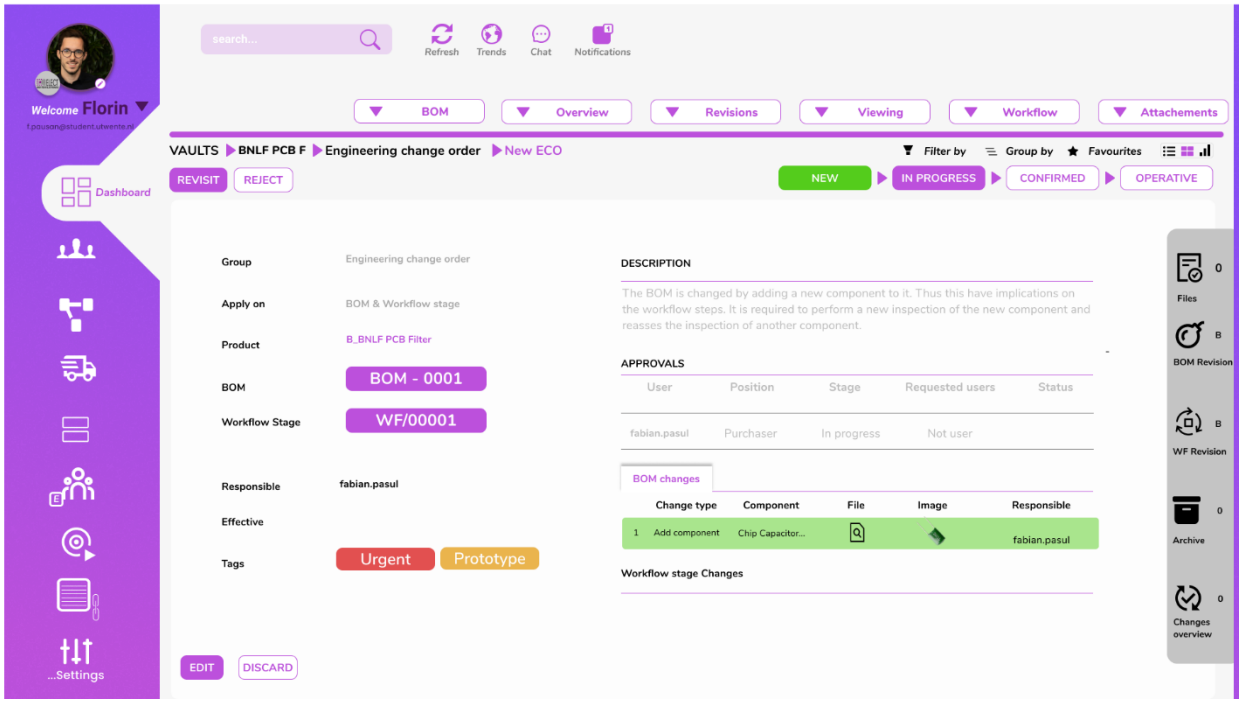


Figure 28 Engineering change order - BOM new component

6.4.15 Workflow change

Scenario: Due to BOM changes and component structure, the product requires new production processes. Additionally the user needs to perform a new inspection on **component Y** on it and bring changes to another product step by adding a new inspection of **component X**. The user in this case is the purchaser who is generally performing this procedure.

Process: The user enters Workflow stage revision B screen by clicking the button “WF B” placed on the right side of the display. The platform displays the previous workflow that requires adaptation to the new requirements. Figure 29 displays the existing processes registered for this particular product that emerged in previous revisions. The process of setting up the workflow stages and how it contributes to the internal process in comparison to the current state is explained in Appendix 9 Workflow management.

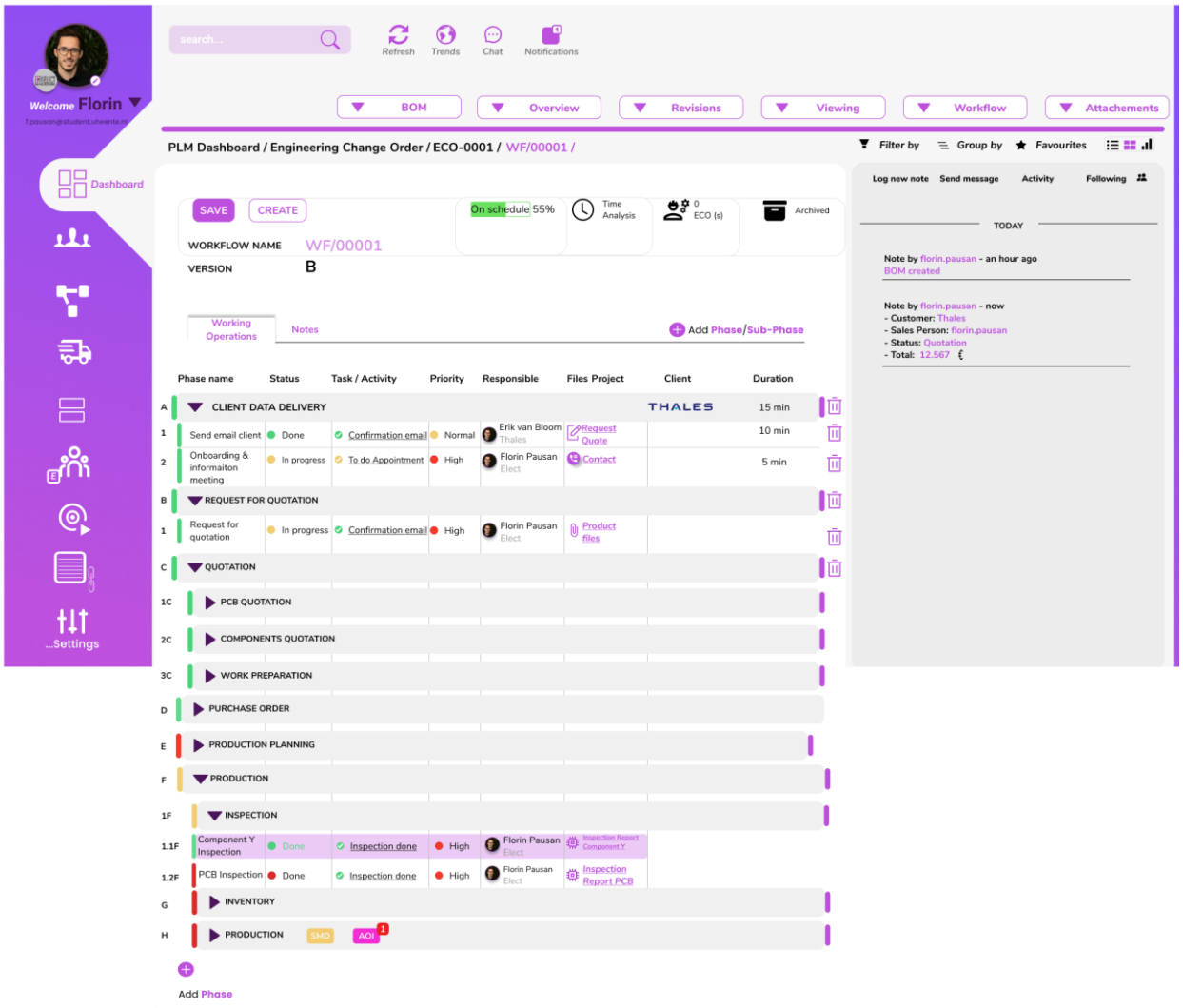


Figure 29 Workflow management

To simplify the understanding of the change the example shows how the inspection is performed on the product and how a new process step can be added in the system. First operation in line is the inspection of the **component Y** that the purchase needs to execute. The purchaser goes to the Inspection stage and clicks on the button called “inspection report component y”. An online form appears automatically on the screen as seen in Figure 30. The inspector performs the check and at the end saves the report to authorize the changes.

Save

Complains report

Notify supplier

Notes & Tasks

F- Incoming Inspection Report PCB

Supplier	Würth	Client	Denkon
Packing slip no.	L301157/0467	PCB artikelnr.:	A-D223353A-[redacted]-A
Navision order intake	195868	PCB description	[redacted]
Project number	19P0658-1	Quantity	15
Delivery date	20-11-2019	Inspection date	22-11-2019

PCB inspection Check List

	Description	Sample	✓	Notes
1	Printversie/ revisie conform bestelling klant order	20	✓	
2	Logo's aanwezig; PCB fabrikant / UL	1	✓	D2234435_A
3	Produktiedatum / batchcode aanwezig	1	✓	
4	PCB elektrisch getest en rapportage aanwezig (eventueel impedantie rapport)	1	✓	
5	Afmetingen (LxBxD), Uitsparingen en afschuinen. Check o.a. etched connectoren.	1	✓	
6	Tekstopdruk (Silkscreen) conform specificatie/bestelling	1	✓	
7	Diameter gaten, wel/niet doorgemetalliseerd	1	✓	
8	Via hole filling (epoxy, koper, soldermask)	1	✓	
9	Alle layers aanwezig	1	✓	
10	Finish volgens specificatie	1	✓	
11	Peel-off conform specificatie	2*	✓	
12	Freeswerk (tekening, bramen, koperresten)	2*	✓	Sample rate
13	Positionering / centrering eilanden-gaten. Per gatdiameter nagaan of spoor/vlak verbonden is met metallisering	2*	✓	
14	Delaminatie	2*	✓	
15	Vlakheid PCB en finish (met name bij PQFP's en BGA's)	2*	✓	
16	Spoorbreedte (onderetsing; met name bij	2*	✓	
17	Positionering en kleur anti-soldeermasker / peel-off Dikte / niet dubbel aangebracht.	2*	✓	
18	Beschadigingen / verontreiniging	2*	✓	

+Add new item

	Measuring instruments / measuring instruments used:	Calibrated	Used
1	Schuifmaat – Mech 1	✓	✓
2	Gatdiameter set	✓	✓
3	Micrometer	✓	✓
4	Liniaal	✓	✓

	Desired corrective and / or preventive measures	Who	Date
1	Description		
2	Description		

TEST RESULT	PCB Inspector	Batch
Not accepted		PCN 3

Figure 30 Component Y Inspection

At the left of each stage there is a color based label which indicates the status and the progress of each stage as follows:

- Green - the stage is completed
- Orange - the stage is in progress
- Red - the stage is not done

Immediately as the purchaser saves the changes, the screen displays the substage called “Component Y inspection” with a green label (Figure 31).

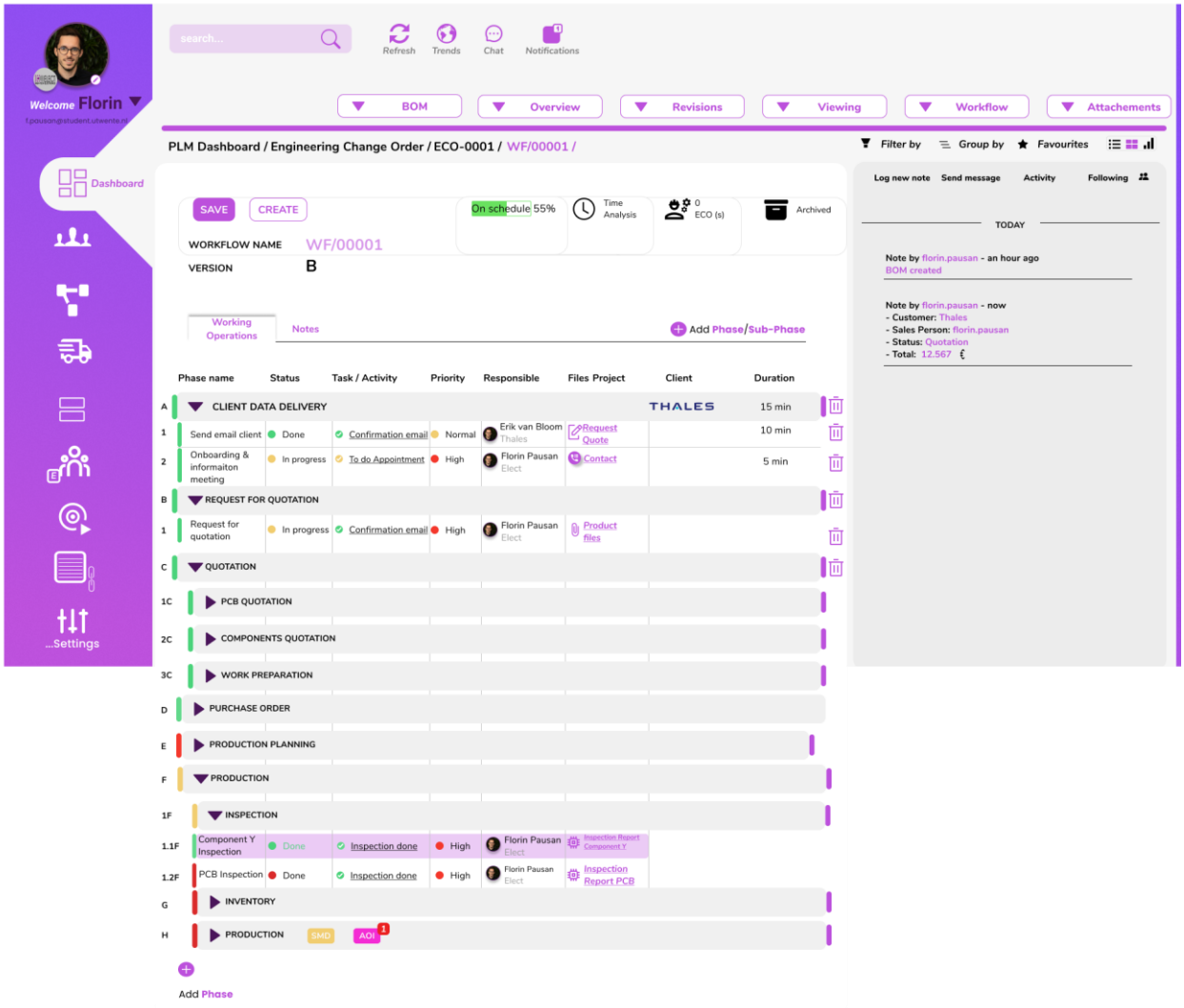


Figure 31 Component Y Inspection Done

With the addition of a new component to the product, the workflow requires rerouting. The user is asked to create a new sub phase in the inspection section for the “component X”. By clicking the button “add phase” a new window pops up (Figure 32) where the user is able to add and select a new sub phase to a

phase. The user selects the phase where the sub phase needs integration by clicking on the drop-down menu and selecting the Inspection phase. The sub phase at its turn is customizable according to the needs of the user. In case the sub phase requires certain forms such as the digital inspection form, or to link people to the sub stage, the system offers the flexibility to customize the sub phase as needed.

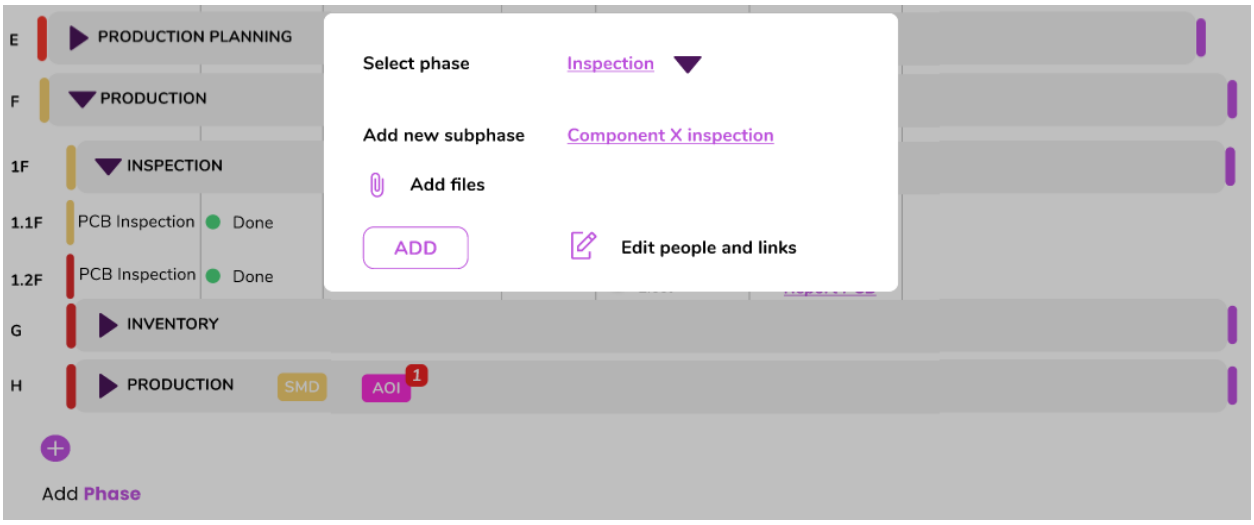


Figure 32 Add sub phase

By clicking the “add” button the new stage is generated, therefore added to the Inspection phase as displayed in Figure 33. It indicates that the inspection of one of the components was performed (green light on the side of the task) by one of the employees as well as the purchaser adding a new sub phase in the inspection stage which represents the new production process step that the manufacturing team needs to execute.

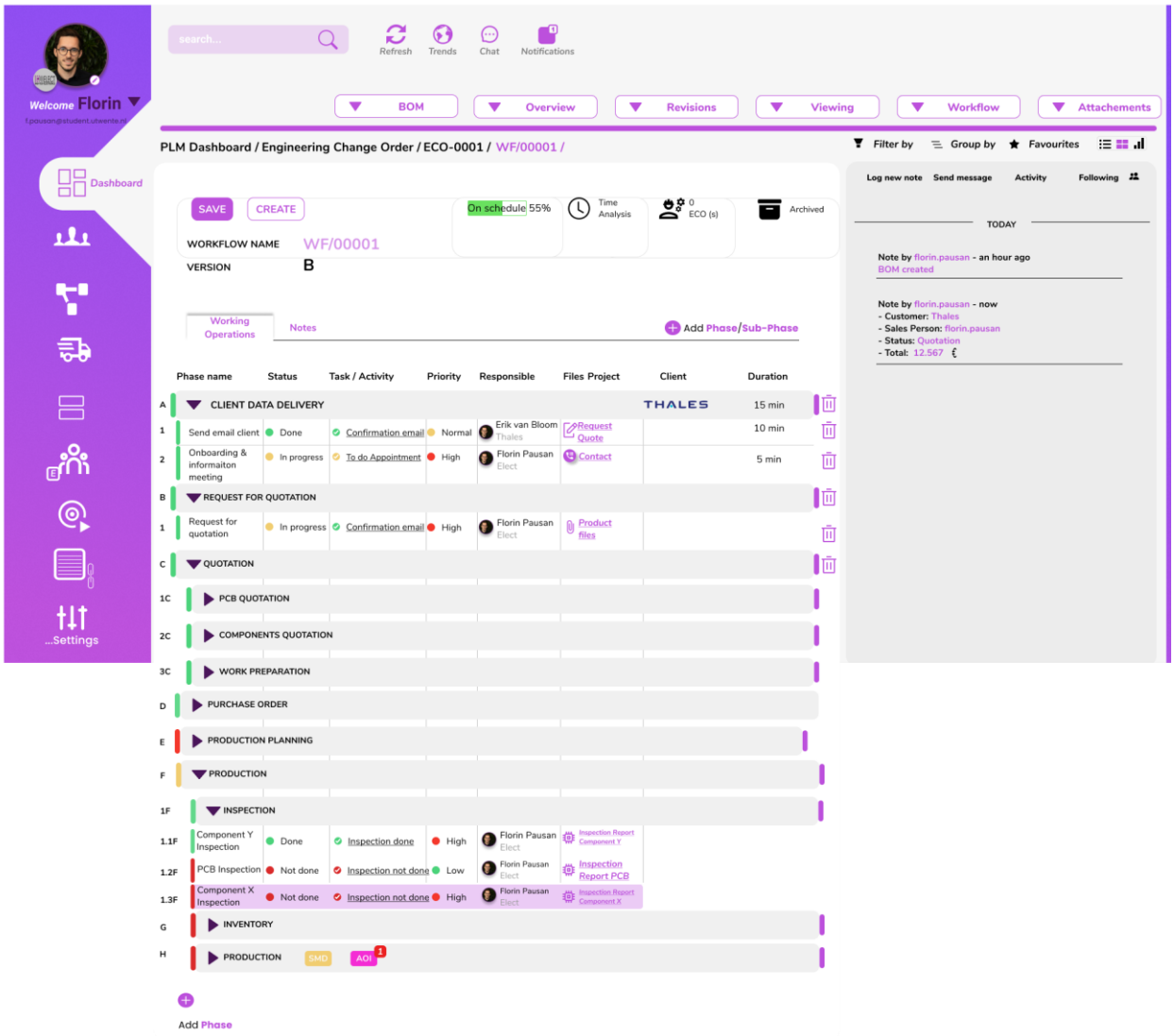


Figure 33 Workflow management - new sub phase added

The changes to the workflow are visible by going back to the engineering change order screen, as seen in figure 34.

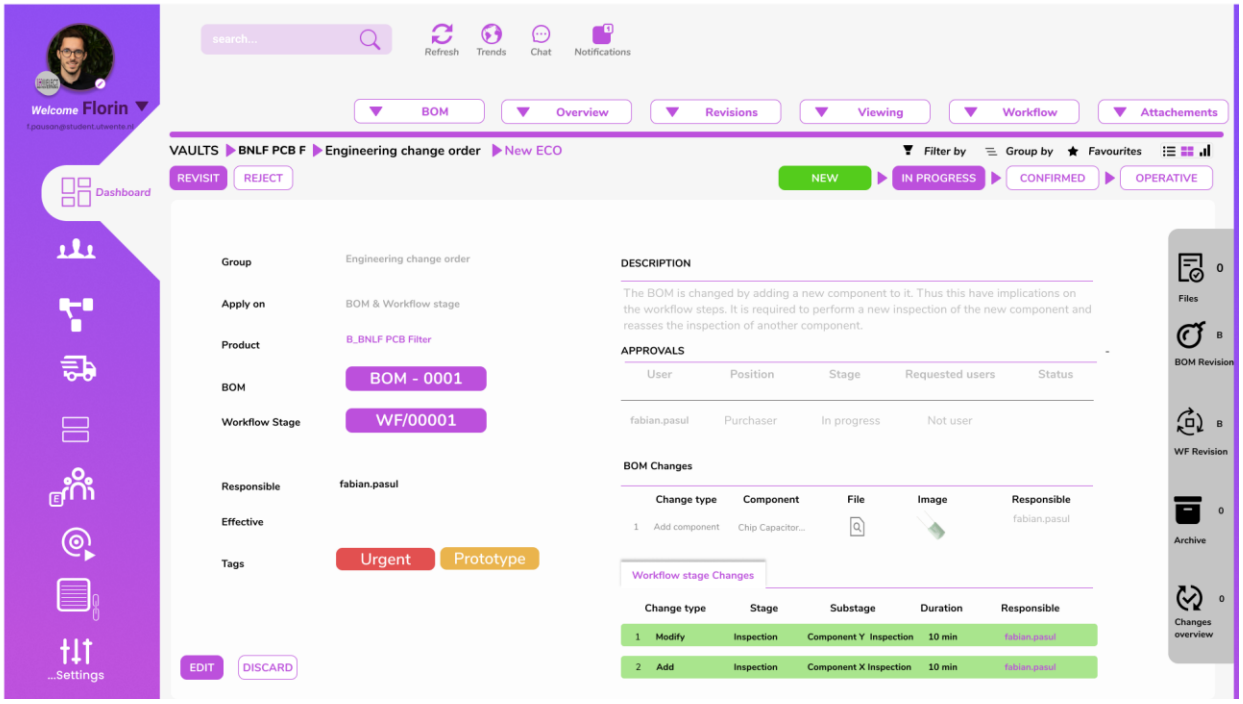


Figure 34 EOC - Modify and Add phase

The approval section displays the people who are authorized to perform the approvals while all changes appear with green.

6.4.16 Reject change

Scenario: Once the changes are done, the approval process starts. The person in charge with the approval receives a notification in the app or through email that changes occurred to the product B_BNLF PCB Filter and there is a need for approving the changes. Now the person that assures the quality of this step is not satisfied with the change that occurred at the product data.

Process: The user rejects the change by clicking the top left button “revisit”. Another window pops (Figure 35) up where the quality assurance person specifies which change is not approved and is able to write observations and add additional files as guiding tools.

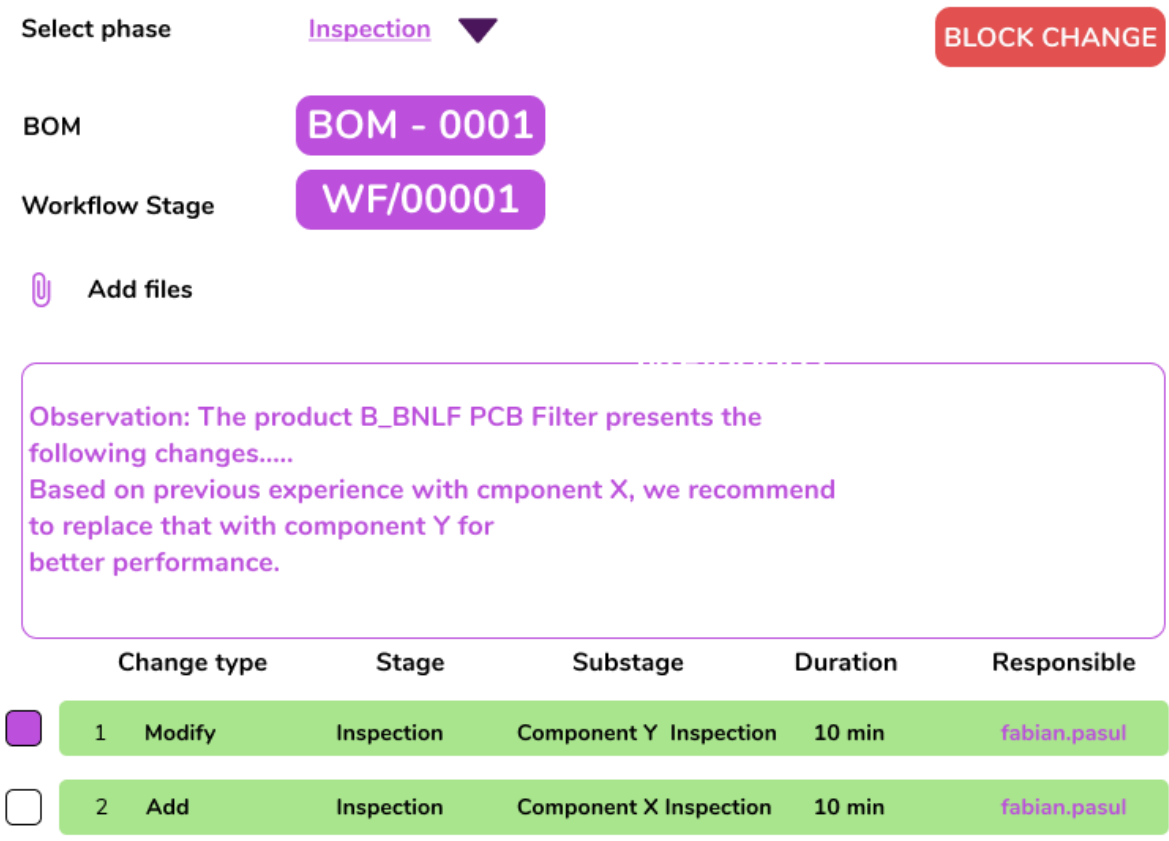


Figure 35 Reject change

Immediately as the user blocks the first change to the workflow it is also displayed in the engineering change order as well as in the Kanban view (Figure 36).

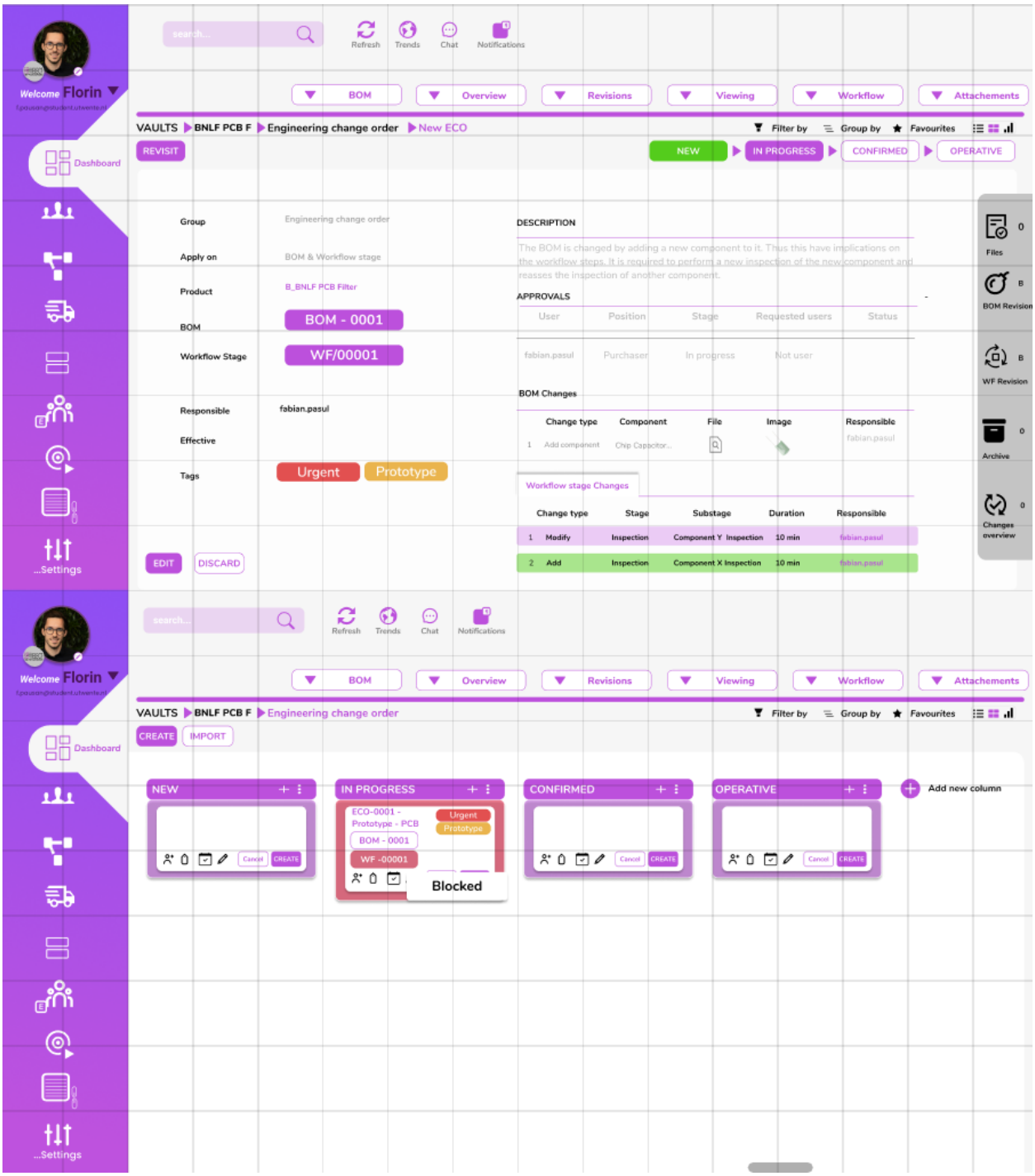


Figure 36 Change rejected - view EOC and kanban

This stays blocked until new changes and approvals are executed.

6.4.17 Approve change

Scenario: the user approves the changes.

Process: By approving the changes to BOM and WF the system moves the process in the “Confirmed” stage. With each transition from one stage to another, the users who are linked to each stage are notified and can follow in real time changes. The “In progress” stage represents the stage where the changes are made and validated for the first time. The Confirmed stage represents the stage where the changes to the new version of the product data are validated for a second time. This is an extra validation step of the product data in order to assure the fool proof of the process.

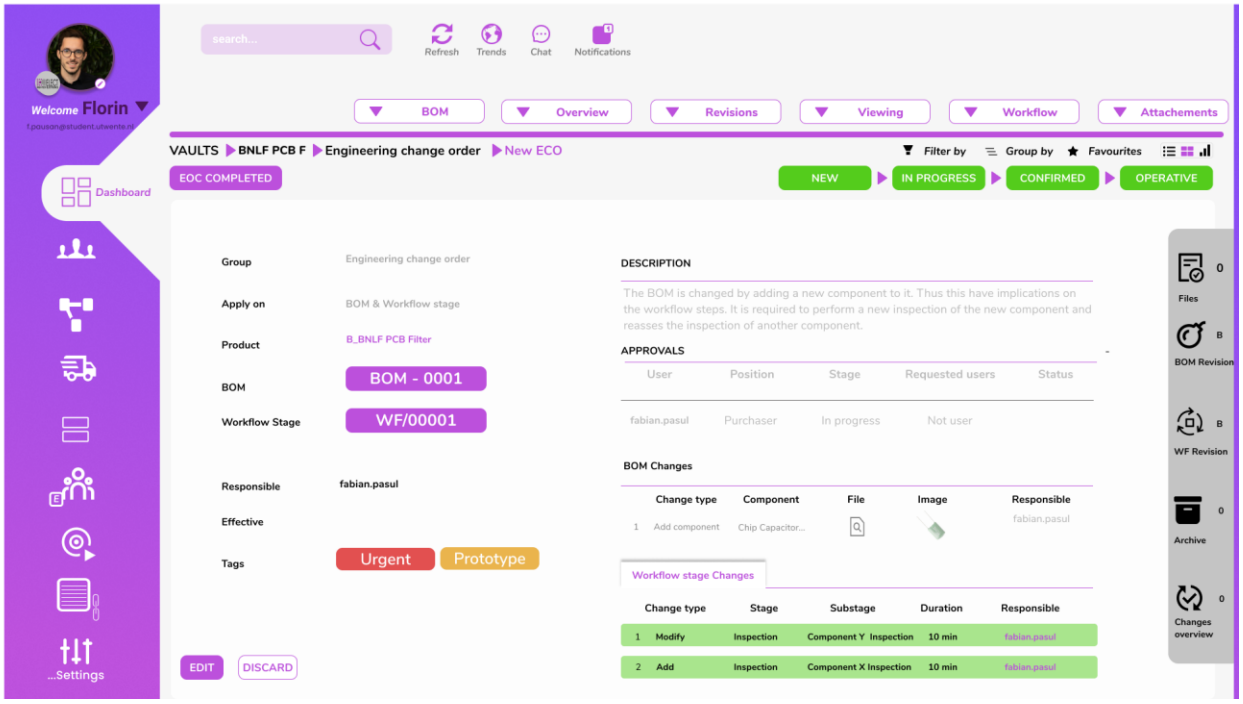


Figure 37 Confirmed EOC

When the user applies the changes, it means that all products similar to B_BNLF PCB Filter are using the version B of the bill of materials and workflow and the changes are operative as displayed in Figure 37.

The product data change arrives at the end and is validated by the users through the PLM system. This is displayed by the system in the Kanban view.

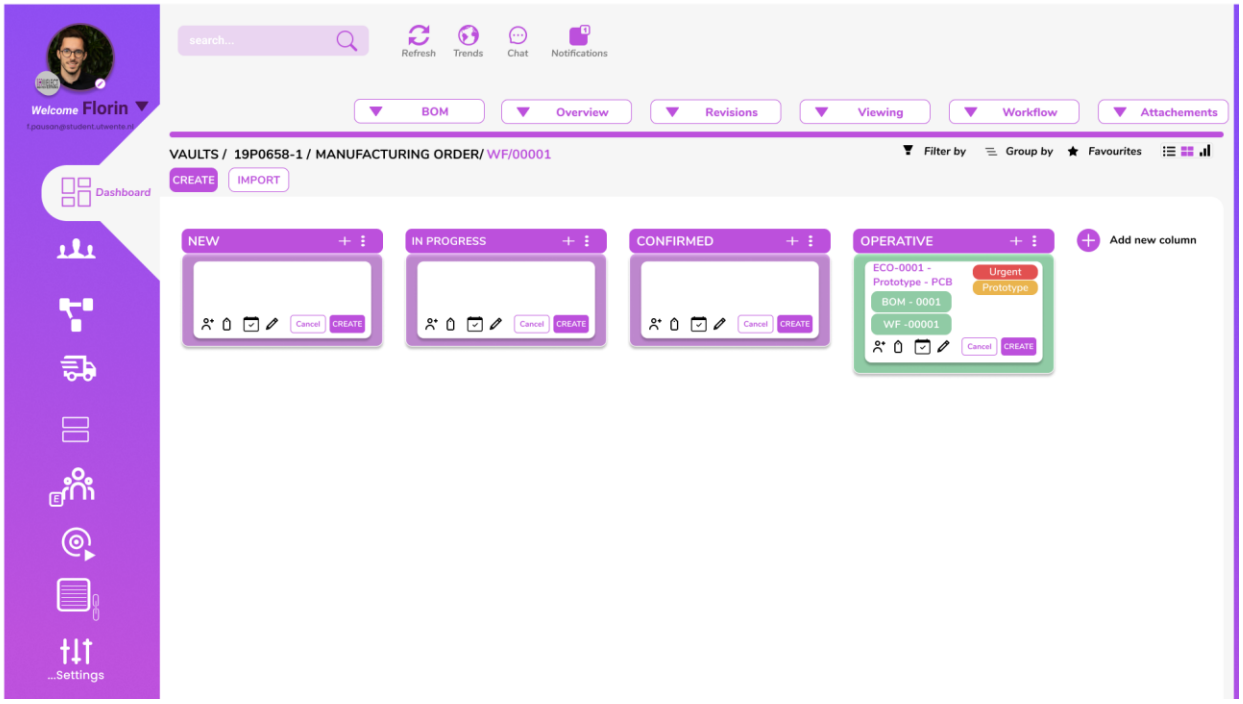


Figure 38 Kanban view validation

If the user would want to have an overview of the changes and notifications that arose during the revision process then it can access the changes overview display by clicking on the "changes overview button" as displayed in Figure 39.

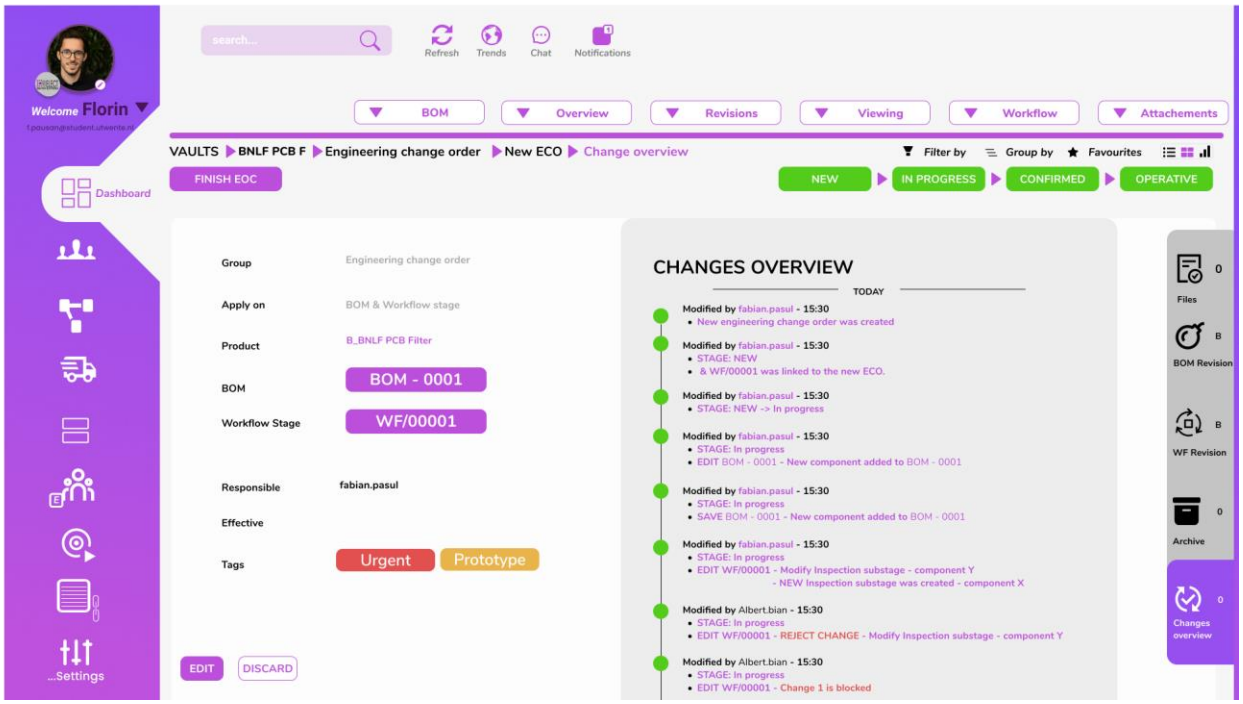


Figure 39 Changes overview

6.5 Additional features

The platform incorporates additional features that weren't presented so far.

6.5.1 **Dashboard**

The dashboard integrates an overview and business analytics that relate to the performance of the company, suppliers, customer satisfaction, and performance of projects, people and products. The dashboard allows Company X to determine churn rates, determine customer satisfaction and it gives access to compelling data visualization based on which the management staff can take fast actions. Please refer to Appendix 17 Dashboard management that includes the link to the dashboard prototype.

One feature that relates to the PLM sphere is product analytics. Figure 40 displays how the dashboard aggregates the product data. The system it provides general information about the product such as:

- Product stages or workflows
- Total suppliers
- Total costs
- Product versions and others.

Additionally the costs can be divided and visualized per stage while it displays information that gives an understanding of the changes at BOM and WF level. The analytics are just an illustrative part of potential functionalities and it does not resemble the real data that is aggregated.

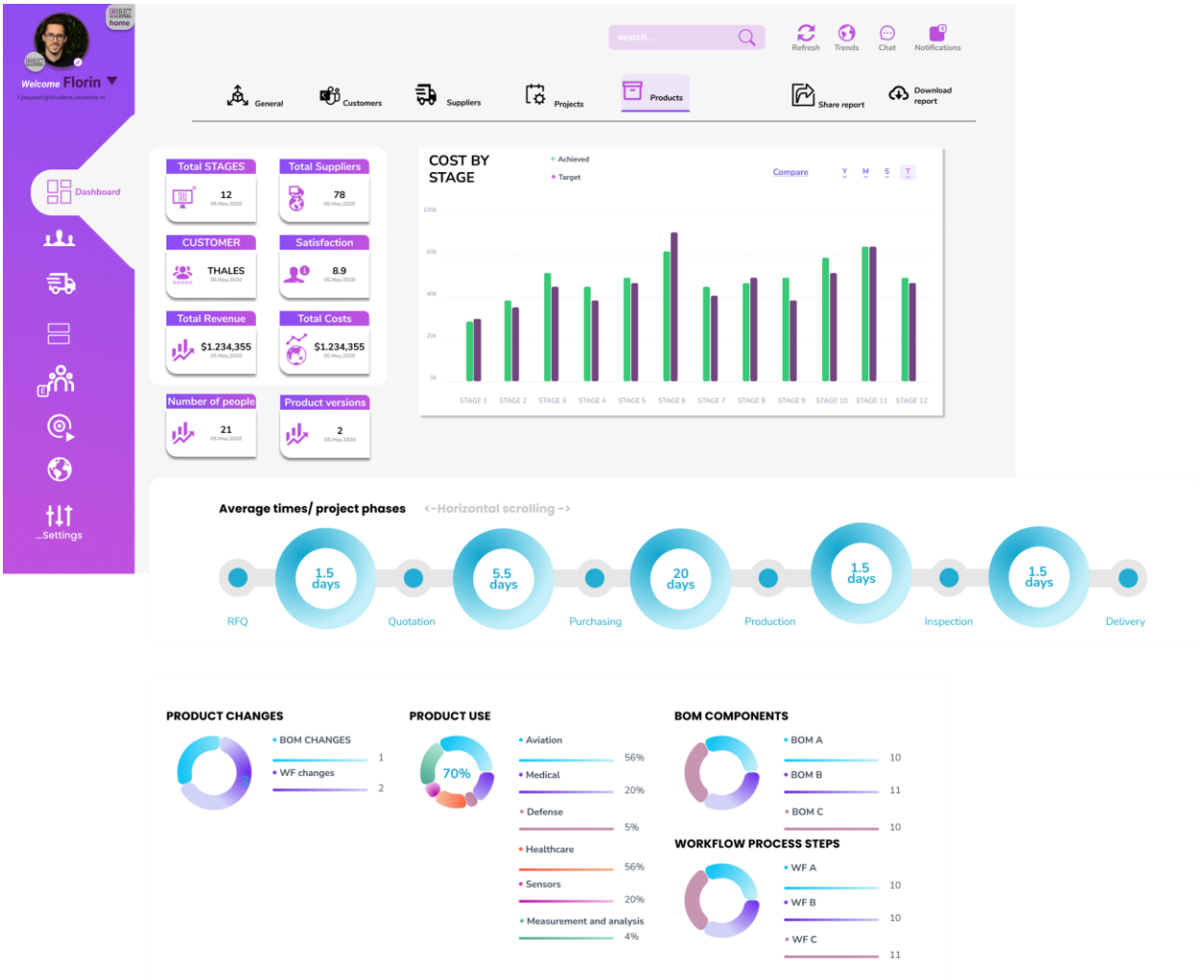


Figure 40 Product analytics

6.5.2 Project management

This includes information and screens that allow users to perform activities, record hours, register tasks with the scope to meet the objectives of the projects. All data that results from this section is aggregated in the dashboard application where is displayed in the shape of graphs and analytics. Appendix 18 – Project management platform gives an overview of the main functionalities that the platform entails aside from the already presented ones in the PLM platform.

Additionally the platform presents additional features such as responsive design or file edition and coding. Appendix 10 Responsive design goes in detail about what it entails.

7 Testing and Evaluation

This chapter captures the testing and evaluation procedure of the proposed solution. Usually the testing and evaluation of such systems is framed in multiple sprints to assure effectiveness and quality of the results so that the customer needs are met during the development of the tool. Due to time constraints the testing and evaluation is compressed in one session that integrates a discussion with the internal stakeholders related to the functionality of the system. In addition to this interview, the management staff was in touch with the results and gave constant feedback.

7.1 Scenario testing and evaluation

The requirements list served as the guiding element in testing and evaluating the PLM platform. The testing and evaluation procedure was at first set up on focus groups to analyze certain parts of the solution with specific users; however, Company X employees suggested conducting this phase with all stakeholders in the same meeting due to time constraints.

This limited the procedure from having two hours designated for each particular user to having about four hours assigned to all users. This implies that further testing and evaluation is required later on in the development process.

7.1.1 Procedure

The testing and evaluation procedure lasted four hours and was divided into two main categories as follows:

- Thirty minutes thesis presentation that incorporates the initial problem statements, analysis results, PLM principles and further directions of the project so that Company X employees can have an overview of the current state and the desired state. This help the users to have an in-depth understanding of what PLM and contextualize the current state.
- Three and a half hours testing and evaluation meeting where the focus was on the PLM application.

The following testing and evaluation methods were carried out:

- The solution principle is evaluated based on the basis of requirements specifications and how these platform functionality meets the requirements.
- Another type of testing and evaluation used is the usability and single click testing which tests and examines the usability and intuitively of the platform.

Several scenarios are created to measure the PLM characteristics and to contextualize the testing and evaluation procedure. The scenarios are an integrated part of the PLM application subchapter. Thus, the testing and evaluation methodology proposes several contexts in which the users are asked to perform activities in the prototype. In addition to the guided session, the approach also incorporated open discussions to capture qualitative data and touch upon the requirements and the functionality of the interface. The questions focused also on the usability of the platform. Thus the users were asked to point out buttons or commands in the platform that perform certain actions.

The following stakeholders participated in the testing and evaluation procedure:

- Two account managers
- PCB Purchaser
- Production planner
- Project leader
- Component purchaser
- Work preparation employee

7.1.2 Testing requirements list

Table 2 Testing requirements list

	Requirement	Observation
Purchasing		
1	The platform should allow the purchasers to make decisions based on insights about relevant information retrieved from the supplier database.	The API connection to the supplier database offers the possibility to enhance the purchasing process by having real-time access to component information delivered by various manufacturers. The system stimulates the purchaser to take faster decisions, by having a clear overview of quality criteria delivered by each supplier. This allows the purchaser to have a quick comparison process of the products and suppliers.
2	The system should be able to provide tracking and scheduling capabilities, which enable the company to manage product development along with resource allocation in real time.	The proposed system displays features in the workflow and BOM screen that allow users to track changes and product data across the development phase. The user interface facilitates an easy allocation of resources which is divided in several categories: 1. Business that integrates reports and logistic data. 2. BOM that comprises the item data 3. Workflow stages that integrate processes, tools, activities and people.
Traceability		
3	The PLM system should allow for backtracking the decision making process by employees who have the authority to perform the check.	The system allows users to perform certain tasks, edit, view data only if prior to the activity are connected to the data.
4	The PLM system should allow tracking and tracing of the decision making process and document all decisions emerging during the development process.	The PLM interfaces aside from the email and phone integrations that capture the decision making process, presents the feature called “changes overview” where the changes are related to people, processes, time and activities. Thus this allows capturing of the decision making process.
5	The system should be able to provide an overview in the current status of the order, which is updated in	The workflow operation window provides an overview of all steps and processes that the product data needs to pass through. Every stage has a label that indicates the status of each phase. All the overviews can be shared with different stakeholders that can have the option to visualise, edit and suggest changes to the process

	real-time and can be viewed by all stakeholders.	and product data. The system is supposed to offer real-time data. However this is complicated to test.
6	The PLM solution should be able to track and trace quality checks.	The last two requirements are addressed through the kanban view or in the workflow stage. The system allows users to perform quality checks at different stages and displays who performed the checks and the rest of activities.
7	The PLM solution should be able allow tracking and tracing of employee activities	
	The system should be able to notify and update the authorized users when a change is made	The notification system is connected to the product data. Immediately as a change is happening all the people connected to product data are notified.
	The PLM solution should provide a clear overview on the product data version history and a clear guideline on which product data version the latest edit was performed.	Completely met The BOM and WF constantly provides an overview of the latest revisions of product data. An overview of version history is not captured in the design.
File format		
1	The system should be able to comply file formats used within Company X	The two requirements are of high importance when it comes to the duration of the product development cycle. Company X complains of long file conversion processes due to missing different file formats that manufacturers and customers are using. This is addressed through API connectors that allow the system to interconnect and automatically exchange and format files and data in the desired format. Additionally the PLM system proposes integrated file formats that will capture the data directly in the PLM system without having the need to store the data locally and after being validated to transition it to the PLM respectively ERP system. The solution is designed in such a way that the users are able to create and manage different file formats directly in the platform.
2	The system should be able to comply with file formats used by customers and suppliers.	
3	The system should allow users to edit and program file formats within the system	One example that allows that is the Inspection list. Another example is the questionnaire in the platform. The system should be capable of creating and editing word, pdf, excel, CVS files etc.
4	The system should be able to extract data from different file formats and compile it in the desired format.	
5	The system should be able to transcript file formats into the desired format.	This is not demonstrated.

6	The PLM system should allow users to edit, view files based on their administration rights	The PLM concept demonstrates how the users are able to view, edit or assign other people to validate the product data. For this requirement there is a clear example in the revision of BOM and WF.
7	The system should be able to fill in forms automatically with preliminary information	The system is supposed to be able to fill in data or suggest. However this is partially proved in the Request for quotation process.
8	The PLM system should allow users to standardize formats.	BOM is one of the examples. When the user imports a BOM file the system allows the user to standardize the format based on the process requirements. This requirement is met because the system allows different perspectives to agree upon the composition and shape of product data which enhances standardization. On top of that, the solution proposes an API connection that will aid the system to convert and standardize file formats from external stakeholders into Company X's desired format.
System integration		
9	The PLM solution should be able to offer cross-functional collaboration between stakeholders.	The system is designed to facilitate collaboration and integrate with other systems. This is one of the main pillars of the systems, to facilitate cross-functional collaboration between stakeholders. This is done through the chat area as well as via the extended PLM functionalities that allow users to collaborate and agree upon product data.
10	The PLM solution should be able to provide open BOM reflecting costs of individual components.	Completely addressed. The proposed BOM contains an open structure thus everything linked to the bill of materials will be transparent. Component costs are always visible in BOM.
11	The PLM solution should be able to notify users about any changes in the solution system	
12	The PLM solution should be able to integrate with the ERP system and allow direct and automated sharing of engineering and manufacturing information	Completely addressed. The proof of concept is constantly communicating with the ERP system. PLM system is the master system that populates the ERP with the BOM.
13	The PLM solution should be able to integrate part of the functionality of Barbone/backbone	This requirement is partly tested and evaluated within the process. Considering that the two project management systems are having extended functionalities, it was complex to convey all their functionality into this concept. Thus, the concept covers only several features that barbone/backbone have, just to highlight the redundancy of the actual systems and to provide a solution on how this can work in the PLM environment.

14	The system should convey supplier connectivity through API connectors that provide information for quotation, procurement.	API connectors are some of the main elements considered for the backend solution. However this is not possible to be tested.
15	The solution should give the flexibility to integrate different CAD systems and communication systems (emails, calls)	Partially met, The system proposes a customizable and scalable solution that can integrate with multiple interfaces. However except ERP, email and phone no other systems are assessed.
16	The system should integrate the internal inventory management system	This is addressed. The proposal meets the requirements by allowing users to access the internal and external inventory management system
17	The system should integrate external inventory management system	
18	The solution should work on all operating systems	Not met. This is not considered.
19	The systems should be able to provide an open source framework	Partially met. This proof of concept provides an open source framework.
20	The system should capture data that is in relation to other entries	Completely met The system is able to capture data that at first is stored in the ERP system.
21	The PLM solution should be able to function in browser, desktop, tablet or app interface.	Completely met The proof of concept presents 3 iterations where the system is displayed in a tablet, laptop and phone screen.
22	The system should be able to allow data integration	
Training		
23	The system should integrate a knowledge transfer platform	Not met The system is not touching upon training and knowledge transfer platforms.
KPI Dashboard		
2254	● The PLM solution should be able to	Completely met

	aggregate the customer overview, performance, satisfaction	The dashboard platform aggregates all analytics about the customer and supplier providing insights into satisfaction, performance, etc.
25	• The PLM solution should be able to aggregate suppliers overview, quality, performance, satisfaction	
26	The PLM solution should be able to store, analyze and arrange the product data in understandable manner.	Completely met The product data as well as the project data are displayed in the analytics page in an understandable manner.
27	The system should be able to identify risks within the project portfolio	Partially met the platform is supposed to integrate artificial intelligence and spot risks and errors. The inventory management system provides an overview of the suppliers and is able to a provide comparison between them in order to exclude risks.
28	The platform should compile and aggregate all the findings from customer feedback and complaints into a clear dashboard	Completely met The platform integrates questionnaires that capture the customers' feedback and complaints and is displaying it in a dashboard.
29	The platform should automatically define the KPIs and shape them into form of analyzed data, and dashboard.	Not met
30	The platform should allow Company X extract the quality dashboard.	Completely met The platform allows users to download quality and logistic data.
31	The PLM system should be able to perform analytics and provide low and high level KPIs for all stakeholders	Completely met The dashboard platform provides the view and required functionality where all KPIs are defined.
Collaboration		
32	The PLM software should be able to align different perspectives of product information (e.g. the	Completely met, The system integrates functionalities that allow different departments to collaborate and agree upon product data

	financial, engineering, manufacturing, etc.) The system should allow collaboration of stakeholders with the aim of defining the product data	
33	The PLM solution should be able to manage, visualize and share up-to-date BOM information across the organization in real time.	Completely met. The Open BOM structure displays at all times if the BOM is up-to-date and if it is synchronized with the latest changes.
34	The system should be able to provide means for validation of product data.	Completely met The system provide features that allow validation of data
35	The system should be able to provide means for planning and validation of manufacturing processes.	Completely met The users are able to plan and validate various manufacturing processes that relate to product data.
Usability		
36	The PLM solution should facilitate an easy to use, straightforward interface. Buttons and icons should be self-explanatory	Partially met This is hard to evaluate given the amount of buttons and functions. However most of the buttons are self-explanatory.
37	The platform should allow the users to maintain task relevant data within the sight while the users navigate through the interface.	Partially met The users are most of the time working in the PLM environment that is easy to navigate.
38	The platform should allow the users to undo or redo previous activities	Completely met This is a function that most of the platforms
39	The system should be intuitive and leave space for establishing the best practices in handling data.	Completely met, The system is intuitive, it has easy to understand buttons and functionalities and it provides freedom to establish best practices.
40	The PLM solution should be able to provide the possibility to compare business statistics within a specific timeframe	Completely met The dashboard provides a comparison based on years and months

41	The solution should be able to allow users to set access levels to sensitive library information items based on specific roles or group hierarchy.	Completely met The user responsibility is set through the platform while setting up the stage or creating a new product.

7.1.3 PLM characteristics evaluation:

Furthermore the testing and evaluation is touching upon the PLM characteristics and .

Singularity: The system provides the possibility to link the product name or product code to the bill of materials, production processes, people and tools. The system is capable of capturing 3 dimensional data as follows:

- Business data that integrates everything from service satisfaction reports to logistic data.
- Product requirements and the bill of materials that provides an open cost structure and components data
- Workflow data that incorporates product processes, people, tools and tasks. This also provides the routing of process operations, approvals, and notifications that are sent between users. Additionally capabilities for project management allow users to plan schedules, tasks and track those to completion.

These three dimensions are built into a product vault where the users can collaborate to build up the product data and eventually validata it by assigning different people to different validation points. This vault acts as the singular source of truth and all the product data is first linked to the product name. Further one the BOM connects all the component data including costs, vendors, quality and technical specifications of products. When explained to the internal stakeholders this became clear and obvious that the version of the product data can be agreed by everyone who is participating in the development process. Moreover, the design tracks and monitors all the product data changes from one version to another version, thus it always indicates the last adaptations and the last product data version. This increases efficiency and the decision making process.

Correspondence: The connection between the physical product and its digital twin that comes in data format is highly associated with the extraction of data. This characteristic can be only tested if the system is functional. However the approach in this case was to assume how this can work. Thus the solution illustrates how different file formats are automatically capturing information, which in this case is increasing the chances of connecting the physical product to its data version. The test users suggested that for this to happen, the production employees need support for change management as well as a concise implementation and training course. Moreover by automating files and conversions of files this will help Company X to build the correspondence between the physical product and its data. However, during the discussion it was pointed out that especially for this PLM principle a functional system is required to properly test and evaluate it.

Cohesion of views: The system allows users to approve or reject data as long as they are responsible for the project and the customer links the right people to the product data. The kanban view highlights how the engineering department and the manufacturing team can collaborate and conduct changes to the bill of materials and the workflow operations. During the interview, the users notice the possibility to have an alignment between different departments or between internal and external stakeholders by assigning roles and responsibilities within the platform. The platform also provides an overview of all processes, tasks, statuses, and people therefore decisions and changes can be requested fast from the qualified employees, thus assuring the quality of product data. The employees mentioned that this provides a clear perspective on the potential impact that one employee may have on another.

Reflectiveness: As in the case of other PLM characteristics, this is hard to evaluate and test due to limited functionality of the design. However it is noticeable that due to automation of file manipulation and regulatory compliance set through the system, the solution has the potential to capture faster a change to a physical product. The virtual counterpart as seen in the solution principle can capture engineering change more rapidly compared to the current approach where all changes are communicated either through email, phone or through meetings.

Cued availability: The usefulness of the product data can be determined only if the right information is imported by the right people at the right time. Additionally the right people also need to validate the product data. In this case it was assumed that the customer is requesting a new product revision. As described in the solution principle the product data needs to pass through different stages in the kanban view which need to be accepted or rejected by qualified users. This is a mechanism that assures that the data is correct and reliable. In case the data is rejected the system will not allow the users to go further in the process, thus it needs constant approval to assure the correctness of product data by the right people.

Traceability: the vault structure provides easy to follow product data changes. The users were able to understand how the path of product information can be seamlessly followed back to its origin. The chat area that appears on the right side of the screens when changes are made, allows users to follow back the changes and the product data progress. Moreover, that section also illustrates the person who performed the change, thus it is easy to follow all important elements that contribute to the product data (people, processes, activities, data, messages).

7.1.4 Usability and Single click testing

The single click testing incorporates the following methodology that is used for this project:

- The users are presented with a scenario where they had to execute and create different tasks, thus different screens were shown during this stage.
- The users were asked to types of questions
    - Where do you click to perform or create a task?
    - How easy was it to find the features to perform or create a task?
- Because the prototype does not link all buttons and screens between each other, the path to complete each task was guided by the researcher in case the user were not able to find certain features of buttons.

Example of questions:

- Considering figure 41, where would you click to enter the bill of material view?
- How easy was it to find the bill of materials?

Overall the users were satisfied with the ease of use that the design proposes. During the testing and evaluation each application (dashboard, PLM and project management) were covered with questions that relate to a single click procedure.

The main observations and strong points of the designs were related to the button design that has on it or next to it a guiding text that indicates what the button is supposed to do (See figure 41). This also helped the user to easily find the buttons and features.

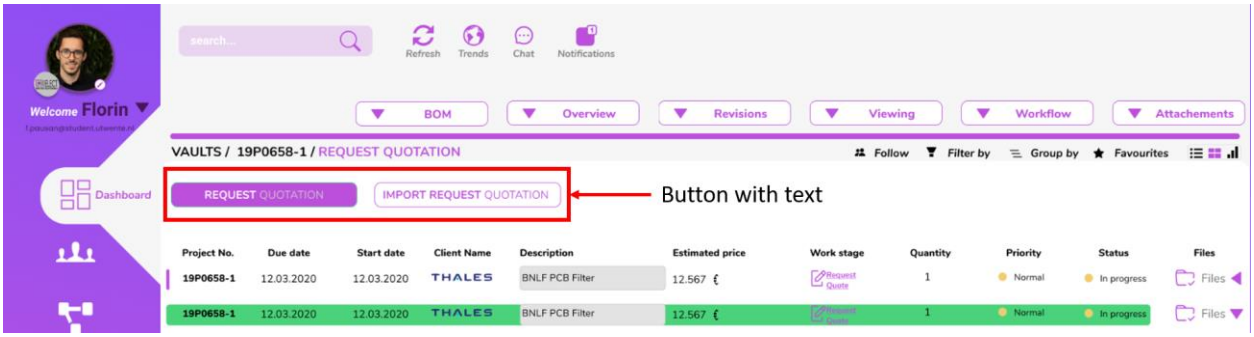


Figure 41 Intuitive design

Moreover the users appreciated the clean design, that does not display only blended, neutrally colored tables, but it provides interactive tables that also provide color based indicators. Figure 41 is one example that was pointed out. The system uses colors to indicate different stages of tasks, different product and project status which enhance the prototype usability.

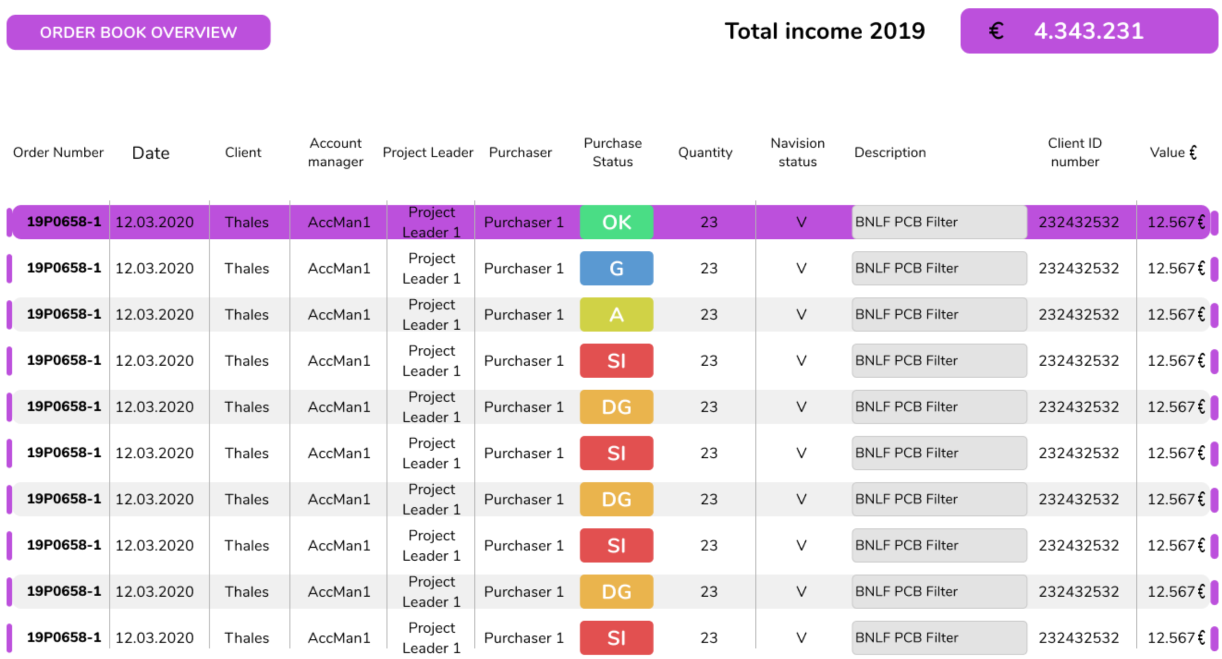


Figure 42 Intuitive design 2

However this does not guarantee that the system is fully intuitive and the efficiency of use if met. The usability testing is recommended to be carried out across multiple phases and in sprints that address different parts of the system. This assures that the design provides the right quality and user experience when interacting with the PLM platform. Like that the effectiveness, efficiency and user satisfaction regarding the solution principle can be captured, thoroughly analyzed and evaluated.

This procedure is recommended to continue into a design that provides a clear understanding of the system, architecture and navigation of the platform.

7.2 Conclusion

The solution covers all the PLM characteristics and the requirements that revolve around them to a certain extent. These characteristics can be fully tested and evaluated only when a full functional concept is developed. The singular source of truth of the product data can be met by meeting these requirements and the functionalities that are developed to address the requirements specifications. Moreover, employees can get an understanding of different perspectives, as well as track and trace change to the product data which will facilitate a faster decision making process.

8 Recommendation and reflection

8.1 Recommendations for further work

The following section includes the recommendations that Company X should consider for further development of the PLM solution. This offers Company X the handles to create knowledge and skills in order to properly tackle the further development of the platform.

1. Scan and evaluate findings

There is an increased amount of findings and evaluations with this report therefore it is essential to study and evaluate the findings to comprehend the challenges, implications and benefits of building such a system.

2. Testing and evaluation

Usually the testing and evaluation of such systems is framed in multiple sprints to assure effectiveness and quality of the results so that the customer needs are met during the development of the tool. Due to time constraints the testing and evaluation is composed in one session that integrates a discussion with the internal stakeholders related to the functionality of the system. In addition to this interview, the management staff was in touch with the results and gave constant feedback. It is recommended that the testing and evaluation follow the advice provided through the PLM roadmap. In case the idea is validated, it is important to build the core functionality of the platform that generates the most of business value. This needs immediate testing in order to determine the errors or unwanted features. This leaves space for experimenting with new features.

3. Training

The process to accommodate employees and various stakeholders in understanding and getting them used to the concept of PLM can be often lengthy. The PLM platforms usually include complex functionalities, as well as integrates additional technical vocabulary that is surrounded by abstract meaning. For this reason, Company X should find ways to provide the required knowledge to their internal stakeholders.

1. Market research

    a. Extensive market research on PLM systems

    b. Extensive market research on customers needs

The market research already conducted provides details into the vendors that provide PLM systems that might solve the problem, however it is essential to further study if there is a demand or not for a new business case for Company X and if there the market is not saturated with solutions. Thus Company X should continue studying the market, identify issues, and spot potential customers that are willing to

participate in the analysis and evaluation stage of the business case. Company X should involve the clients and the manufacturers in the PLM development process to assure that the needs are met.

The fact that existing PLM vendors are not fulfilling the needs of SMEs is an aspect that still needs to be considered for further research. Now the study captures the capabilities of ten PLM vendors, however many more other solutions might fit Company X, thus it releases the pressure of taking the responsibility of developing a PLM system. This is highly dependent also on the market needs.

2. Current design evaluation

Considering the time and the complexity of the project the final mock-up integrates most of the requirements; however, it is essential that the concept is divided into multiple scenarios that are tested separately with specific users in mind. Having a user centric approach will facilitate better understanding of the main problems and the main features that the user needs. The ideal situation for this project is to start small with a prototype that integrates the most important functionalities and determine if that is demanded or not. Furthermore, the other set of functionalities can be added periodically depending on the user requirements and response to the new system.

3. ERP system capability study

During this process, what was difficult to grasp was the understanding of the ERP system, its capabilities and how this will mesh-up with the PLM system. During the interviews the functionality that the ERP system provides became clearer, however there is no in-depth research on understanding what is the full spectrum of features that the ERP system provides. The main take away from the analysis phase was that Company X is not maximizing the performance from the features that the ERP system provides. Thus there is a need to investigate which is the business and manufacturing potential the actual ERP subscription provides before investing into a PLM system.

Another aspect to consider when investing into a PLM system is if the new PLM system will actually provide features that will make the ERP system redundant.

Company X eventually should create an integrated ERP and PLM environment to share data with different customers and manufacturers. This should streamline the engineering and manufacturing process and aid at eliminating any inconsistencies in the process.

4. PLM implementation plan - management and technological plan

As exposed in the research, small to medium companies are struggling to understand the PLM environment due to its abstraction of dealing with something intangible such as product data. In order to increase the success of PLM, Company X is required to develop a concise framework on several levels to assure the success of the PLM implementation. Without a concise roadmap that integrates short and long term business KPIs, Company X will stumble into unpredicted obstacles during the implementation

process. To have a better understanding of what is expected from a PLM implementation plan please consult the link within Figma and Appendix 18 PLM roadmap integration that covers the PLM implementation roadmap and essential elements that should be considered when implementing a PLM system.

5. Change management

This topic is a key element in deploying a new IT infrastructure within Company X's environment. It is often hard to produce drastic changes within an organization like Company X where employees have long established routines, culture and structure. ThIs is essential to be tackled immediately as Company X is considering developing the system. It is essential to keep the stakeholders involved and informed in further development of the PLM system to promote the sense of responsibility and ultimately to end up with a system that fits the designated users.

6. System integration

    a. Barbone/backbone or further development Company X should research more into the possibility to fully implement barbone respectively backbone functionality into one PLM interface. Thus the PLM systems have inbuilt applications (project management and PLM applications) that integrate several functionalities from Barbone and backbone systems.

    b. Communication Tools

The technical aspects of the integration do not fall under the scope of this research thus it is recommended to further study how such integrations can happen.

7. Website and rebranding

According to the market research, the companies that have a competitive advantage over Company X have a well-designed branding and website that provide a clear, consistent and persuasive message. This is an incentive for Company X to consider investing in the image of the company in order to increase the possibilities of expanding or attracting new clients.

8. Build or buy?

When deciding whether to build or to buy a PLM software it is also important for Company X to consider several implications and aspects:

- The complexity of the needs that the company has and how those needs translate in system functionalities
- The human and material resources as well as the knowledge that is required to build the system
- The urgency of building the system

Additionally the market research provides a perspective on some of the existing PLM vendors that are struggling to resize the PLM systems to the needs of SMES. Moreover, the PLM interest and market share is constantly increasing thus these elements give part of the incentives for Company X to develop such a system with the intention to address not only their needs but also the electronic manufacturing market needs. Is essential to point out that developing an internal PLM system can be still feasible considering that a great amount of SMEs are still afraid of disruption or are accommodating with the idea of adopting a PLM system. Company X can capitalize on increasing awareness and understanding of the PLM benefits and implications.

All the above-mentioned recommendations require building up a methodology that constantly includes knowledge and practice.

8.2 Reflection

8.2.1 Benefits for practice

The design and development of a new PLM system that addresses the specific needs of electronic manufacturing companies is beneficial for Company X. The proof of concept aligns with the goals and business strategy of Company X thus it provides the features that support the internal users in executing their tasks in a systematic manner.

The PLM platform functionality allows Company X to make changes and adapt product data even before production, which results in benefits like reduced costs, reduced development cycles and risks in manufacturing. Additionally through automation of processes and data formatting Company X can benefit from business scalability because it can react to product changes and customer demand faster.

Company X craves to solve the problem of EBOM to MBOM transformation due to an increased amount of time. The customization and flexibility of the platform reduces the time from weeks to days by proposing an open BOM structure that can be reshaped and customized in order to fulfill both engineering and manufacturing demands.

The research provided a practical experience through workshops, stakeholders interviews based on which different assessments were made. The workshops and interviews are elements that should be considered as a future methodology in similar circumstances.

8.2.2 Limitations of for practice and research

The complexity of a PLM system requires multidisciplinary teams, knowledge and skills. Therefore the research does not go in-depth into back-end technical providing full understanding of the capabilities and technologies that stand behind a PLM system.

The research is limited in validating the business model. It would be wrong to take all findings for granted and that the existing research touched upon all aspects that validate an entire business model. The market analysis should be continued carefully where potential customers of the platform should express their interest and needs in adopting a PLM system from Company X. Additionally when creating a complex

system it is important to have an extensive evaluation of the functionalities that will differentiate the platform from the existing ones. This is partially met.

The vagueness and broadness of the assignment made it difficult to focus on specific goals at first for designing the prototype. The analysis provided an extensive list of bottlenecks and problem definitions that in a way or another were related to PLM. The difficult part was to focus solely on PLM core functionalities because PLM has implications also on project management, customer management and relations. Resuming everything to several core focuses in this development stage would have allow the research and development to dive into specifics of core PLM functionalities. Therefore, it is to be considered for the future to narrowing down the goals and potential benefits in order to address them accordingly.

Breaking the holistic concept into smaller concepts help at increasing productivity and focus on the main goals. The testing and evaluation was supposed to integrate the testing and evaluation of smaller parts that address specific functionalities, however this was not manageable because users unavailability. Therefore the testing and evaluation was limited in the research including the holistic concept in the process. The goal of testing and evaluation was to make sure that the proposed functionalities are meeting the user needs. However, this is partially. The main parts of the PLM platform are addressed such as BOM and workflow stages, as well as the inventory management system. However, there was not time to go in details on functionalities and the user interface.

9 Conclusion

This research aimed at designing a proof of concept that resembles the functionality of product lifecycle management systems. The PLM systems intends to aid Company x in standardizing and improving the product data procedures and flows while it allows internal and external parties to collaborate on defining the product data. Eventually the scope of such a system is to offer understanding on how to create a full spectrum of product data defined at different stages by various departments.

Company X generally deals with difficulties in understanding the current information flow and IT infrastructure that aligns different perspectives, processes, people, and technologies. This implies that difficulties appear in communication between internal and external stakeholders, thus this makes it difficult for Company X to manage product data. Awareness of the general challenges was already built and the management staff already initiated actions that address these challenges.

The goals defined for this research are as follows:

- Contribute at structuring and managing data related to products, processes, people and systems.
- Understand the existing PLM solutions and the main functionalities that such solutions integrate.
- Design a proof of concept that helps Company X standardize product data and processes.

These goals serve the study to answer the research questions.

The findings of the current state analysis bring to surface common pain points that small to medium companies are facing in terms of product data management.

The information maps point out that struggles appear from missing a coherent and interconnected IT infrastructure. Data is dispersed across multiple systems that facilitate different actions. This results in long data processing time, repetitive work, increased manipulation of hard copies. Data formatting is a tedious process because usually the files received from various sources differ thus each file format needs individual attention. Overall Company X adopts a semi-structured strategy to standardize the product data that results in multiple bottlenecks that have an effect on the overall performance of the company.

Customers on the other hand pointed out that by enlarging the service offer, streamline communication and provide digital continuity; Company X can improve the chances for long-term collaborations.

During the research of PLM vendors, some barriers were identified in adopting PLM systems into SMEs ecosystem. An important part deals with the increased implementation costs, complexity and dependency to the software providers. Additionally, one of the most impactful reasons is the lack of human resources that possess knowledge and skills about PLM software development.

Eventually the project has two main outcomes:

1. The current state analysis that represents a reference model indicating how people, processes, systems and data interrelate. All the findings were incorporated in data maps.

2. The PLM interface proof of concept that represents the desired outcome that offers an extended range of functionalities with the scope of understanding how PLM can benefit Company X in addressing their needs.

Regarding the current state that includes data maps there were 15 stakeholders that entered the interviews. The outcomes are represented by the data flows associated with descriptive steps as well as lists of problems and observations that serve to capture the essence of the current state. First two research question were addressed in this step as follows:

1. What data flow does Company X possess in its environment and across its supply chain?

As already mentioned previously in the research the enterprise has a semi-structured data flow. The data is organized up to some extent, while a good part of the data is still in the shape of hard copies and excel based files. This lowers the performance of the company through means of increased file formatting time and repetitive work that comes with the semi-unstructured data. Though the data maps generated within this research this research question is fully addressed. This touches upon the first goal of the thesis project that is to contribute at structuring and managing data related to products, processes, people and systems. The goal is fully met. The maps are offering analysis of the main departments in Company X that provides a concise structure of how data, systems, processes interrelate.

2. What are the means of centralizing data and offering data singularity?

Simply put, the IT infrastructure plays an important role in collecting, storing and centralizing data. By not having a master software that is dominant and interlinks with the other software, centralization of data is becoming redundant.

Apart from the current state, the proof of concept provides an understanding of the existing PLM solutions and the general features that that existing solutions provide in the market. Additionally it offers a group of tools that allow cross-functional collaboration, while customers, suppliers and Company X are enabled to actively take part in defining the product lifecycle development process. The last outcome reflects on the last research questions

1. How can people, systems and processes be connected to product data to provide a predictable product outcome?

This questions is addressed by the proof of concept and its functionalities. One of the core focuses of PLM system is to provide a collaborative tool where people can agree upon concepts. The interface facilitates these features and users can collaborate on creating a predictable product outcome based on defining and agreeing upon product data.

2. How can the demands of the customers be matched faster with the capabilities of the suppliers?

Balancing the demand side with the one of the suppliers is not easy. The PLM interface facilitates features that allow the aggregation of customer needs, thus suppliers, in this case Company X can identify faster the needs and address them accordingly. The fact that the communication becomes seamless with the design of the new interface, allows the demands of customers to be met faster with the capabilities of Company X.

3. What platform functionality can serve Company X in achieving data singularity?

To answer this question it was important to understand what type of data Company X manipulates. The BOM and product requirements are the main input data thus through the PLM interface it is proposed to link all data to the bill of material and requirements. The workflow is linked to the bill of material and any data that is linked to the workflow automatically is linked to the BOM. The study integrated a PLM platform analysis that provides an overview of the main functionalities as well as the main distinctions between existing solutions. This provided guidance in defining the functionality of the platform. The analysis extended at how different PLM platforms initiate the product development cycle. Therefore solutions for managing the BOM were defined. The main challenge was to define the functionalities that link the product data to BOM and to the workflow. These challenges were tackled by analyzing existing solutions and notice what functionalities they use. Another important functionality that was addressed in this research is related to validating the product data and allowing the people with the right expertise to assess each phase of the product data development. This brings in play the vault feature that allows users to assign responsibilities, validate, accept or reject data. This is one of the most important functionalities that aid at achieving data singularity.

Generally this research has been completed successfully by addressing the goals and the requirements of the project. There are requirements that are not met because are highly dependent on other areas of expertise. However the recommendation area covers parts of future work that needs to be done.

This report also brings academic value aside from the practical one, in terms of understanding PLM principles and methodology and providing a new perspective on how and what a PLM platform should fulfill and do.

To conclude the research covers important aspects of PLM software knowledge and development and it provides a proof of concept that can benefit Company X in achieving the desired PLM maturity. PLM platform has demonstrated significant improvements in standardization of processes, activities, people and system in relation with product data and its development cycles.

10 References

Fitz, T., Theiler, M., & Smarsly, K. (2019). A metamodel for cyber-physical systems. Advanced Engineering Informatics, 41, 100930. https://doi.org/10.1016/j.aei.2019.100930

Geissbauer, R., Schrauf, S., Koch, V., & Kuge, S. (2014). *Industry 4.0 - Opportunities and Challenges of the Industrial Internet.* https://www.pwc.nl/en/assets/documents/pwc-industrie-4-0.pdf

Kiel, Daniel & Arnold, Christian & Müller, Julian & Voigt, Kai-Ingo. (2017). Sustainable Industrial Value Creation: Benefits and Challenges of Industry 4.0. *International Journal of Innovation Management*. 21. https://doi.org/10.1142/9781786347602_0009

Falk, M., Klien, M., Schwarz, G. (2015). *Große Sachgütererzeuger planen 2015 kräftige Ausweitung der Investitionen.* https://www.wifo.ac.at/jart/prj3/wifo/resources/person_dokument/person_dokument.jart?publikationsid=58253&mime_type=application/pdf

Smit, J., Kreutzer, S., Moeller, C., & Carlberg, M. (2016). Industry 4.0. *Study for the ITRE Committee, Policy Department A: Economic and Scientific Policy, European Parliament, Brussels*. https://www.europarl.europa.eu/RegData/etudes/STUD/2016/570007/IPOL_STU(2016)570007_EN.pdf

Stark, J. (2015). Product Lifecycle Management. Product Lifecycle Management, 1–29. https://doi.org/10.1007/978-3-319-17440-2_1

Grieves, M. (2005). Product Lifecycle Management: Driving the Next Generation of Lean Thinking: Driving the Next Generation of Lean Thinking (1st ed.). McGraw-Hill Education.

Free Resources - CIMdata. (n.d.). Cimdata.Com. Retrieved February 15, 2020, from https://www.cimdata.com/en/resources/about-plm

PLM (Product Lifecycle Management). (n.d.). Ptc.Com. Retrieved February 15, 2020, from https://www.ptc.com/en/technologies/plm

PLM Software - The Complete Guide. (n.d.). Productlifecyclestages.Com. Retrieved February 15, 2020, from https://productlifecyclestages.com/plm-software-the-complete-guide/

Stark, J. (2013). Product Lifecycle Management: 21st Century Paradigm for Product Realisation (Decision Engineering) (Softcover reprint of hardcover 2nd ed. 2011 ed.). Springer. https://doi.org/10.1007/978-0-85729-546-0

Maropoulos, P., & Ceglarek, D. (2010). Design verification and validation in product lifecycle. CIRP Annals, 59(2), 740–759. https://doi.org/10.1016/j.cirp.2010.05.005

Grieves, M. W., & Tanniru, M. (2008). PLM, process, practice and provenance: knowledge provenance in support of business practices in Product Lifecycle Management. International Journal of Product Lifecycle Management, 3(1), 37. https://doi.org/10.1504/ijplm.2008.019969

Tomovic, M., & Wang, S. (2010). Product Realization: A Comprehensive Approach (Softcover reprint of hardcover 1st ed. 2009 ed.). Springer. https://doi.org/10.1007/978-0-387-09482-3

What is ERP? Definition of Enterprise Resource Planning (ERP). (n.d.). Oracle.Com. Retrieved February 15, 2020, from https://www.oracle.com/erp/what-is-erp/

Cimalore, C. (2012, August). ERP and PLM: Defining their roles and creating a collaborative environment for success | InnoFour BV. Innofour.Com. https://www.innofour.com/8733/news/latest/erp-and-plm-defining-their-roles-and-creating-a-collaborative-environment-for-success

Jackson, C., Houlihan, D., & Aberdeen Group. (2008, June). Integrating PLM & ERP: It's not just a one way street. Aberdeen Group. https://www.plm.automation.siemens.com/zh_cn/Images/5244-RB-integrating-plm-erp_tcm78-67672.pdf

Cimalore, C. & Omnify software. (2009). ERP and PLM: Defining their roles and creating a collaborative environment for success. Published.

Koomen, B. (2018). PLM in SME, What Are We Missing? An Alternative View on PLM Implementation for SME. Product Lifecycle Management to Support Industry 4.0, 681–691. https://doi.org/10.1007/978-3-030-01614-2_62

Cimalore, C. (n.d.). Selecting a PLM Solution - Addressing the Needs of a Small Business | InnoFour BV. Innofour.Com. Retrieved May 22, 2020, from https://www.innofour.com/4551/news/literature/selecting-a-plm-solution

Silventoinen, A., Papinniemi, J., & Lampela, H. (2009, June). A Roadmap for Product Lifecycle Management Implementation in SMEs. https://www.researchgate.net/publication/232423505_A_Roadmap_for_Product_Lifecycle_Management_Implementation_in_SMEs

Shilovitsky, O. (2017, April 28). PLM is good for small businesses. If you can afford it. . . Beyond PLM (Product Lifecycle Management) Blog. http://beyondplm.com/2017/04/28/plm-good-small-businesses-can-afford/

The Rise Of Cloud Computing Extends To PLM. (2012, March 6). Manufacturing.Net. https://www.manufacturing.net/home/article/13056507/the-rise-of-cloud-computing-extends-to-plm

Shilovitskyy, O. (2014, April 21). Why PLM stuck to provide solutions for SME? Beyondpl,.Com. http://beyondplm.com/2014/04/21/why-plm-stuck-to-provide-solutions-for-sme/

Trustradius. (n.d.). TrustRadius. Trustradius.Com. https://www.trustradius.com/

G2. (n.d.). Where you go to buy software. G2.Com. https://www.g2.com/

DISCOVER THE LEADING SAAS SOFTWARE COMPARISON SITE. (n.d.). CompareCamp.Com. https://comparecamp.com/

Kenton, W., & Scott, G. (2021, March 30). How SWOT (Strength, Weakness, Opportunity, and Threat) Analysis Works. Investopedia.Com. https://www.investopedia.com/terms/s/swot.asp

Schooley, S. (2019, June 23). SWOT Analysis: What It Is and When to Use It. Businessnewsdaily.Com. https://www.businessnewsdaily.com/4245-swot-analysis.html#:%7E:text=A%20SWOT%20analysis%20is%20a,in%20making%20a%20business%20decision

Antonelli, D., Chiabert, P., & Villa, A. (2012). Introducing Product Lifecycle Management to Small Medium Enterprises: discussion and analysis. IFAC Proceedings Volumes, 45(6), 1059–1064. https://doi.org/10.3182/20120523-3-ro-2023.00261

Miedema, J., van der Voort, M. C., Lutters, D., & van Houten, F. J. A. M. (2007). Synergy of Technical Specifications, Functional Specifications and Scenarios in Requirements Specifications. The Future of Product Development, 235–245. https://doi.org/10.1007/978-3-540-69820-3_24

Veal, R. L. (2020, December 29). How to Define a User Persona. Careerfoundry.Com. https://careerfoundry.com/en/blog/ux-design/how-to-define-a-user-persona/

Duran, A. F. (2018, September 12). Responsive web design: our 5 proven principles. Level-Level.Com. https://level-level.com/blog/responsive-web-design-our-5-proven-principles/

Almeida, F., & Monteiro, J. (2017, December). The Role of Responsive Design in Web Development. https://www.webology.org/data-cms/articles/20200515031209pma157.pdf

Potasinski, T. (2019, June 12). An Introduction to Email APIs and How You Can Use Them. Nylas.COM. https://www.nylas.com/blog/how-you-can-use-email-apis/

Potasinski, T. (2019b, June 18). Transactional Email APIs vs Contextual Email APIs. Nylas.Com. https://www.nylas.com/blog/transactional-vs-contextual-email-apis/#:%7E:text=Contextual%20email%20APIs%2C%20in%20contrast,for%20their%20end%20user%27s%20benefit

Wikipedia contributors. (2020, December 22). Create, read, update and delete. Wikipedia. https://en.wikipedia.org/wiki/Create,_read,_update_and_delete

Twilio Inc. (n.d.). Twilio Voice API Overview. Twilio.Com. Retrieved January 26, 2021, from https://www.twilio.com/docs/voice/api

Wikipedia contributors. (n.d.). VoIP phone. Wikipedia. Retrieved January 26, 2021, from https://en.wikipedia.org/wiki/VoIP_phone#Common_functionality_and_features

Alumio. (n.d.). Alumio Platform Features. Alumio.Com. Retrieved January 26, 2021, from https://www.alumio.com/platform/features

Alumio - Integration Platform for Commerce Connectivity. (n.d.). Alumio.Com. Retrieved January 26, 2021, from https://www.alumio.com/?utm_term=alumio&utm_campaign=ED_-_INT_-_S_-

Brand%7C_Alumio&utm_source=adwords&utm_medium=ppc&hsa_acc=9045171972&hsa_cam=10484766181&hsa_grp=109200657772&hsa_ad=466781290251&hsa_src=g&hsa_tgt=kwd-924776115036&hsa_kw=alumio&hsa_mt=e&hsa_net=adwords&hsa_ver=3&gclid=Cj0KCQiA1pyCBhCtARIsAHaY_5edVPcukI6G4uBNb33vEvzdS1LFlf8B8wvFAW0WhRoWdTIuQ6ghrLQaAvRAEALw_wcB

Bluestar PLM. (n.d.). Bluestar PLM. Bluestarplm.Com. Retrieved January 26, 2021, from https://bluestarplm.com/?utm_term=microsoft%20dynamics%20365%20plm&utm_campaign=Kundeemner-ny-strategi&utm_source=adwords&utm_medium=ppc&hsa_acc=6811597029&hsa_cam=1598986009&hsa_grp=61965584098&hsa_ad=303379665346&hsa_src=g&hsa_tgt=kwd-916935916522&hsa_kw=microsoft%20dynamics%20365%20plm&hsa_mt=b&hsa_net=adwords&hsa_ver=3&gclid=CjwKCAiAouD_BRBIEiwALhJH6MI_0Yhg16pPKZLcWM_FksT35nmG4YqAw-Ef36rveDjusDziWGDnPRoC3SAQAvD_BwE

Open Text Corp. (n.d.). Types of EDI. EDIBasics.Com. Retrieved January 26, 2021, from https://www.edibasics.com/types-of-edi/

IBM. (n.d.). What is EDI: Electronic Data Interchange. Ibm.Com. Retrieved January 26, 2021, from https://www.ibm.com/nl-en/topics/edi-electronic-data-interchange

Smith, W. (2021, May 13). Why an API Connection is Key to a Streamlined EDI System. Ecosio.Com. https://ecosio.com/en/blog/why-an-api-connection-is-key-to-a-streamlined-edi-system/

Smith, W. (2021b, May 26). Why an API Connection is Key to a Streamlined EDI System. Ecosio.Com. https://ecosio.com/en/blog/why-an-api-connection-is-key-to-a-streamlined-edi-system/

Abdulhadi, S. (2018, September 21). How to use a REST API to Convert Document formats - codeburst. Codeburst.Io. https://codeburst.io/how-to-use-a-rest-api-to-convert-document-formats-e34408c9b7a

Red Hat, Inc. (n.d.). What is a REST API? Redhat.Com. Retrieved January 26, 2021, from https://www.redhat.com/en/topics/api/what-is-a-rest-api

Klippa App B.V. (2020, December 11). OCR API - Realtime data extraction for receipts, invoices, passports / IDs. Klippa.Com. https://www.klippa.com/en/ocr/ocr-api/

Idler, S. (2021, December 25). *5 Key Principles Of Good Website Usability*. The Daily Egg. https://www.crazyegg.com/blog/principles-website-usability/

1 Appendix - Stakeholder division

Company X has a clear collaboration with its customers. The tasks are clearly defined as seen in Figure 43 below.

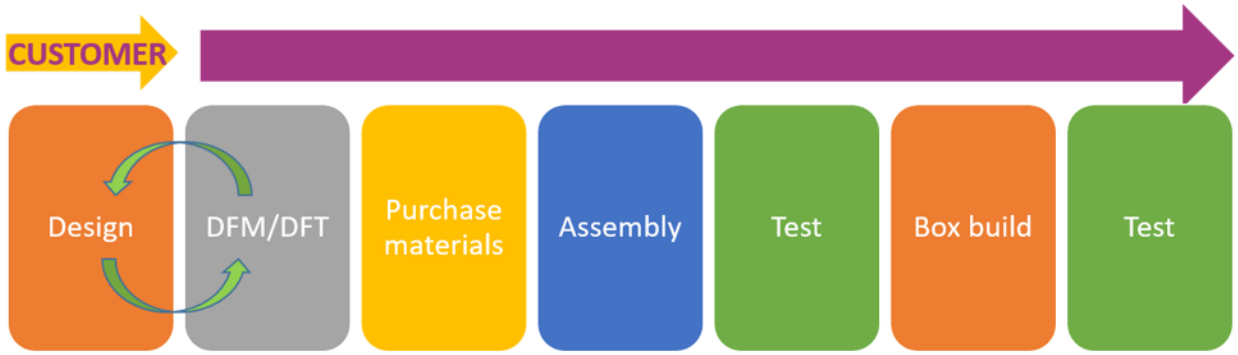


Figure 43 General collaboration flow

Company X does not have any interference in the engineering and design process of the product. This area is completely assimilated by the customer while Company X executes the manufacturing processes of the product. Company X intends to extend the design for manufacturing and testing (DFM/DFT) services in order to further satisfy their customer needs. Figure bellow provides a clear understanding of the work stream between the company and its customers.

While proceeding with the analysis of the current state of Company X, it was discovered that there is a need to fully comprehend which are the stakeholders that play a key role in defining the effectiveness of business processes and assure the data flow. The management team to clearly define the persons that need to be interviewed drew out a preliminary overview of the internal stakeholders. Furthermore, the internal employees pointed out by the management team were invited to participate in several interviews.

There were a number of two semi-structured interviews and several unstructured feedback sessions conducted as follows:

4. First interview to discuss the current situation, tasks, activities, responsibilities, data flows within Company X.
5. Second interview to integrate a feedback and revisiting session of the data maps.

6. Aside from the two semi-structured interviews, there were other spontaneous interviews with the same stakeholders to refine and validate the findings.

During the analysis phase, the maps were created and revisited in close collaboration with the internal stakeholders by having periodical meetings where the maps were defined in the final form.

A similar procedure was followed in the case of the external interviews. The only difference is that the second interview was replaced with a written feedback and data validation session. This means that all findings were forwarded to the customers and asked for feedback and validation.

The interview procedure encompasses open questions for each stakeholder. Open questions are a good way to comprise an in-depth understanding of what each stakeholder is doing, with clear examples while giving them the freedom to express their thoughts with no restrictions. For the researcher it gives the opportunity to approach each interview in a flexible and easy to comprehend way.

The main leading questions used in the interviews were as follows:

- What are the tasks, activities executed by each stakeholder?
- Which are the improvements that Company X should adopt in order to increase its efficiency in managing data?
- What type of data is exchanged between stakeholders?
- What is the format of data managed?
- What are the main technological systems used to manage and build up the product data?
- How is each stakeholder using the systems?

The external interviews, in addition to the above-mentioned questions, touched upon other areas of interest; however, this is detailed in the external interviews section.

The interviews were conducted with four customers and eleven employees of Company X that have an influence on defining and managing the product data.

It was agreed together with the management staff that the following are the relevant actors that have a consistent impact in internal as well as external processes of Company X:

3. Internal Stakeholders
    a. Management staff - two persons
    b. Account managers - two persons
    c. Component purchasers - two persons
    d. PCB purchasers - one person
    e. Project leader - one person
    f. Production leader - one person
    g. Warehouse worker - two persons
4. External Stakeholders
    a. Customers - four company representatives
    b. Suppliers

The list of stakeholders as is enunciated above is grouped into two main categories defined by internal and external stakeholders.

The final results of the interviews encompass the internal and external stakeholders perspectives in the shape of data flows and maps. These data flows integrate the main areas of interest in PLM which are the product data, people, processes, IT systems, communication and business processes.

Internal stakeholders

Management staff

Description: Is defined by the Chief Executive Officer CEO and Chief Financial Officer CFO who are responsible with business strategy and other key policy issues.

Account manager

Description: The manager of a project, the first line support in case of customer communication. The primary stakeholders are dependent on information provided by the account manager. The account manager is often one person, who has the most contact with the client and possesses the most information about the project. Is the person that aggregates all the product information.

Component purchaser

Description: The component purchaser is responsible for the purchase of different components for projects executed by Company X. Based on the project needs and the already existing inventory the purchaser reviews the components chosen by the client and in the eventuality of a better component fit suggests new components.

The purchaser collaborates with the internal stakeholders, components suppliers and when needed (when changes related to components are suggested) with the clients.

PCB purchaser

Description: The PCB purchaser is responsible for the purchasing process of PCBs within the enterprise. It often also involves the inspection procedure of the PCBs when they are delivered by suppliers.

Usually the PCB purchaser verifies all the technical and non-technical data regarding the PCBs and immediately after selects the suppliers. It requires constant contact with the suppliers, and internal stakeholders and if needed (when related to PCB are suggested) with the client.

Production planner

Description: This role has as main responsibilities the technical governance of all projects running within the production line. The person is responsible for the overview of projects and planning projects depending on the people's availability and manufacturing capacity. This stakeholder has a close interaction with all the other internal stakeholders in Company X because the production planner requires information from each party to be able to execute the necessary tasks.

Project leader

Description: The production leader will check if all the parts are ready for production, will make the list of tasks and people/task unit. The tasks require the production leader to work closely together with the production planner, and communicates the specific production needs of the project to the production planner. Moreover a close collaboration is with the internal stakeholders and in case of any production specific remarks, suggestions and observations the project leader might come into contact with the customers.

Production operator

Description: The production operator works in the production line executing the tasks assigned by the project leader. Each person working in the production line is knowledgeable of several manufacturing units and machineries and can execute multiple tasks. The production employees are closely working with all stakeholders except the external ones.

Warehouse operator

Description: The warehouse can be defined as the inventory area, where the electronic devices and components are delivered by the customers, respectively suppliers. All components, PCBs and any other parts are verified, registered, and eventually stored until it enters the production.

External stakeholders

Customers

Description: The customers are defined as all companies that are benefiting from the services the Company X offers. The customer communicates with multiple people from the project team

Following, the next part of the analysis is included in this chapter and incorporates the internal analysis where all the above-mentioned internal stakeholders are interviewed.

Suppliers

Description: The suppliers are all the collaborators of Company X that deliver services, products, components and PCBs. The focus for this research is on the components and PCB suppliers who have a direct influence on the product data and the production goods done by Company X.

The suppliers have indirect contact during the components purchasing process, because in general the purchasing is done via online services/platforms.

The PCB suppliers have a direct contact with the PCB purchaser while the other internal stakeholders do not interfere in this process.

2 Appendix Platform analysis

The following list captures some of the most essential information about the commercially used PLM tools.

Software	Software website	Price	Target group	Deployment method	Devices supported	Key features	Observations
PTC Windchill	https://www.ptc.com/en/products/windchill	Price at request - no pricing information available. PTC Standard – suitable for small enterprises PTTC Premium Enterprise – suitable for medium enterprises PTC Enterprise – suitable for large enterprises	S M L	• Cloud • On premise	• Phone • Tablet • Desktop	• BOM Management • Change and configuration management • Manufacturing and process management • Model-based system engineering • Product data management • Product reliability management • Project and design collaboration • Governance and workflow management • Quality and management • Requirements and test management • Service process management • IoT design integration • Software integrations • Environment compliance	The user experience of the system is complex and not usually friendly. Due to the complexity of the systems it can be difficult to integrate old data.
Siemens Teamcenter	https://www.plm.automation.siemens.com/global/en/products/teamcenter/	Price at request - no pricing information available	S M L	• Cloud • On premise	• Phone • Tablet • Desktop Works on Windows, Linux, Android, MAC, web based, windows mobile.	• BOM Management • Change management • Document Management • Workflow management • Electrical design management • Environment compliance • Manufacturing data and process management • Product Cost management • Product configuration • Quality management • NX integration • Requirements and test management • Service process • Search & analytics • Simulation management	Opening big files is a bottleneck of the software. Integration with Catia or other software that support big files are not smooth. The user experience of the system is complex and not usually friendly. It consists of a complex and non-intuitive interface. It requires a lot of training.
Autodesk Vault & Fusion	https://www.autodesk.eu/products/vault/overview?term=1-YEAR	Vault professional – 1985$ every 3 years Vault workgroup – 1065$ every 3 years Vault office – 500$ every 3 years	S M L	• Cloud	• Desktop Works only on windows, mac or web based	• Product data management • New product development • BOM management • Change management • Quality management • Supplier collaboration • Cost management • Workflow management • Project and reporting • Revisions • Data standardization	**Vault office** – design file management to help automate data creation and organize documentation. **Vault workgroup** – represents data management for teams, automate design tasks, enforce standards, and manage revisions. **Vault professional** – connects external parties to it.
OpenBOM	https://www.openbom.com/	User – free Professional user – 30$ a month Professional team 2100$/year Company – 4500$/year Enterprise - quote	S M	• Cloud • On premise	Undefined	• BOM management • Revisions and history of changes • Import/export excel, pdf, csv files • Production, planning and inventory control • API custom integrations • Team administration • Data sharing and collaborations – simultaneous edit • Change management • Quality management, Maintenance • Product development process	This is not a specific PLM software, however it offers the possibility to reach the full functionalities of a PLM software through its integrations. The user interfaces is not highly intuitive The catalogues in open bom take time to be set up.
Odoo	https://www.odoo.com/app/plm	Pricing differs from application to application. PLM – 16 EUR/month – requires manufacturing and inventory Manufacturing -32 EUR/month Inventory – 24 EUR/month	S M	• Cloud • On premise • Open source	• Phone • Tablet • Desktop Works on Windows, Linux, Android, MAC, web based, windows mobile.	• BOM Management • Product data management • New product development • BOM management • Change management • Quality management • Supplier collaboration • Cost management • Workflow management • Project and reporting • Revisions • Data standardization • Business analytics	The interface seems user friendly and more modern compared to other interfaces. Cons is that the business lacks in qualitative customer support due to high amount of employees.
Propel	https://www.propelplm.com/	100$/Month	S M L	• Cloud	• Phone • Tablet • Desktop Works on Windows, Linux, Android, MAC, web based, windows mobile.	• Audit management • Change management • Complaint Management • Compliance management • Cost tracking • Data quality control • Defect tracking • Document coding and control • Document management • Project management • Product data management • New product introduction • BOM management • Collaboration	The search tool does not always facilitate a correct search. Exporting files is slightly challenging. The high range of features integrated in the software slows down the performance and increases the learning curve of users. It is difficult to find guiding elements for training and accommodating with the functionality of the PLM system.
Aras PLM	https://www.aras.com/en		S M L	• Cloud	• Phone • Tablet • Desktop Works on Windows, Linux, Android, MAC, web based, windows mobile.	• Document management • BOM management • Change management • Configuration management • Quality management • System architecture • Requirements engineering • Technical documents • Manufacturing process planning • Digital Twin core • Office connector	Consists of a good search tool that provides quick and efficient access to documents, however it uses a different terminology than other platforms.
SAP PLM	https://wiki.scn.sap.com/wiki/pages/viewpage.action?pageId=26764	Price at request - no pricing information available	S M L	• Cloud	• Phone • Tablet • Desktop Works on Windows, Linux, Android, MAC, web based..	• BOM Development • Strategy and Planning • Innovation Management • Portfolio Management • Program and Project Management • Collaborative Development • Product data sharing for component and task sourcing • Design and manufacturing synchronization • Product Compliance	Requires a high degree of customization to accommodate to a company processes. Has complex features thus the learning curve is high. The user interface looks old fashion. There is no copy-paste functionality
Oracle Agile PLM	https://www.oracle.com/scm/product-lifecycle-management/	Price at request - no pricing information available	S M L	• Cloud	• Phone • Tablet • Desktop Web based	• Innovation management • Requirements management • Product development • New product development • Project management • Product compliance and sustainability • Change management • Quality management • Collaborations • Document management • Analytics	This represents one of the most expensive solution on the market. Does not support data extraction in different data formats. Due to complexity it leads to high learning curve for users. The user experience is not too intuitive
Arena PLM	https://www.arenasolutions.com/platform/plm/packages/	Price at request – no pricing information Arena PLM launch Arena PLM Scale	M L	• Cloud	• Phone • Tablet • Desktop Web based	• Product record control • Document Management • Change management • Regulatory and compliance • Collaboration • Supplier quality management • Project management • Requirements Management • Business analytics • Training management • Information sharing	Provides solutions only for medium to large enterprises Training management and integrations require extra costs. However other vendors are not providing the trainings

Figure 44 Platform analysis

Competitor analysis

Procedure

The analysis that falls under the scope of this project is focused on business features (industries, certificates, service offer, etc.) and technical interfaces (website and platform usage). In total there are ten competitors from Overijssel province which fall under the category of direct competitors. Additionally six other companies from The Netherlands were included in the research and lastly the market study incorporated also an international company.

Company X is compared head to head with the rest of the companies included in this analysis. For the research, there is a grading system in use as follows:

A part of the features analyzed are graded with stars from 1 to 5 – (1 is really poor while 5 is really good) and the rest of the features and elements are using check or uncheck marks which indicate if the feature or content exists in the company. Most of the check marks are accompanied with observations and remarks that indicate the validity and reliability of each studied element.

The research started with the analysis of the competitor websites where all competitors are presenting their business model. The websites and the business offer are analyzed based on the five key principles of good website design and usability, and the content and services presented in each webs page as follows:

1. Availability and accessibility which includes aspects such as broken links, server uptime (ensure that visitors are not getting errors when trying to load the website) and mobile responsiveness which deals with the usability when using multiple scree sizes.
2. Clarity defines the simplicity of the website, where the focus is on the content and what is important. Familiarity refers to what people already are used with. This implies also guidance by design and how the data is displayed in order to take the visitors to further engage with the services and products offered on the website.
3. Learnability – human beings are wired to patters and recognition, thus it is essential to analyze the website in terms of intuitive design and usage.
4. Credibility – the website should evoke trust about each business when navigating through it. Of course this works hand in hand with the content of the webpage which builds up the trustworthiness of each website. This is usually done through design elements, company expertise, and especially testimonials, work references or in the last years a high importance is given by social media platforms, visitors and followers.
5. Relevancy – it refers to the how relevant for the viewer the content is on each webpage. Idler S (2021)

Main findings:

According to the analysis, the companies that have a relatively high score in website design and content are Aemics BV, Benchmark Company Xronics, Deos Control, Global Company Xronics, Batenburg

ELectronics BV and Phuntronix BV. Considering the level of details in these web pages it indicates that the companies modern, keeping up with the technology and marketing trends and are inclined towards innovation and technology adoption. This is also indicated by different features that are incorporated through the websites such as **direct online quotation or direct price calculation.** On top of that, five out of six companies that scored high on website design and content architecture **are having a customer platform** that is used for purposes like **online traceability or manufacturing operations**. In all cases it is not clear the degree of traceability and the features and capabilities that companies have in their internal platforms. The requirement to access those platforms and their services is to apply though a fill out form or request to register as a customer in the platform. Companies that had a low score (three stars or below) in website design and content quality offer a decreased range of services and also are less technologize compared to the high rated companies.

There are no results indicating the present of a PLM system in any of the competitors that were studied, except Benchmark Company Xronics. One of the customers participating in the interviews who is also collaborating with Benchmark Company Xronics mentioned that the collaboration on product development and engineering is proceeding through a PLM platform.

In general most of the companies are promoting their services as being fast, flexible and high quality, an aspect that also Company X considers it is one of their strong points and gives them a competitive advantage. This might also suggest that Company X is not fully aware of the competition and their technological advancement. The traits, capabilities and services are highly similar to what Company X is offering.

In terms of quality assurance and certificates, 10 companies out of 17 are providing the same list of certificates for electronics, while the other are either not indicating in their website the certificates or have less certificates.

Compared to Company X these competitors have a clear, modern website with content elements that are really explanatory and simple. Company X reaches maximum score in terms of content, because all content on the website is self-explanatory, detailed and relevant for any customer that accesses its website. However, the design, and the website architecture is not favorable to Company X and might indicate that the company is not innovative, creative and open to transition to the next level of digital maturity. The website does not incorporate any online application for contacting, online quotation or integration with any of the internal systems.

Company X is focusing on providing new products and services to its customers. There is already a need expressed by different customers in having access to repairing services as well as well as extended testing capabilities. According to the competitor analysis, there are four direct competitors (Benchmark, DEOS and Global Company Xronics, Ellange Company Xronics) who are providing similar services as Company X and additionally are providing also repairing services. Additionally three other companies who are categorized as indirect competitors are providing repairing services. These findings can be a good incentive for the management board to extend the service package and include as well repairing services.

Reviews - It is interesting to see that the first three companies that have the most extended list of services and are rated the highest in terms of business model and website design and content are having also reviews or testimonies from various clients. The reviews usually add social proof and increase the trust in the brand. One more essential aspect that reviews can describe is the customer relation services provided by companies. It indicates that the voice of the customer is carefully captured while the data and information that results from customer interactions could improve the overall experience and product development.

Conclusion

A conclusion of the 2nd phase analysis is that companies who are invested in innovating technologies are also more inclined to look and be perceived as being more innovative and digitized at both corporate and manufacturing level. This increases the chances for those companies to attract new clients and expand their collaboration. One important aspect that stands out for the companies that are 5 stars ranked on website and content design is that are making use of customer platform for an easier way of collaborating with customers. The same companies are usually more technologized and provide a wider range of services and IT possibilities such as customer platform, extended testing capabilities and traceability of products. It is known from the internal analysis that Company X communicates with customers via Email or phone that usually results in scattered information. A customer platform can benefit Company X in having all communication elements into one overview that will give the company clarity and an easier way of managing data. Company X consider itself as an innovative, fast, highly flexible and qualitative company and believes that this are some of the competitive advantages that they have over their competitors. However, the results show that more than half of the companies analyzed are offering at least the same advantages as Company X which leads to the fact that Company X has a biased opinion about its services. This is a good reason for self-reflection and building up a clear and concise approach towards a more digitized production and processes.

The next list incorporates the main bottlenecks and points of improvement that Company X should undertake in order to earn competitive advantage over the main players in its business sector:

1. **Low branding visibility** - Website design and branding improvements are required for Company X
2. **Low marketing promotion** - Social media, newsletter, blogs tools are some of the main features used by the best rated companies to promote and marketer themselves. It is important to notice that Company X superficially making use of social media platforms while the rest of marketing tools are not in use.
3. Repairing services and extended testing capabilities are on high demand.
4. **Companies have a competitive advantage compared to Company X by multiple technological adoptions, while customer platform and product traceability** is used by the most competitive companies
5. Quotation, contact form and price calculator integrated in websites and/or platforms
6. Overall competitors are promoting the same production technologies while about one third of the companies are more innovative and technologized, providing extended manufacturing, testing and repairing services.

7. Company X is biased regarding the competitive advantage in the market.

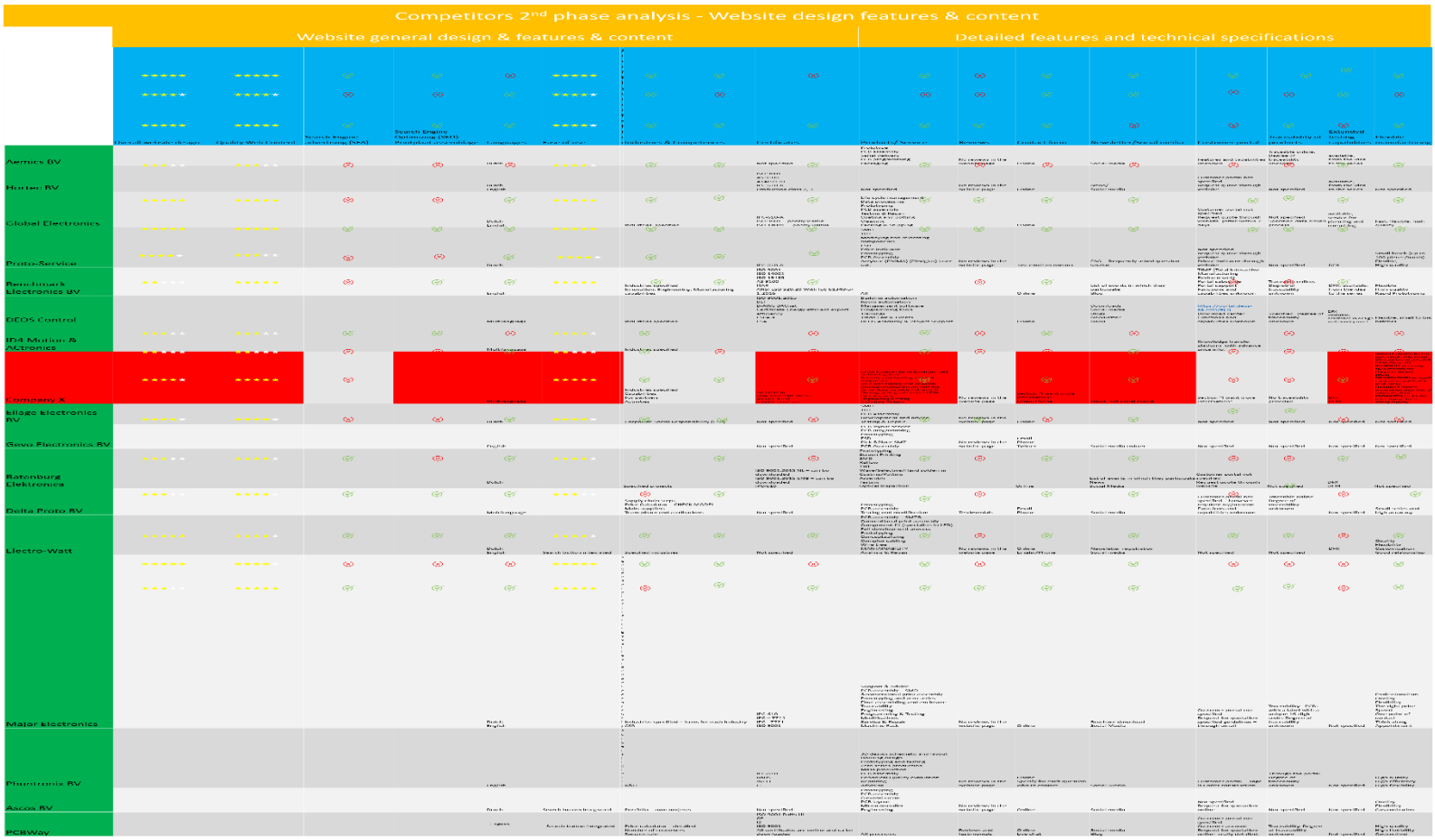
This outcome come also as an incentive for Company X to proceed further with the analysis and the development of the business case intended for its business area. Competitor analysis is essential for Company X to determine the where it stands in the market and to keep track of what technological adoption are happening in competitors spectrum.

Moreover this also incentivizes the continuation of this thesis and the development of the platform.

As a next step Company X should proceed with interviewing companies in the region to determine the validate the market research and analysis as well as the bottlenecks and needs that companies in PCB sector have.

Competitor analysis

List, location and website



Competitors 1st phase analysis		
	Location	**Website**
Aemics	Province: Overijssel	https://www.aemics.nl/
Hortec BV	Province: Overijssel	https://www.hortec.nl/
Global Electronics	Province: Overijssel	https://global-electronics.nl/
Proto-Service	Province: Overijssel	http://www.proto-service.nl/
Benchmark Electronics BV	Province: Overijssel	https://www.bench.com/
DEOS Control	Province: Overijssel	https://www.deos-ag.com/en/company/
ID4motion	Province: Overijssel	http://www.id4motion.com/
Ellage Electronics BV	Province: Overijssel	http://www.ellage.nl/
Gevo Electronics BV	Province: Overijssel	http://www.gevo.nl/
Batenburg Electronica	Province: Gelderland	https://www.batenburg-elektronica.nl/
Delta Proto BV	Province: North Holland	https://www.deltaproto.com/
Electro-Watt	Province: North Holland	https://www.electro-watt.com/
Major Electronics	Province: Drenthe	https://www.major-el.nl/
Phuntronix BV	Province: Utrecht	http://www.phuntronix.com/
Ascos BV	Province: Gelderland	http://ascos.nl/
PCBWay	International	https://www.pcbway.com

Figure 45 Competitor analysis

IPT competitor analysis

Company	Characteristics							
	online order	digital production	repair service	traceability/Intern	flexibility	prototyping	development	quantity
Zollner https://www.zollner.de/leistungen-plm/traceability/	x	yes, degree of connectivity unknown	x	availabe, via MES	available, small series to large series	x	available, development team for assistance	low to high, depending on the variance
HEITEC https://elektronik.heitec.de/de/loesungen-dienstleistungen/fertigung	x	x	✓	available	available, prototype to mass production	✓	available, from the idea to the series	x
NEWAYS https://www.newayselectronics.com/de/leistungen/pcba	x	yes, degree of connectivity unknown	x	available, complete transparency in development and manufacturing	x	✓	available, development on the basis of the customer idea	low to high, depending on the variance
BMK Group https://www.bmk-group.de/ueber-bmk/	- Customer portal available - component catalogue - Create parts list via	yes, degree of connectivity unknown	✓	x	available, serial production with a high degree of flexibility	✓	available, consulting and development teams specially put together for the client	x
ASTEELFLASH https://www.asteelflash.com/solutions/prototyping/	only via contact formula	x	x	x	available, prototype to mass production	✓	available, service for development and design	x

Company	Characteristics							
	online order	digital production	repair service	traceability/Intern	flexibility	prototyping	development	quantity
KATEK https://katek-group.de/	x	yes, degree of connectivity unknown	x	available, via MES	x	x	available, in cooperation with customer	x
ML&S http://mlands.com/manufacturing/t_data/	x	x	x	x	x	✓	available, consulting/assistance during development	x
KUTTIG Electronics https://www.kuttig.de/ems-dienstleistungen/leiterplattenbestueckung.html	x	x	✓	x	available, small to medium series production	✓	x	x
GRUNDIG https://ems.grundig-gbs.com/ems-dienstleistungen/	x	yes	✓	available	available, also time-related	✓	available, assistance in design and development	x

Figure 46 Platform analysis

3 Appendix Communication Integration

One of the main goals of the platform is achieving the singular source of truth. This means that also the decision making process needs to be captured in the interface, a process that is mainly executed through means of calling and emailing.

Thus, a few opportunities for integration are listed below:

Email - The PLM system is able to run in the backend architecture an API integration that connects the email service provider to the interface. In doing so, Company X can benefit from a highly customizable system that empowers the exchange of communication with the client. The main benefits of an email API integration is that it leverages the automation of capturing the decision making process. According to Potasinski, T. (2019) an Email API allows applications to access functions delivered by the email provider.

The email APIs are broadly separated into two main categories:

- transactional
- contextual.

At a first look, transactional email APIs are used for routine emails like notifications, password reset emails through third-party platforms. Potasinski, T. (2019b)

Contextual email APIs are designed to integrate concise and robust email connections directly in the website application such as productivity tools or customer relations management systems (CRMs) Potasinski, T. (2019b). This also allows following general CRUD (create, read, update and delete) functionalities Wikipedia contributors. (2020) . Integration with the email system allows the user to build a reliable information structure with very little effort. To accomplish this, Company X PLM platform should be able to integrate with the email interface as intuitively as possible.

Phone calls – the intention in this case is to be able to make and receive phone calls and voice messages in the website application. This is based on similar technical principles as in the case of email APIs. There are a variety of software that can have quick, precise and reliable connectivity to log calls in the platform. Some of them are Microsoft Teams and Twilio of which integration capability can make, receive and manage calls from any web interface or mobile application Twilio Inc. (n.d.). The technology that stands behind this connection is called voice over internet protocol (VoIP) that allows users to place and transmit calls over an Internet connection Wikipedia contributors. (n.d.b). Considering that Company X is already using cordless phones to communicate internally, the same equipment can be re-routed and connected to the PLM platform.

These integrations can provide functionalities for phone, email, chat and as well as for social media for marketing purposes. However, the technical aspect of the integration does not fall under the scope of this research thus it is recommended to further study how such integrations can happen.

4 Appendix Back-end technical solutions

ERP

The PLM software should interface with the ERP system in real-time for all the core business processes, prices and logistics based on an API-connector. This means that BOMs, customer specific prices, order costs, delivery time, product specifications, payment methods are some of the elements that are exchanged between the platforms. According to *Alumio - Integration Platform for Commerce Connectivity*. (n.d.) a company that offers pre-build connectors and collaborates with the same ERP service supplier as Company X, mentioned that such API connectors aside from the fact that they are directly functional, it can be also customized so that IT specialists can adjust the code according to any wish of the company. Other options are to add mappings, or add specific product data as new services to the solution. Moreover the same company mentions that such a connector can provide triggering and notification functionality,

as well as managing the data quality and can work as an integrated interface solution such that in case of additional software adoptions to connect them.

Now the ERP is also used for warehouse monitoring of inventory levels. During the research it was found that the existing ERP system is capable of executing inventory management tasks precisely to maintain optimal stock-levels during the year.

Cloud base solution

By connecting the PLM and the ERP system into a collaborative solution, it enables engineers and manufacturers to work around the singular source of truth across the product lifecycle. This can be achieved through a cloud based solution for capturing and sourcing data.

This arrangement comes with several advantages as it follows:

- Maintenance and upgrades are done by the provider.
- Flexible adjustment of storage space.
- Date stored remotely via the internet.
- Accessible wherever there is internet access.

A problem that is usually visible to the cloud based solution is that if the internet connection is not very strong there can be troubles accessing the data. However, the new software can have a built in function to work and access data when offline. This can lead to the following scenario:

- The user will be able to access and edit data while the data synchronization is executed as soon as the internet connection is established.

Similar to the Alumio interface, Bluestar PLM. (n.d.) offers a concise cloud-based ERP-PLM integration This allows users to collaborate across the enterprise at any time and from anywhere.

Moreover the cloud based in this context is also considered a software integration hub where different business to business (B2B) collaboration can incorporate different API interfaces to streamline more efficient business processes between different parties. The cloud will be the API management system on the back-end side while the front end solution is represented by the PLM system. The cloud will be the developer tool for various APIs.

Application Programming Interface (API) connectors database

Currently, Company X employees spend an increased amount of time manipulating files from different vendors and stakeholders. This brings the question of how this aspect can be minimized. Automation through API connectors is one of the possibilities that can tackle this challenge. One example is the component purchasing and BOM manipulation. Currently the component purchaser extracts component data and financial information manually from different manufacturer websites. An adaptive system that is based on an API connection can directly access the vendor’s database and extract the cost information and item data automatically. The considered solution involves the data extraction that afterwards can be accepted or rejected by purchasers after a rapid verification. After the system extracts data, and is actually

trained to recognize patterns, the system is able to provide suggestions on which manufacturers perform better and are more reliable.

When it comes to additional forms of structured exchange of business data and files between companies, electronic data interchange connectors can be an option. This topic however can be consulted in the Appendix 5 – Electronics data interchange.

REST API

Ideally, the solution should be straightforward through simple integration like API. This type of connection should allow the PLM and ERP system to transmit data real-time to another system owned by customers or manufacturers. One API interface is the doc conversion API which is a representational state transfer (REST) API Abdulhadi, S. (2018). Generally speaking, REST APIs enable companies to communicate files and data through various services and integrate those services in a single system through simplistic programming language Red Hat, Inc. (n.d.). Doc conversion API allows companies to convert word, excel, powerpoint, HTML, pdf and different image formats in various formats Abdulhadi, S. (2018). Thus, there are opportunities for Company X to overcome manual manipulation and conversion of files at low costs and high speed. Real time scan, text recognition and extractions are a matter of seconds through the REST APIs Klippa App B.V. (2020). This can aid Company X in cutting down costs that results from redundant, repetitive processes that include file manipulation.

For this particular case it is assumed that the system will exchange and translate files via API connectors. This aspect is still a topic for further research that Company X should consider in the future.

5 Appendix - Electronic data interchange

Electronic data interchange (EDI) connectors – This is one of the most common forms of structured exchange of business data and files between companies through different digital interfaces Open Text Corp. (n.d.). The PLM software can incorporate an EDI translation software that will help Company X, customers and manufacturers handle with ease different file formats. This will allow standardization of business documents as well as product data. With EDI connectors Company X and its stakeholders can share information from an application to another. The EDI connector can be arranged in such a way that it defines the location and order of information in a document format. This will aid Company X to rapidly share data with customers and manufacturers while the file formats are not a hustle anymore.

Manually entering data from files that have different formats into the PLM system will be automated. The system is adaptive and can be taught by the user to learn from errors. In case of any errors in conversion, the user can delete or try to correct the values. Some of the files that can be automatically converted from one format to another are purchase orders, invoices, requests for quotations, etc.

EDI transmissions are divided into two main types according to the software corporation IBM. (n.d.):

1. Point-to-point or direct connection – in this case two systems connect over the internet through secure protocols.
2. Value-added network (VAN) – this involves a third-party network that manages data transmission.

EDI and API

When it comes to converting files with different supply chain stakeholders, the implemented systems should be able to translate all file formats that are received or sent via different file transfer protocols.

Considering that EDI integrations are coming with limitations, such as the sender of the files has no proof that the receiver obtained the files, thus it does not provide clear traceability of the file Smith, W. (2021). However there are new protocols such as AS2 or AS4 that contribute to eliminating this limitation Smith, W. (2021). A point that was stretched out by some of the customers during the interviews was related to the product data traceability. None of the connections provided by EDI systems are offering full process traceability Smith, W. (2021b). This however can be overcome by EDI via an API connection that allows users to source messages, search for messages, locate documents, define the location and the order of the information in a document, while users can use any identifiers that are placed in a message such as product number IBM. (n.d.). This will also allow the users to have direct access to product data in ERP or PLM systems.

This can be considered a solution for complex processes. However Company X should consider a simple approach with a minimum of costs that proves that the file conversion procedure works. Thus, this EDI via API connectors can be considered for later research.

6 Appendix User persona

According to Veal, R. L. (2020) to a user persona is an imaginary depiction of the main users of a product, which in this case is the PLM interface. As the earlier research incorporates the bottlenecks and pain points of internal and external stakeholders, a user persona will summarize in a simple overview their needs, goals, and depict patterns in their behavior. It is important to understand who will be using the PLM platform.

Due to time limitations the decision was made to create the final prototype into one fluent screen that contains multiple features of which purpose is to address the needs of multiple stakeholders. Thus the prototype does not focus on a single user flow, but integrates multiple perspectives. However, user breakdown and personas will benefit Company X in the next phase of the PLM implementation process when the prototype needs to be divided into multiple interfaces that satisfy each user's needs.

Customer

- **Bio**: High tech companies that are active in communication, medical, military, aviation, portable devices and process industries. The companies have a specific region in which they are active

while some of them might reach out to international markets. They are open to collaboration, proactive and innovative. They always strive for quality, reliability and transparency.

- **Frustrations**
  - Not predictable costs
  - Would like to benefit of more services from the same supplier in order to reduce the list of suppliers
  - No traceability of product data and components
  - No digital continuity
- **Goals**
  - Spend less time in exchange of data
  - Have access to extended assembly, prototyping and testing services
  - Increase the degree of digital connectivity with collaborators
  - Clear cost structure
  - To have partners that take more responsibility in engineering processes
  - Product and project traceability
- **Motivation**
  - Price reduction
  - Speed the process
  - Product quality assurance at early product development stage.
- **Preferred channels**
  - Central system to exchange data and communication
  - Face to face conversations that promote the personal interaction
  - Email
  - Phone

Company X employees

Management

- **Bio:** For the manager, time, cost efficient activities and processes are the key to satisfaction. The manager believes that the technology assists the growth of the company, thus is taking measured risks in investing in new technologies. The need to invest in these technologies is to get more insights into business KPIs, measure the healthiness of the company and share those insights with his main collaborators. Clear cost overview, people performing, task overview and digital continuity with customers are the elements that will make this person happy. The manager is really open to listen to different opinions, to communicate and collaborate with anyone who intends to help him in achieving the desired goals.
- **Profile**
  - Entrepreneur, business owner
  - Leader
  - Age ~55
- **Frustrations**
  - Not being able to access up to date data and share it to customers.
  - Not having insights of a product or service performance.
  - Not being able to have a clear overview of how data is managed.

- **Goals**
    - Needing to know what is the value for the money that he is investing in products.
    - Would like to have a clear overview of all products, projects and resources distribution.
    - Have information accessible 24/7 from any location that has internet connection and from multiple devices.
    - Data dashboard where the manager can assess the healthiness of the company at different levels.
    - Satisfy customer needs by extending services and product range as well as providing clear insights into company's capabilities.
    - Reduce costs
- **Motivation**
    - Growth
    - Price
    - Speed
    - Quality and loyalty
- **Preferred channels**
    - Mobile
    - Email
    - Personal interaction

Production employees

This user persona includes the demands, wants, needs of Company X employees. Thus purchasers, production planner, production leader, warehouse employees and account managers are all fictionally considered one user persona.

- **Bio**
    - Company X's employee is a professional that has multiple skills and extended knowledge about different processes. Even though the person can be described as an old fashioned person, the user shows openness for new ideas and innovative projects under clear guidance. The persona generally prefers to stay in a comfort zone and work sometimes with rudimentary tools and hard copy papers that slows down his work. One aspect that characterizes the person is his loyalty and comfort of having a long term collaboration with the company. Usually the person is responsible, proactive however not so innovative. The person would like to have less paperwork, and great technology to work with, however is afraid of the difficulties that come with implementing new technologies and how this will impact the existing work routine.
- **Profile**
    - Engineer, middle level to high level education.
    - Age ~ 45
- **Frustrations**
    - Too much paperwork that they need to handle.
    - Too many systems that need to be used to capture data.
    - Adapt to a new work routine.
    - Implement new technologies.

- **Goals**
    - Know how new technologies will impact the work routine.
    - Reduce paperwork and more streamlined processes.
    - Standardized working methodology for those with the same position so that they can pick up on someone else's work when they are for any reason missing from work.
    - Receive support and guidance on how to use new processes and tools disrupt their working habits
    - Achieving greater productivity in their job position
    - Saving time, and reducing the workload that results from manipulation of hard copies.
- **Motivation**
    - Professional growth
    - Salary
- **Preferred channels**
    - Mobile
    - Email
    - Web interface
    - Personal interaction

7 Appendix Request for quotation

Scenario : When the customer enters the platform the platform displays multiple boxes that are connected to the product data. Now that the product vault is set, the client would like to request a quotation from Company X.

Process: Within the newly created vault, the customer enters the RFQ toolbox (Figure 47) by clicking on it and an overview of the existing RFQs is displayed. The folder is already customized with a Kanban structure through which the RFQ needs to go. How this work will be elaborated at later within the "create new revision" subchapter.

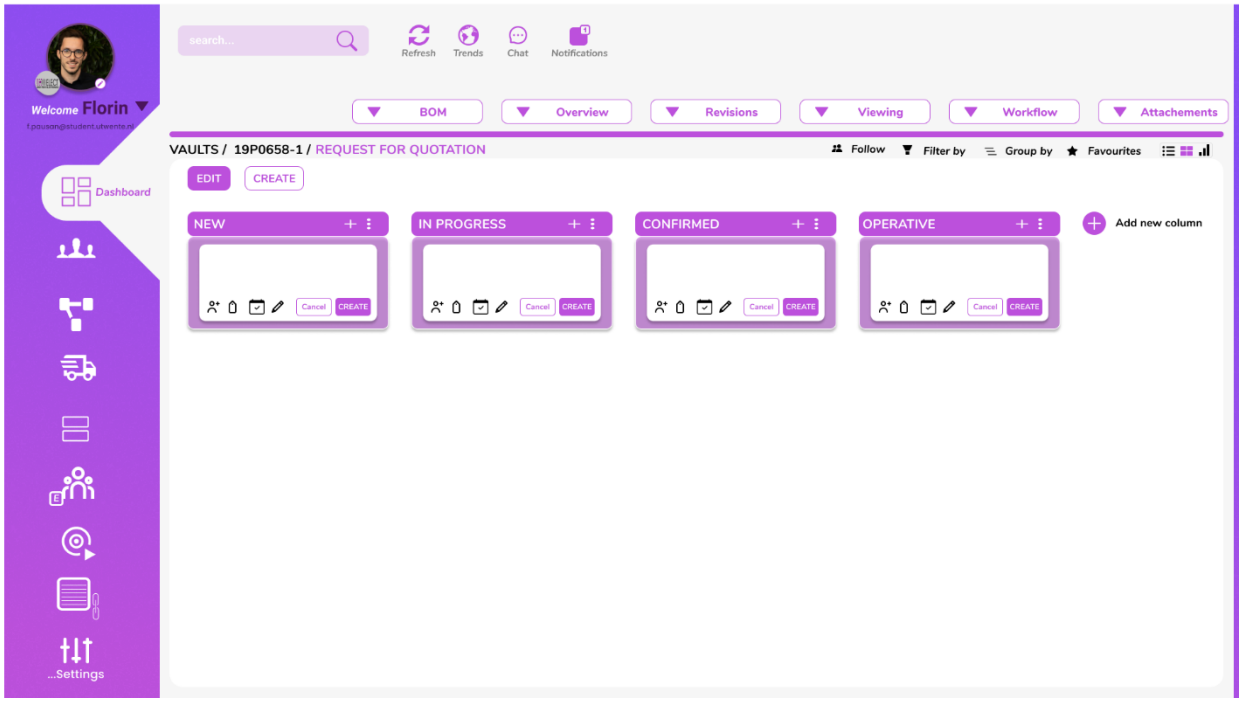


Figure 47 Vault overview

In order to request a new quotation the customer has to click the “in progress” (Figure 7) box and immediately after a new window appears where by clicking the “request quotation” button (Figure 8) the customer is able to perform the request.

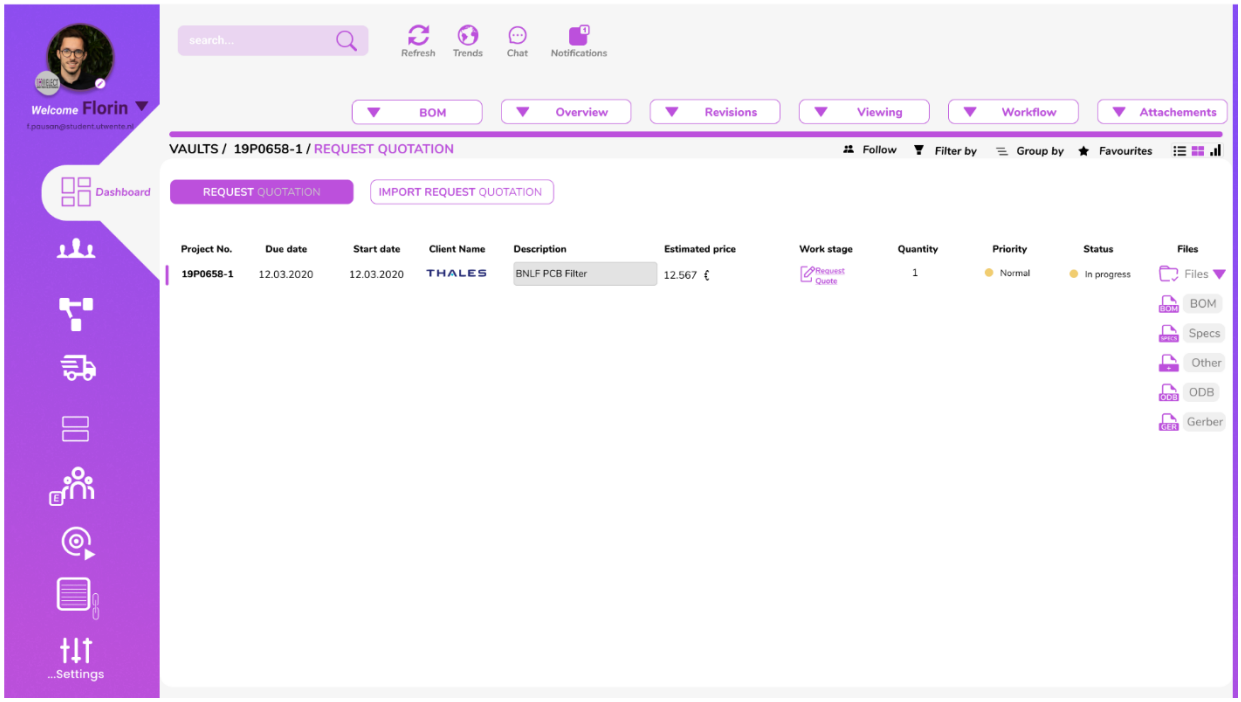


Figure 48 Request quotation

This will lead to a new window displayed in Figure 9 where the user is able to fill in extra information, the product requirements and attach the technical data that sets the base for product execution. To the right side of the screen the user is able to see the chat area.

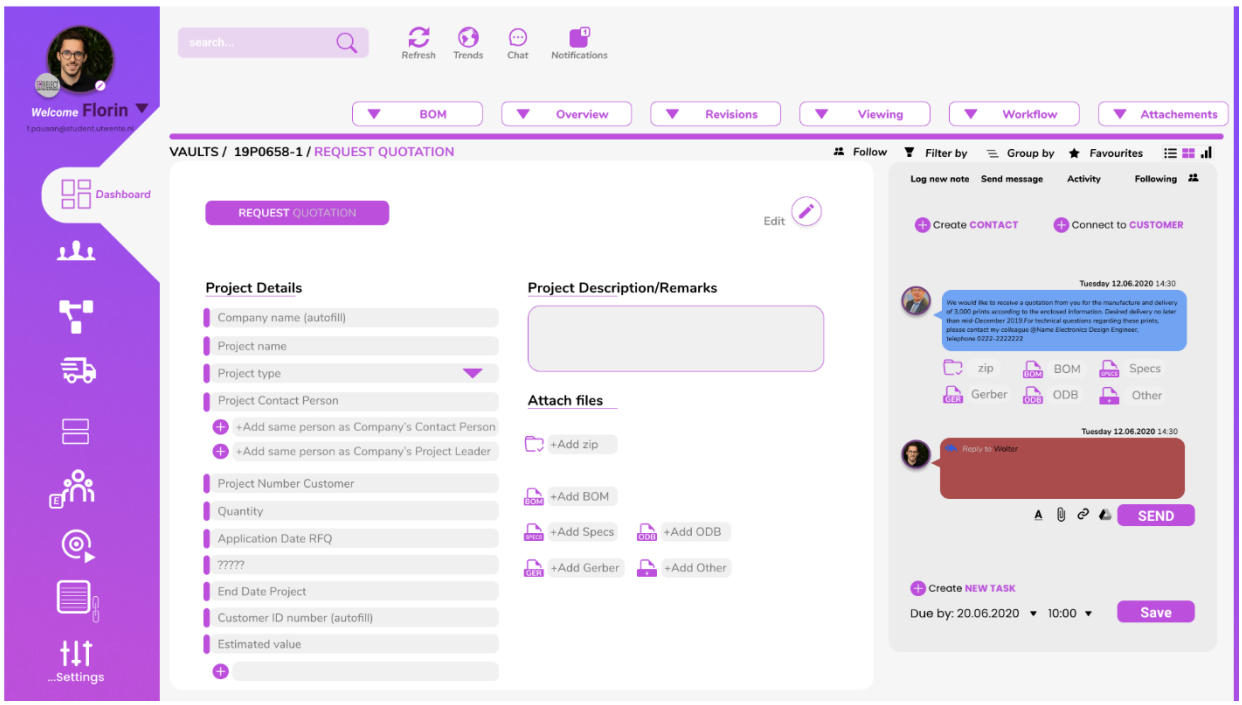


Figure 49 RFQ fill in

As soon as the request form is filled in by the customer, the RFQ is automatically saved. The request is completed and generated when the user clicks again the “request quotation” button.

Figure 10 showcases the fact that the RFQ was completed correctly (green color) and the system is already notifying the Account Manager and any other person connected to the vault that the request for quotation is valid and can be checked and approved.

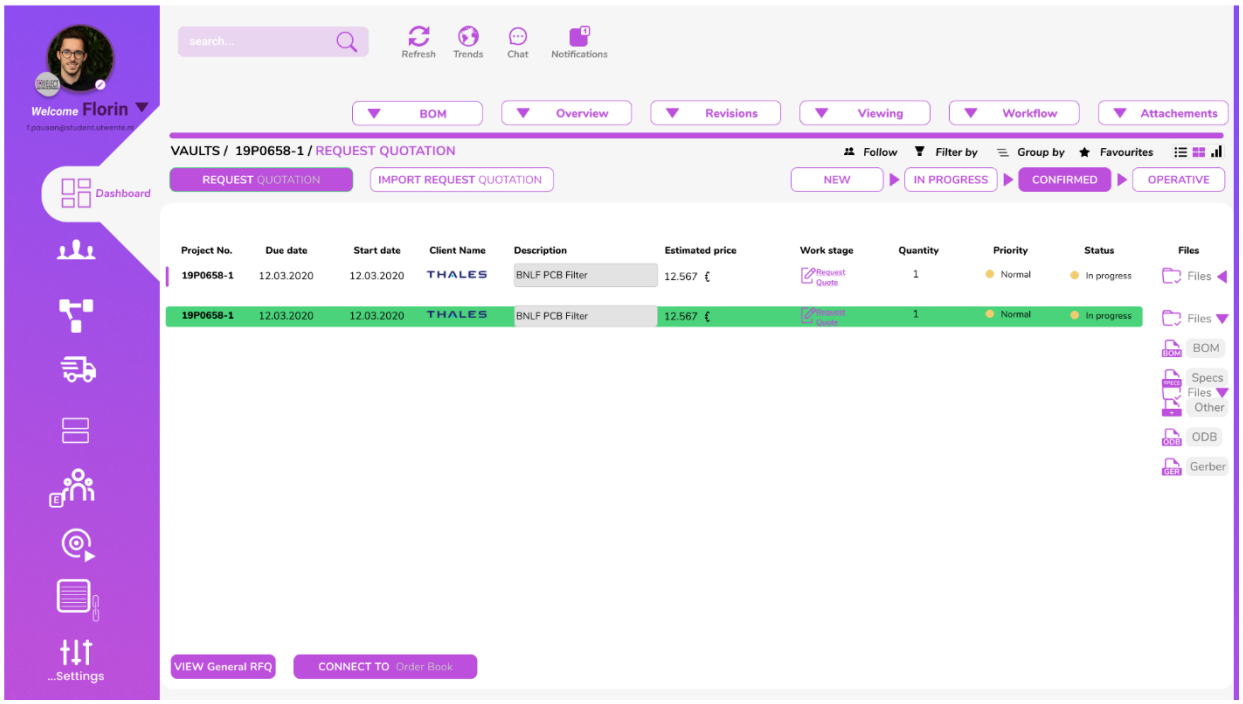


Figure 10 RFQ saved

The account manager can validate the request by accessing the same toolbox, accessing the RFQ and checking and approving the information that was attached. Aside from that, the account manager is able to perform other tasks in this screen, such as viewing the existing RFQ in the general RFQ overview. The general RFQ works as a general space where all RFQs and the data that comes with it are gathered together. It provides also a space to monitor and manage the customer demands and projects, thus it can be considered as a customer funnel where different prospects are registered and their progress is monitored.

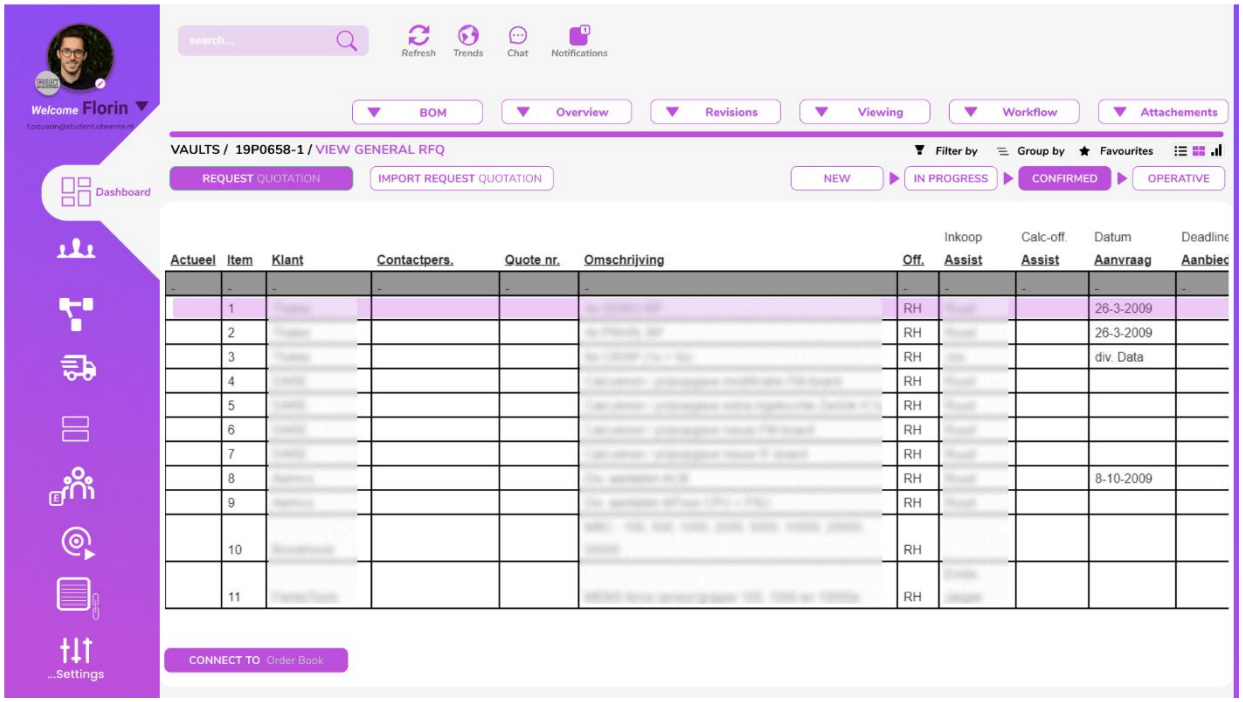


Figure 11 General overview RFQ

On top of that as soon as the quotation is issued out, the AM can connect the product vault directly to the order book (click button “Connect to Order book”) which is a booking system for all quotations that are accepted by the customer. Currently these two processes are manipulated manually, thus the solution proposes a more streamlined process and the automation of these two steps.

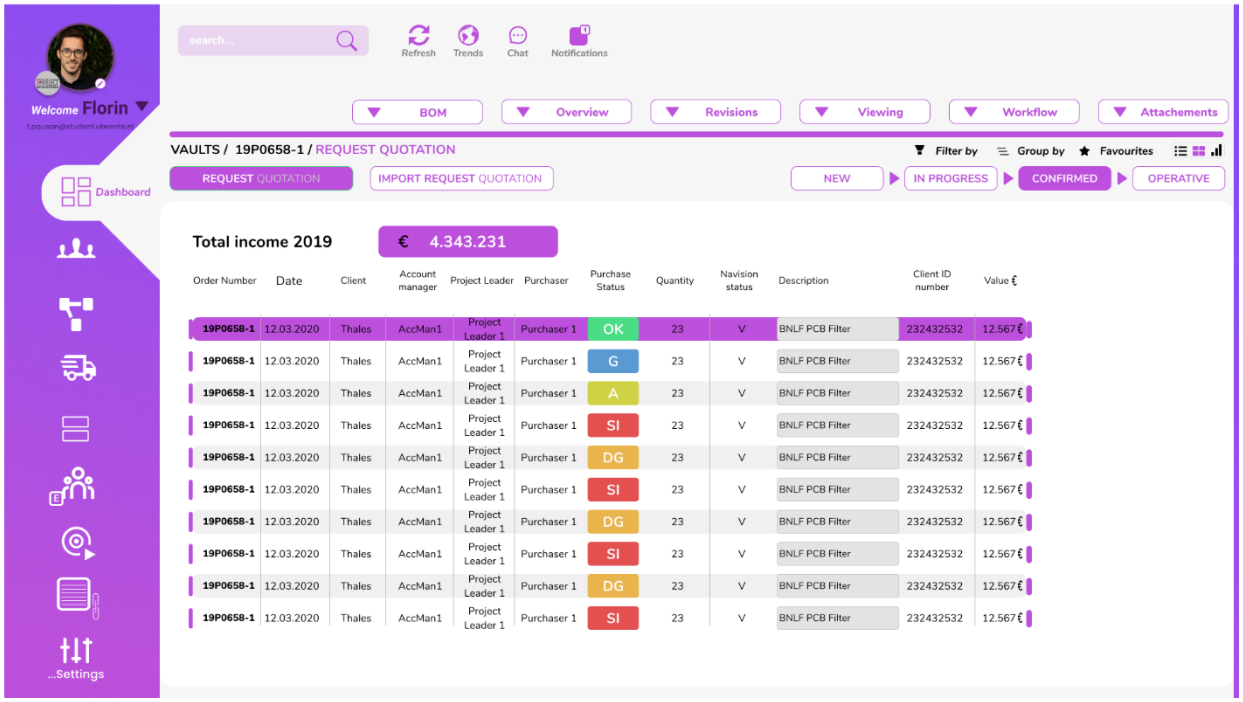


Figure 12 Order book

If the client opts for RFQ via email, the message also pops up in the PLM platform, in the chat area. The chat can be opened and a new window with the conversation appears in the right part of the screen. The Account manager is able to see the message as well as the files attached to the email in the platform itself. Same procedure can be followed via the PLM interface by attaching the files directly in the platform. This ensures the connection of the product data that is generated through the communication tools with the data that is composed directly in the platform. In case any tasks emerge from the discussions, the users can directly capture the decision making process by creating tasks and linking them to the product code. Thus the user can directly create tasks and capture decisions that are strictly related to product data immediately after the communication has ended by clicking the button “Create new task”

After the request is made by the customer, the next step in line is to build the quotation. According to the current process the quotation starts with the EBOM and technical data provided by the customer. Thus the next step in line is proposing a new way of managing the bill of materials.

8 Appendix BOM management

Scenario: the customer uploads the BOM in CVS format and the system automatically scans and translates the structure into the PLM platform BOM configuration area. The customer would like to have access to an open BOM where the costs of individual components are visible. Usually this step is executed by purchasers and the work preparation department. Thus the next process takes into consideration the purchaser as the user of the platform.

Process:

There are two options to create the first version of the eBOM in the system:

- The first method implies that the user creates the BOM directly in the platform. The platform allows the user to configure a BOM structure that captures the relevant information. Additionally the user is able to access a digital component catalogue from where the user sources the components that build up the bill of materials. For an extended explanation please refer to the “add section”.
- A second methodology to set up the BOM is to simply import a spreadsheet that already includes a predefined structure and data. The moment the file is imported into the system, the platform performs a scan of the structure and replicates the same structure in the interface, however providing a flexible and customizable structure. In case the BOM requires additional columns and rows the user can simply add them as an addition to the already imported structure.

From the RFQ view the purchaser clicks the “BOM” button that opens a new window with the imported BOM structure. The platform automatically converts the spreadsheet into the predetermined BOM structure. Figure 13 shows a simple example of BOM.

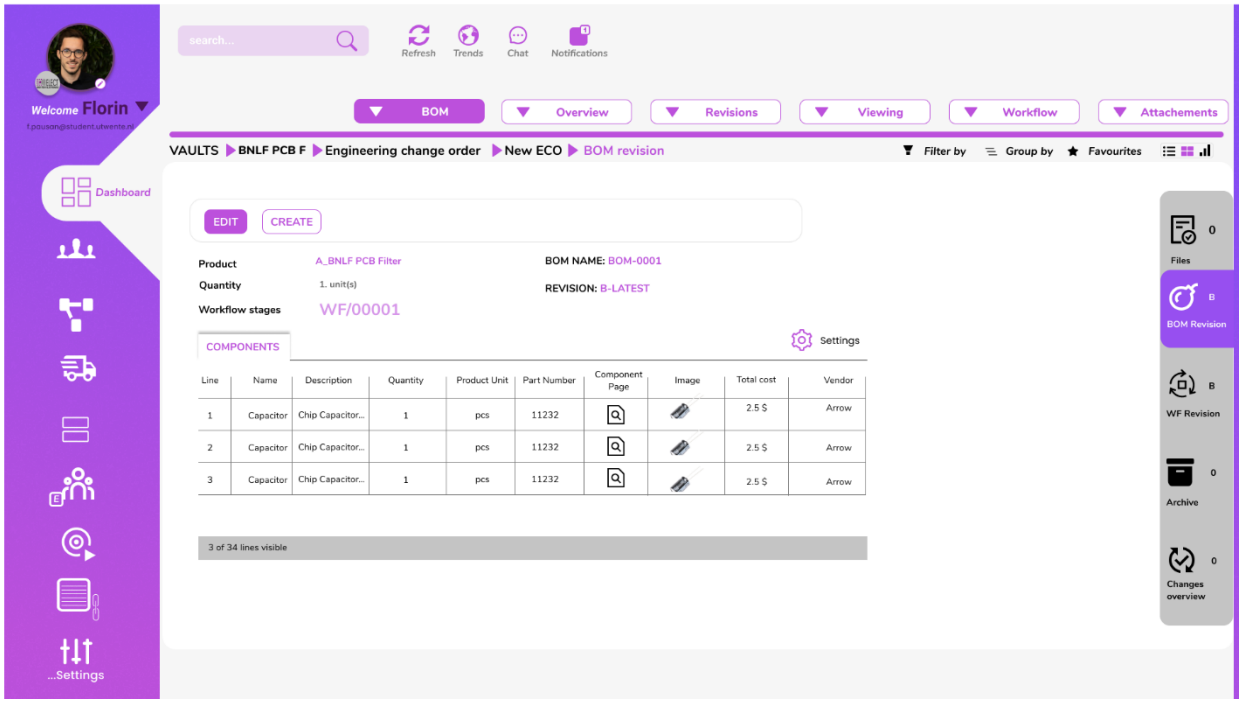


Figure 13 BOM overview

The BOM is connected to the product identifier BNLF PCB Filter as well as to the process workflow “WF/00001” and it contains a short list of components. This represents the engineering BOM and now Company X would like to take part in the process of further defining the engineering BOM and eventually designing the manufacturing BOM.

When entering the Digital BOM there are a list of three items that are listed in the BOM. To add or modify the list of items in the BOM the user can click edit and can start editing the BOM as it is seen in Figure 13.

As the user navigates through the system, items can be simply removed from the BOM structure and new components, columns and rows can be added to the structure. The open BOM structure offers a high degree of customization and flexibility, by adding or removing columns. Open BOM can also capture the component reference-instant relationship. This means that items that are defined in the PLM database can be used in multiple BOMs because the backend structure of the system is capable of capturing the relationship of the items with different BOMs, worflows and products.

The current product development phase handled by the client and Company X integrates two types of BOM:

- Engineering BOM
- Manufacturing BOM

Usually the mBOM is created from eBOM by coping and synchronizing processes where the structure of BOM is changed. The mBOM adds a different part identification number which is called manufacturing part number. This is a tedious process and it takes Company X a high amount of time and effort. Thus the proposed solution displays a single BOM where engineering and manufacturing teams are able to make changes and agree on a single version. The intent is that the BOM is generated within the engineering processes and modified for manufacturing purposes. The single BOM version is using both part identification, the engineering and manufacturing part identification. First the engineering part number is added and during the manufacturing process the manufacturing part number is connected to the engineering one. Because of the high flexibility that the system provides, the BOM can include data that describes both engineering and manufacturing processes.

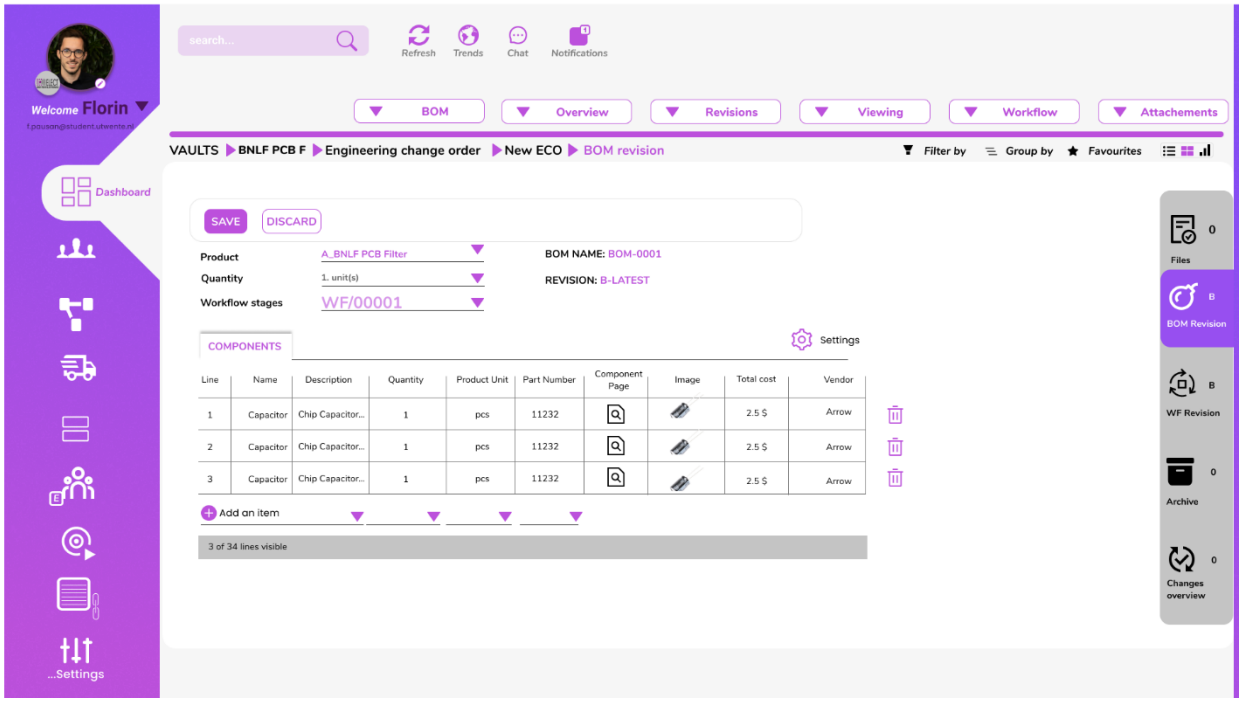


Figure 14 Edit BOM

These items can be directly imported from the internal inventory system within the ERP or from the manufacturers' database. Both entities, the inventory management system, in this case the ERP and the supplier database are connected to the PLM interface. By clicking the "add item" button, the user can filter through the item list or can search in the manufactures' database. This will reduce considerably the BOM conversion steps that are causing a lengthy process.

Adding a new column to the BOM:

Scenario: The user would like to link to the BOM the manufacturing identification part number.

Process: While in BOM view, the user enters the edit mode and selects the button "settings". A window pops-up (figure 15) where the user can configure the structure, more specifically the sequence of the items by dragging and dropping the items in the desired position.

Open BOM system offers Company X and its customers the possibility to easily share data that have common properties. One problem that Company X is currently facing is the matching between the customer part number and the internal part number when the manufacturing BOM is created. For the proposed solution Company X can already search through a list of properties within the engineering BOM defined by customers in the PLM platform and integrate those properties into the manufacturing BOM. Also the other way is possible so that the customers are integrating public properties of Company X into their internal processes.

As in the case of Open BOM software these properties are of two types:

Public properties - in case the collaborators want to share properties and match and validate different product data faster, the properties in the BOM can be set to public. This gives also the option to select the company and the user who is able to view the properties.

Private properties - if the company does not want to share specific properties, these can be set to be private properties so that only the internal team can see them.

Figure 15 Public properties

To add a new column to the BOM the user clicks the “add section” button and selects within the drop down menu the property called “manufacturing part number”. Now the selection appears in the window (Figure 16). Additionally the user can create and edit properties, implicitly properties that require specific settings within this screen.

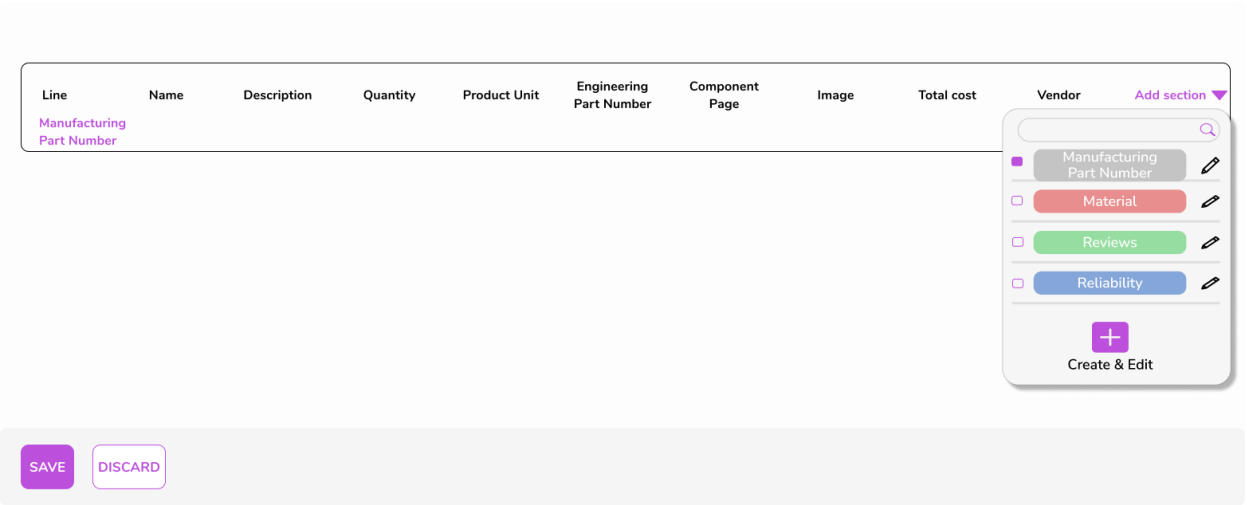


Figure 16 New property

To complete the process and add the new column to the BOM, the user needs to save the changes by clicking the “Save” button. As displayed in Figure 17, the highlighted column is added to the BOM structure.

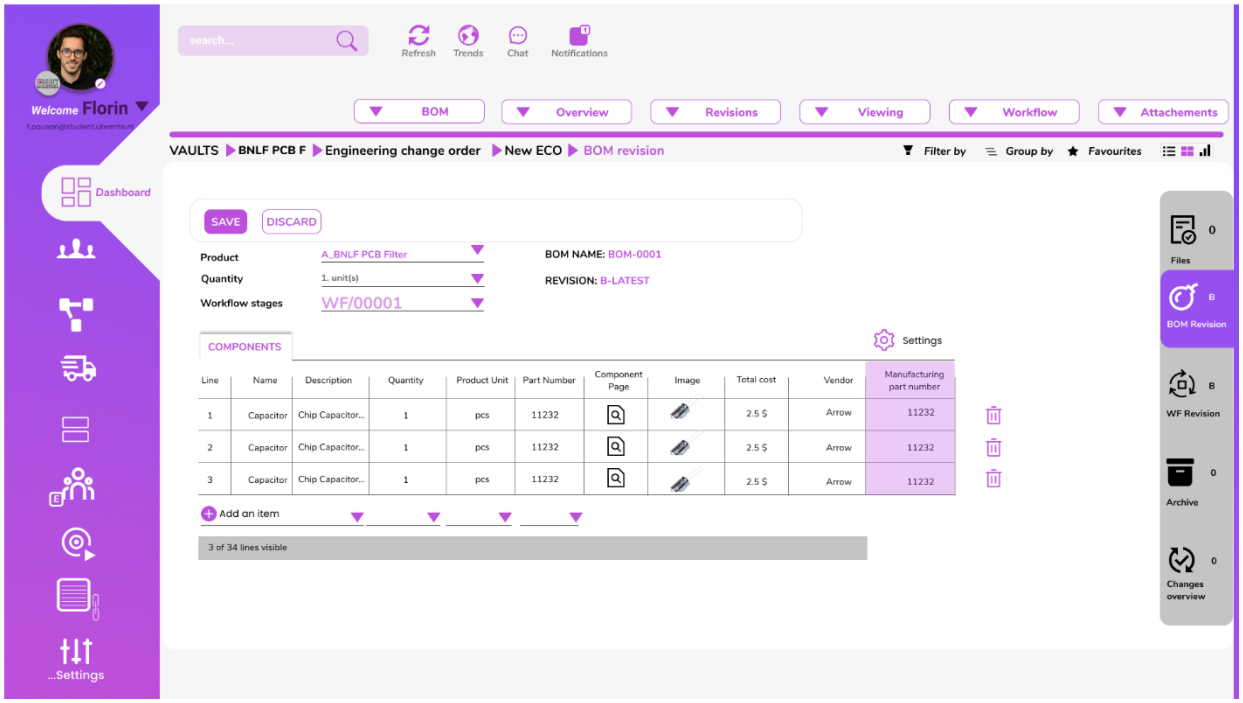


Figure 17 New column added

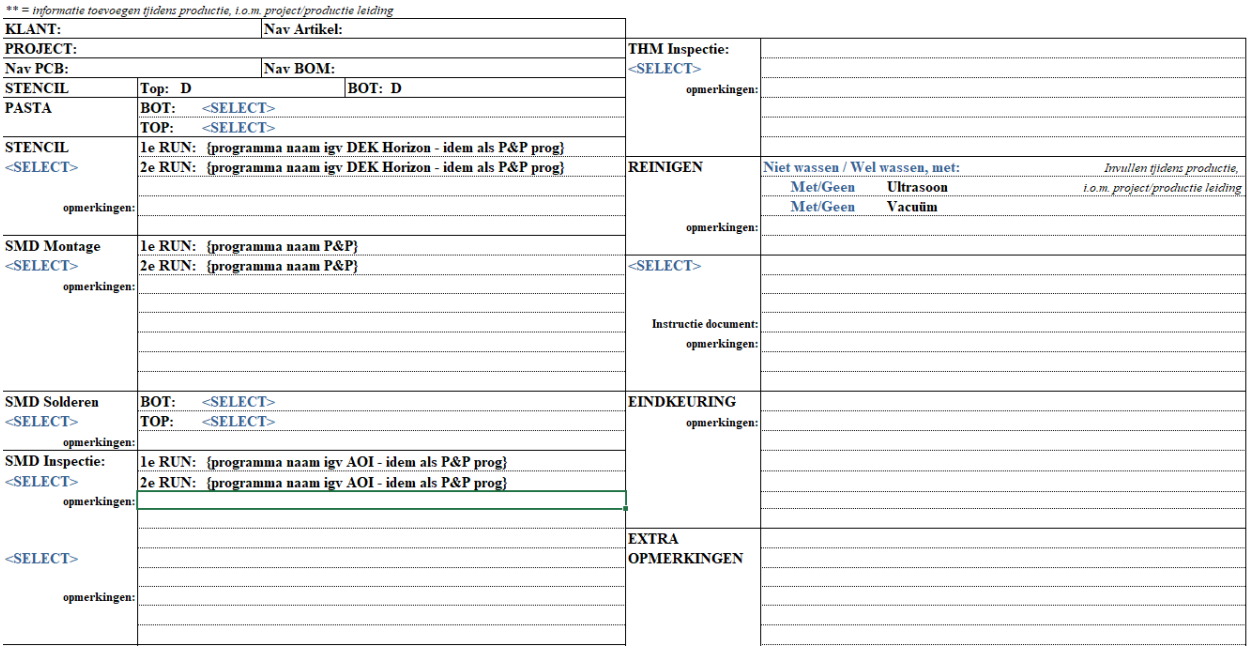
The BOM relies on a flexible structure that allows the purchasers or who is maneuvering it to customize it in order to capture a full overview of the product data. Examples of such functionality are presented in Open Projects software or Monday software, tools that deal with project management tasks and allow the user to customize the rows and columns according to their needs. Open BOM software presents similar functionality to use and define BOM properties.

9 Appendix Workflow management

By accessing the work stage, the user is allowed to create the overview of the product manufacturing process and its operations. Momentary Company X is making use of Barbone and backbone to capture this information. The user will edit an existing product that already has an active workflow.

The project guidance card which provides the manufacturing activities that Company X employees execute during the manufacturing process is the main file of this phase. Currently this file takes the shape of a hard copy file that flows between employees from one production unit to another while executing manufacturing processes on a product. All changes are captured on paper. This should be captured in the existing project management systems, however this encounters several problems thus the data ends up

outdated in the systems. Only after the production is done, the data is updated in the existing systems and sometimes it happens that the data is partially uploaded. As figure 18 illustrates, the project guidance card is an excel file that is built based on the product requirements and after the quotation is done. The information is manually entered by the work preparation department every time a new product is requested.



** = informatie toevoegen tijdens productie, i.o.m. project/productie leiding

KLANT:	Nav Artikel:			
PROJECT:			THM Inspectie:	
Nav PCB:	Nav BOM:		<SELECT>	
STENCIL	Top: D	BOT: D	opmerkingen:	
PASTA	BOT: <SELECT>			
	TOP: <SELECT>			
STENCIL	1e RUN: {programma naam igv DEK Horizon - idem als P&P prog}			
<SELECT>	2e RUN: {programma naam igv DEK Horizon - idem als P&P prog}		REINIGEN	Niet wassen / Wel wassen, met: *Invullen tijdens productie,*
				Met/Geen Ultrasoon *i.o.m. project/productie leiding*
opmerkingen:				Met/Geen Vacuüm
			opmerkingen:	
SMD Montage	1e RUN: {programma naam P&P}			
<SELECT>	2e RUN: {programma naam P&P}		<SELECT>	
opmerkingen:				
			Instructie document:	
			opmerkingen:	
SMD Solderen	BOT: <SELECT>		EINDKEURING	
<SELECT>	TOP: <SELECT>		opmerkingen:	
opmerkingen:				
SMD Inspectie:	1e RUN: {programma naam igv AOI - idem als P&P prog}			
<SELECT>	2e RUN: {programma naam igv AOI - idem als P&P prog}			
opmerkingen:				
			EXTRA	
<SELECT>			OPMERKINGEN	
opmerkingen:				

Figure 18 Project guidance card

The solution is providing a more simple and automatic approach in capturing this data by auto-fill options and withdrawing information from previous forms that were completed in earlier stages. Thus when a similar product is requested by a customer, the project guidance card is used immediately with the instructions attached to it.

The new solution (Figure 59) proposes a flexible and customizable procedure through which the user can customize the number of operations that the product needs to pass through, select the right people and visualize the status of each stage, write a description of the job to be done and attach useful documents to the production stage.

Figure 19 illustrates that the user is able to access the working flow by clicking the button called “WF/00001”. All the working operations linked to the product and BOM are listed below. Each operation is organized in phases and sub phases Thus the user can customize and create working phases and additional sub phases according to the needs of the customer and requirements of the product. The same flexible and customizable structure is proposed as in the case of Open BOM or Open project software.

The work stages allow the user to determine which work is executed at which work station. Each stage integrates the name of the person responsible with that stage, the files that are linked to it and the average time to execute the operation. All instances work according to the reference instance model

where people, processes, tools, files, products are properties of the system that are connected between each other. For instance, to achieve increased efficiency in the production processes, all properties need to be in a good, and balanced relationship. Employees perform a manufacturing process on a product using technologies. Usually data turns out to be the outcome from those activities. It can be a file, a report, a description of what tasks to follow at the specific production unit, or comments about the product or a process. Through the reference model a link is created between all these elements. In case there are processes which are not in place, or ineffective this will project on all the other elements and the system is able to detect. This results in a framework that interconnects processes, people, tasks, files together. This enforces the ability of the company to touch upon the PLM characteristics and achieve data singularity.

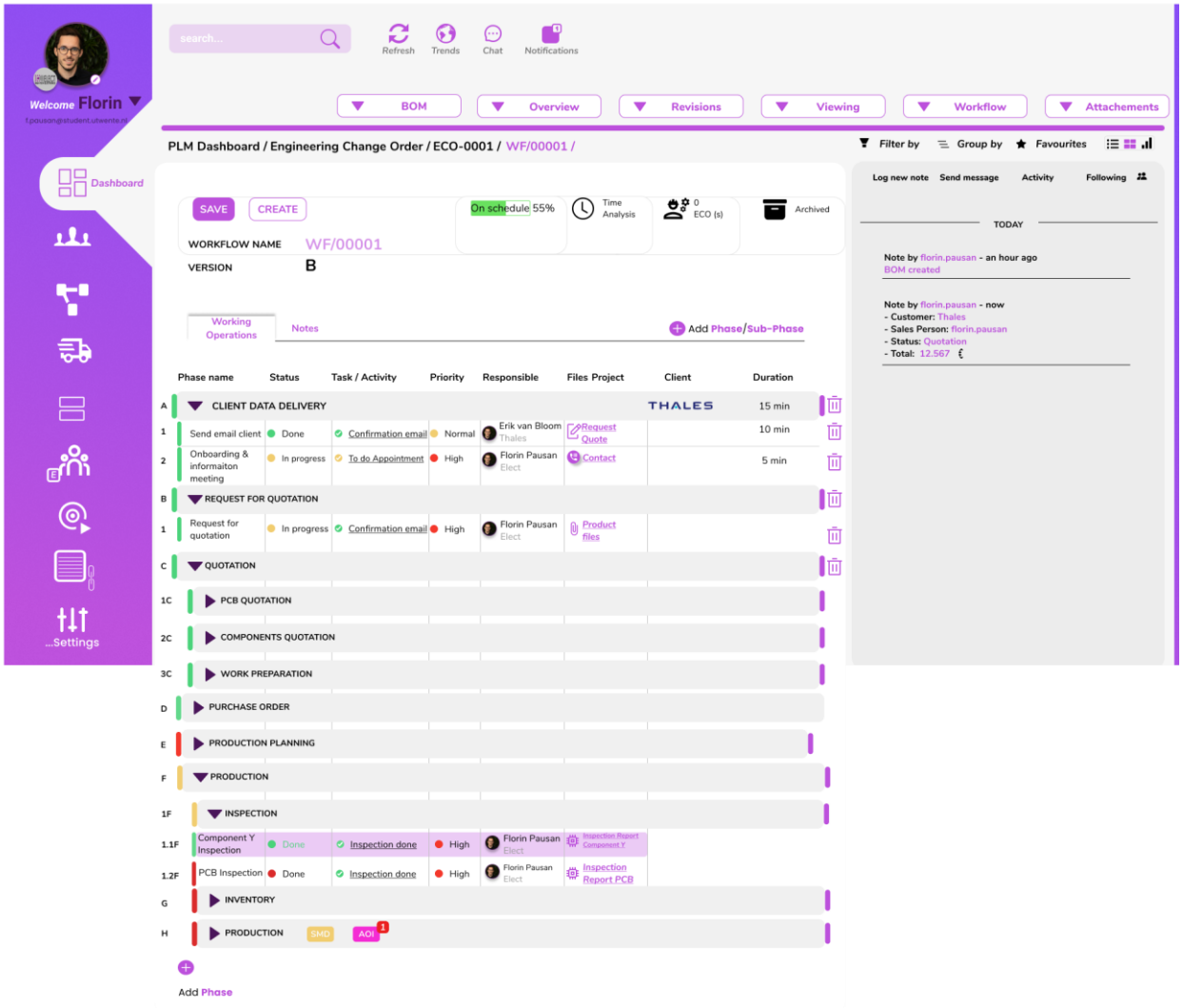


Figure 19 Workflow stages

Similar to the component catalogue, a traffic light system is adopted also in this case to determine the progress of each stage. The color code is applied as follows:

- Green means that the operation is finished, therefore the operator can proceed to the next operation.
- Orange means that the operation is in progress or it needs reviewing and approval from a second or third party involved in the process step.
- Red means that the operation is not initiated or is rejected thus it needs reviewing before being sent for approval.

Production planning

***Scenario**:* The main task of the production leader is planning the projects for production. Thus together with the project leaders they create a general overview of the projects that are running in production. Currently this entails a great deal of manual manipulation of data that usually takes time executing the projects.

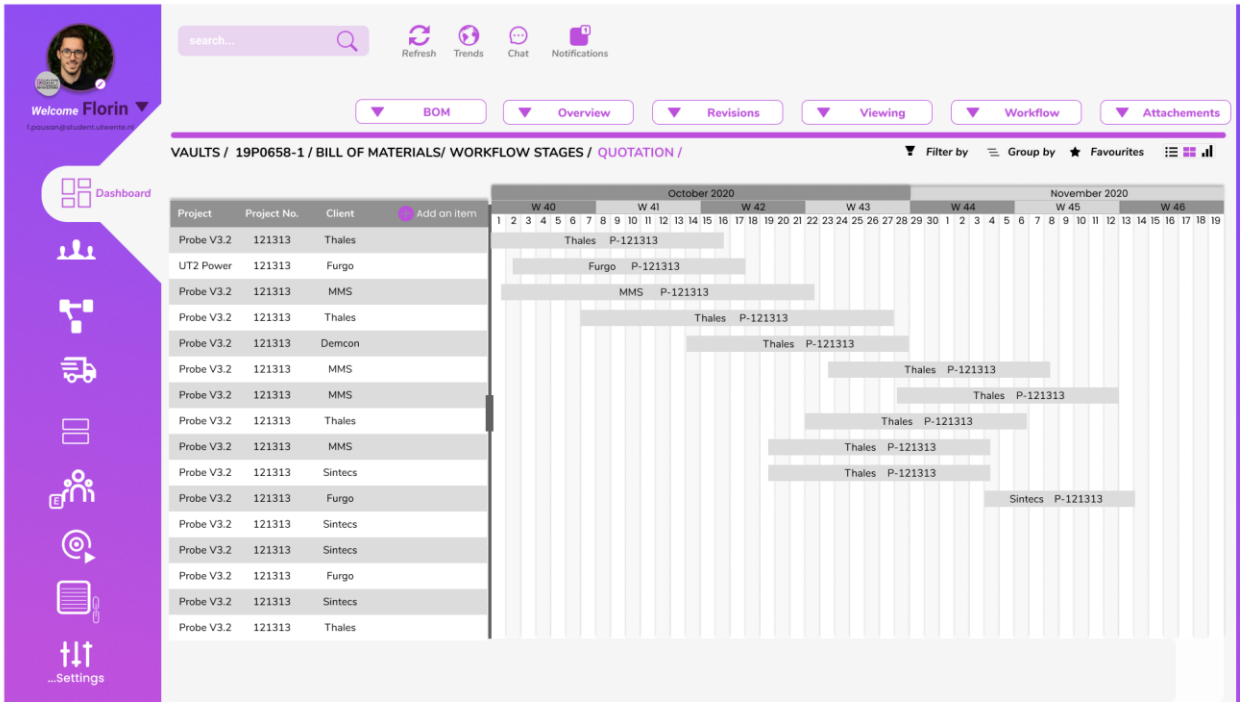


Figure 20 Production planning

***Future situation**:* Figure 20 proposes an alternative to the excel project management overview. The project planning will be executed in the proposed platform, where the relevant data for each project is already placed in the platform in an initial phase. Data such as start date, end date, client, project number are already registered in the RFQ, thus the system is able to withdraw all that data and propose it to the planner. However those dates suffer modifications during quotation depending on Company X's availability of people and machineries. As a solution, the planner can create dependencies in the production timeline between products. Hence in case of any delay in a product production, the other products which are dependent on the delayed one will suffer time adjustments automatically. This enhances a faster planning and decision making process.

Additionally the production leader is able to change the project timeline just through the drag the ends of each time bar to the left or to the right, instead of manually changing the start and end date of the project. Also the production leader can access useful information by just selecting one of the projects in the timeline.

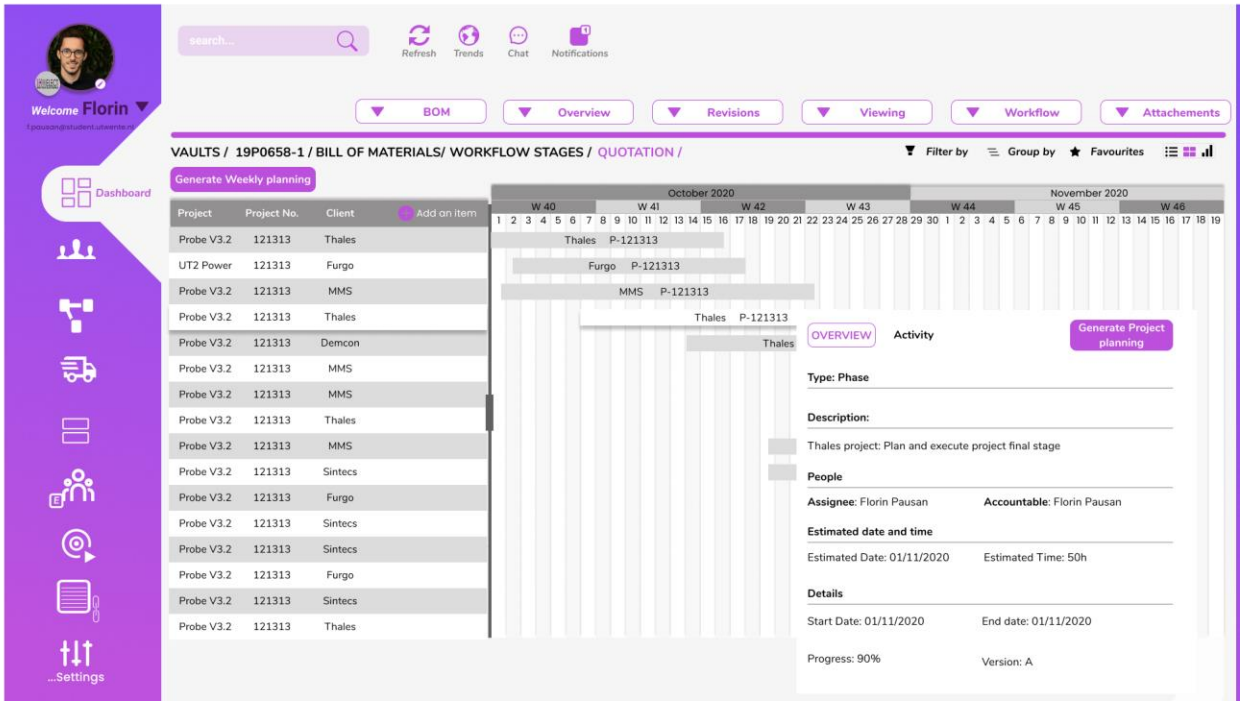


Figure 21 Production timeline edit

Project Leader

Scenario: The main task of the Project Leader is to plan the production process for the particular project that is responsible for. Currently the production leader withdraws manually the planning for the upcoming week, planning that gives a clear perspective of the main responsibilities and priorities for short term periods. However the design proposes a new solution for that as described in the next paragraph.

Process: The project leader usually generates a project overview for each week. A problem is that the project leader needs to extract manually the information from the general work planning and place it each week in the weekly overview. As a solution, the platform allows the project leader to select the week for which he needs the planning. By clicking on the “generate weekly planning” button the user is able to automatically generate one overview of all the projects that are ongoing in that particular week. Due to reference model the system knows which products/projects are linked to the user, thus the user only needs to select the week that is intended to be planned. This allows the employee to take fast decisions regarding the task prioritization of production employees and reduces the time spent on file manipulation.

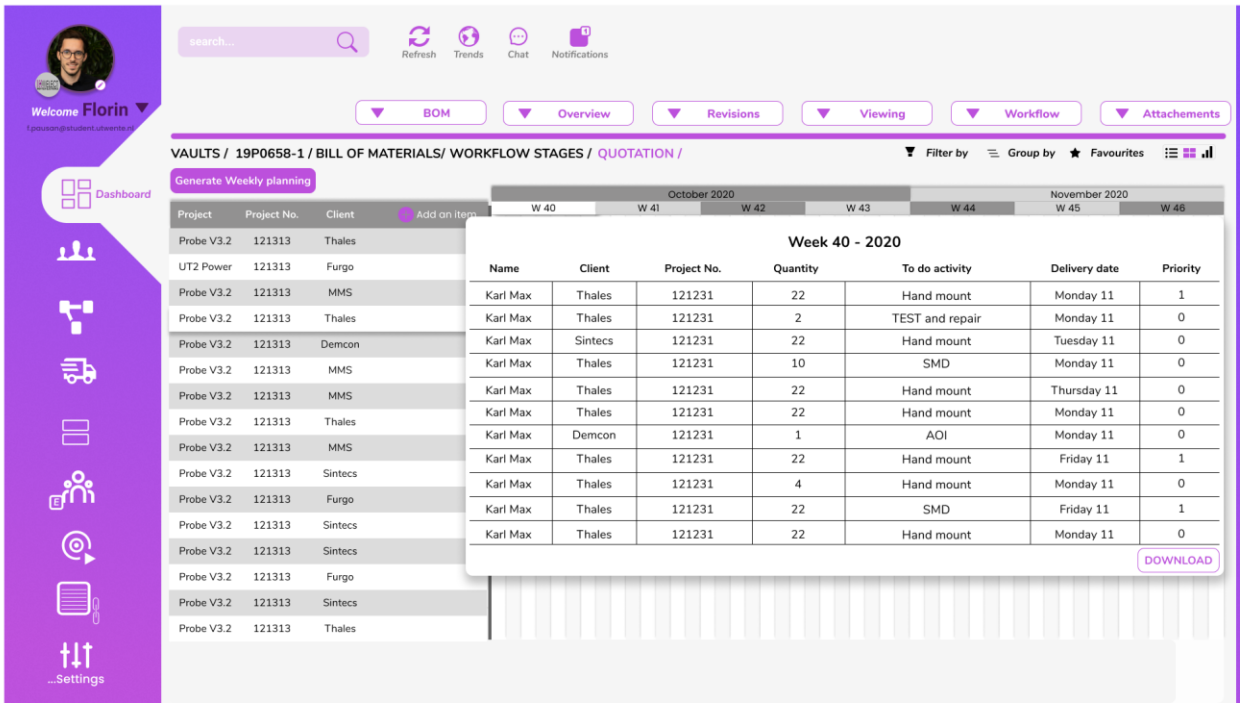


Figure 22 Generate weekly planning

File editing and coding

Scenario: As the BOM is agreed by both the engineering and manufacturing team, the production process can be the next operation in line to be tackled. Thus the scenario involves a production employee who is going to bring changes to the workflow that is required for the product BNLF PCB filter.

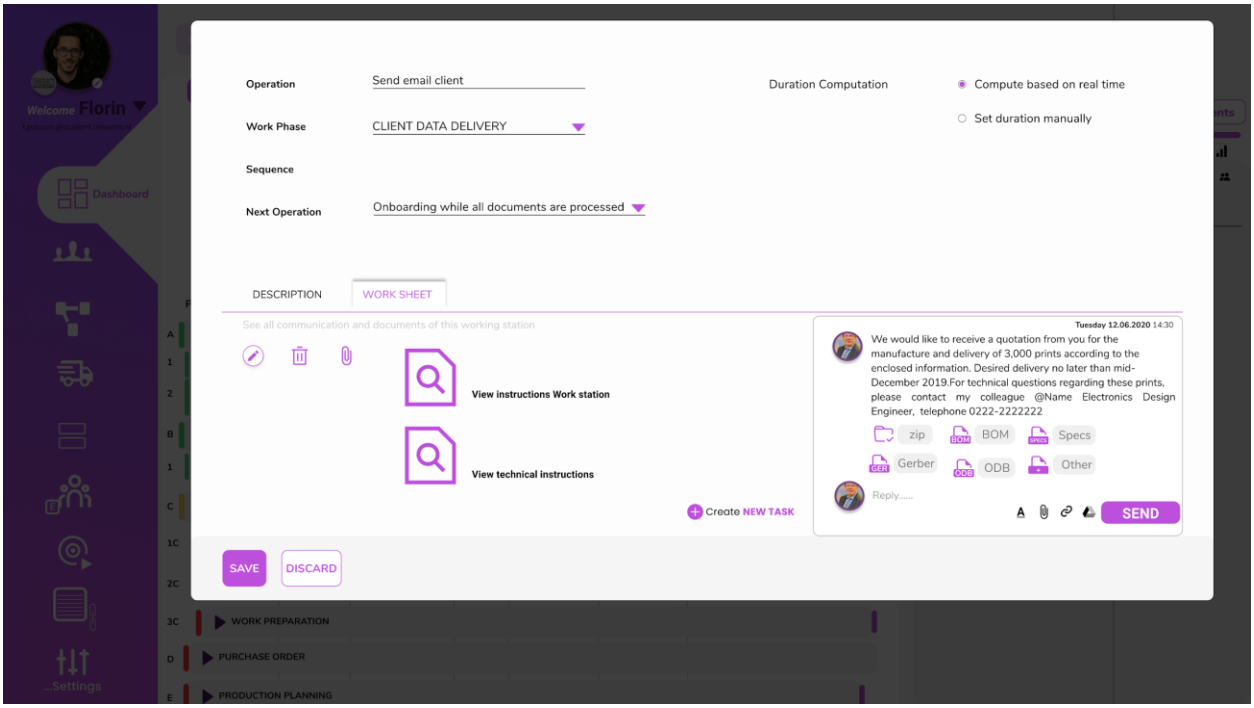


Figure 23 Attach file to workstage

Another important option that contributes to achieving the PLM principles is the ability of the platform to allow users to attach documents to the sub phase, documents that can be related to the technical details of the product or just instructions on how the product needs to be handled in that specific operation.

Figure 23 illustrates how the user can visualize, edit and create new revisions of the files in case there are observations, or changes are required. The user clicks on the first sub phase “Send email client” which belongs to the phase ““Client data delivery”. A window pops up (figure 23) where the user can visualize the description of the phase as well as the worksheet panel that includes all files which are linked to this sub phase.

To the bottom right, the user is able to see the chat and the conversation that the user had with the account manager. It is assumed that the user is the production leader who needs to check the documents.

By clicking the file called “Instructions workstation” will allow the user to access the document. The document presents similarities to a PDF document or it can be a PDF document that is editable directly in the platform. Similarly it goes also for the technical instructions document where the user can make remarks and point out different instructions for the manufacturing process figure 24.

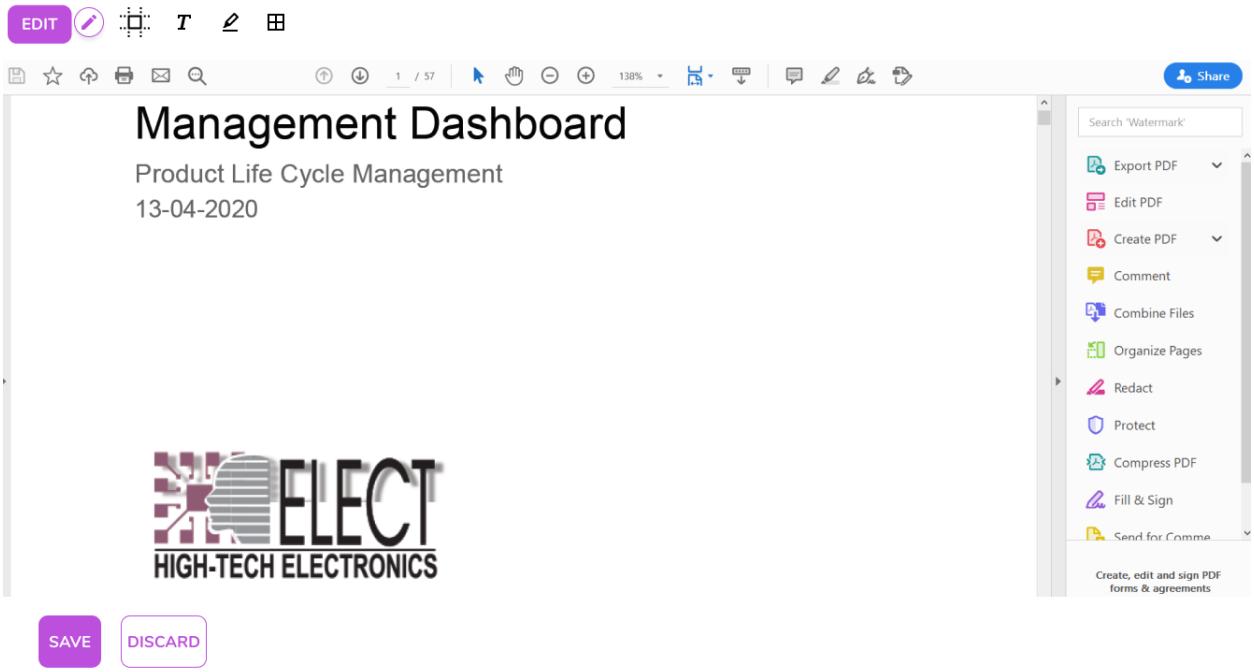


Figure 24 Edit document online

The user can also base the time computation on real time, or on a manually setting of time as seen in figure figure 25) thus providing the platform the possibility to incorporate the required planning for the execution of the operations. At the moment all those operations are captured through Barbone/Backbone software. However, the solution implies that Company X will detach from using Barbone/Backbone for planning processes and incorporate all the functionalities in the PLM platform.

To showcase how the changes and observations to product are actually approved there will be an explicative process described in section “PLM characteristics”.

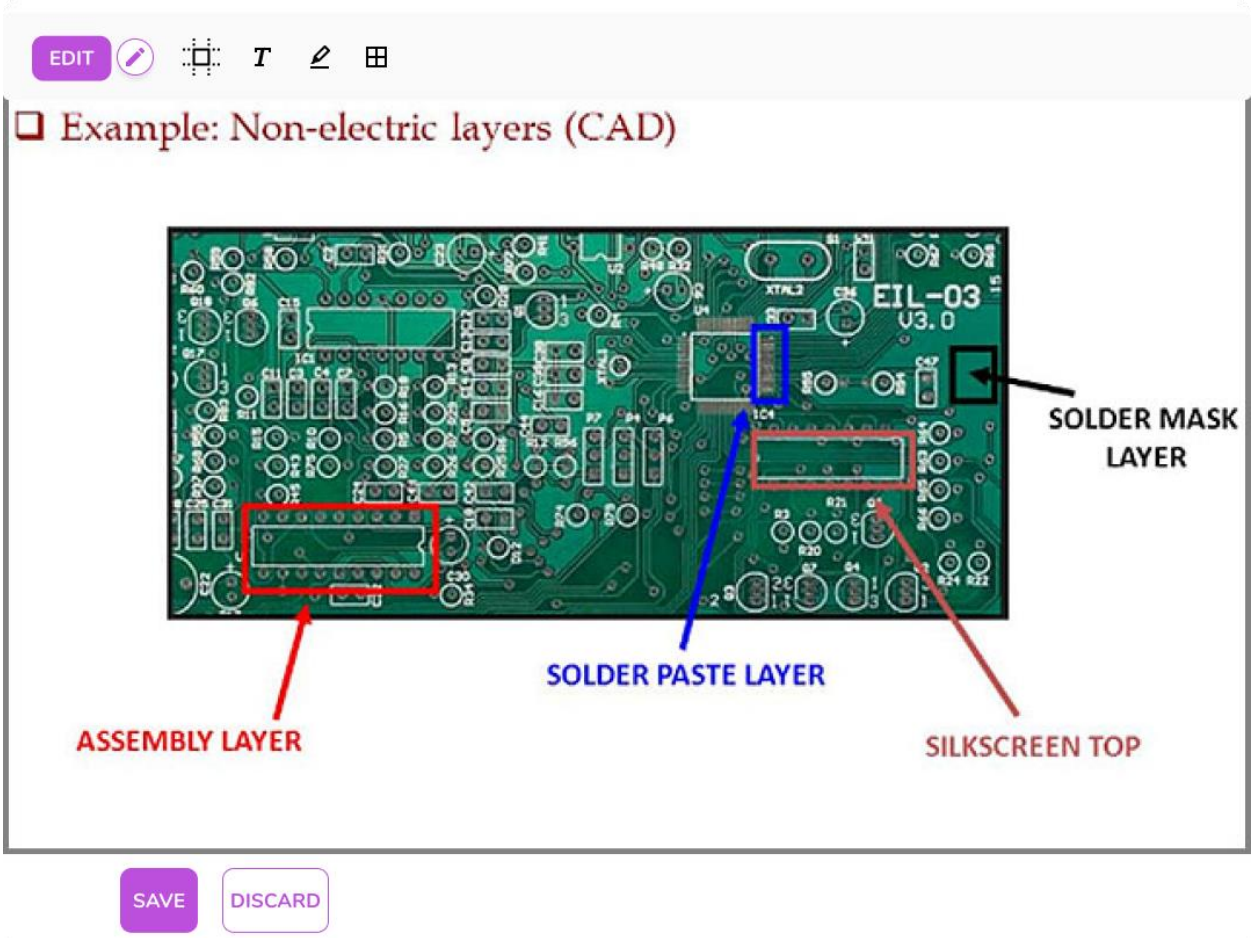


Figure 25 EDIT document

10 Appendix Responsive design

App - responsive design

Current Scenario: The management board would like to visualize the information and product dashboard from mobile devices, however this is not possible because the current applications do not allow this functionality.

Problems addressed:

- Data accessibility from multiple devices and from different locations.

Future scenario: Most of the people nowadays are making use of their mobile phones or tablets to quickly access platforms and data. This is also the intention that Company X has with this platform and is one of the requirements that were stated by the management board to have a platform that can be easily

accessible on any devices. Thus the development phase of the platform should cover responsive design principles Duran, A. F. (2018). Responsive design permits software engineers to build interfaces that can dynamically accommodate the size of the device Almeida, F., & Monteiro, J. (2017) . This will ensure the usability of the web application across mobile, tablet and desktop devices. The example below highlights how the platform can adapt its design to different devices.

- Mobile

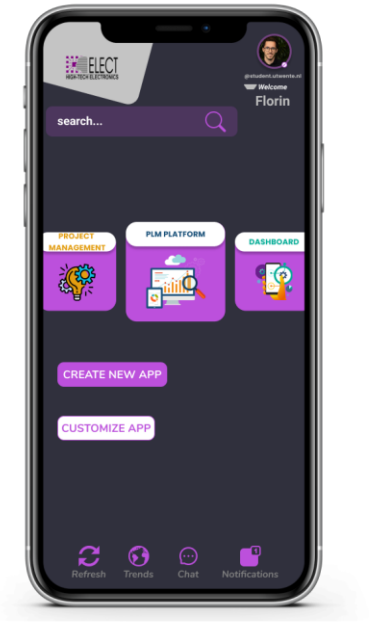


Figure 66 Mobile app

- Tablet

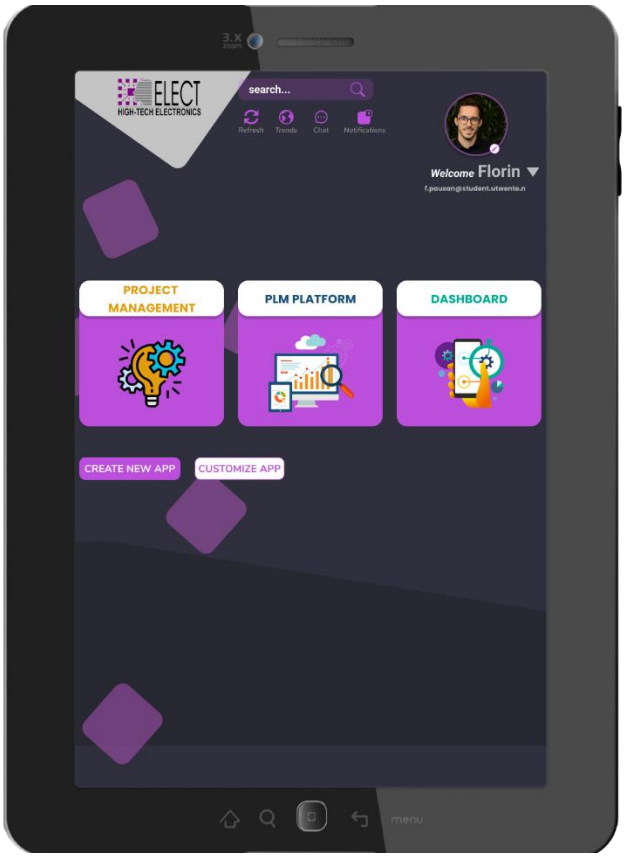


Figure 67 Tablet view

- Desktop

Figure 68 Desktop view

11 Appendix Data centralization

Appendix 16 data centralization compiles the information overview for each stakeholder. This entails the interaction between product data and stakeholders.

The following aspects are comprised within this Appendix:

- Data received during the product development phase.
- Type of data (word, excel, pdf, etc.).
- Means of exchange.
- If the data requires conversion to standardize file format for Company X
- Data provided to Company X
- Documents used in hard copies by each employee.

Based on this overview Company X can establish the level of authority in the platform for each user by knowing at each phase in the process to whom to give authorization to access, edit or view information. This provides Company X the means for planning the data conversion during the PLM implementation process to be. Additionally it is essential to source all files at each phase of product development in order to create the implementation roadmap for the PLM interface. This should be further research on the customer end because the engineering process is intended to be more inclusive within Company X services, thus changes are expected to happen in terms of managing product data. More precisely, in addition to the existing documents that are constituting the product data within Company X, there are other documents that are usually generated by the client in the initial phase. These documents might have a degree of influence on how the product data is shaped thus it is essential that Company X has an understanding and overview of the exact product data that they need to handle.

Stakeholder	Data provided by Elect	Type of data	Exchange of data	Required Conversion in Elect format - required data action	List of hard copies	Data proviced to Elect	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies
Customer	Quotation	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	Quotation	Email or phone call information	Other	via Phone-via Email	Yes - connect Email and phone call information	Project specifications
	Order confirmation	PDF	via Phone-via Email	Yes	Packinslip	BOM	XLSX	via Phone-via Email	Yes - Format file/ capture into new interface	Purchase order (PO)
	Notification for late delivery	Other	via Phone-via Email	Yes	Invoice	ODB++	Other	via Phone-via Email	Yes	Montly forcasts
	Packinslip	PDF	via Phone-via Email	Yes		GERBER	Other	via Phone-via Email	Yes	Quality dashboards
	Invoice	PDF	via Phone-via Email	Yes		Project specifications	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	
	Data requested in the future					Purchase crder (PO)	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	
	Status of RFQ	Other	Other	Capture into new interface		Request for quotation (RFQ)	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	
	Status of Quotation	Other	Other	Capture into new interface		Montly forcasts	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	
	Process updates and traceability	Other	Other	Capture into new interface		Quality dashboards	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	
	Project updates and traceability	Other	Other	Capture into new interface						
	Cost structure	Other	Other	Capture into new interface						
	Test reports	Other	Other	Capture into new interface						
	Notification on updates	Other	Other	Capture into new interface						

Stakeholder	Data provided by Elect	Type of data	Exchange of data	Required Conversion in Elect format - required data action	List of hard copies	Data proviced to Elect	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies
Supplier Components	Order request via website	Other	Other	Yes - Capture into new interface		Confirmation email	Other	via Phone-via Email	Yes - Format file/ capture into new interface	Packing slip
			via Phone-via Email			Materials	Other	Other		Invoice
						Packing slip	Hard copy	Other	Yes - Format file/ capture into new interface	
						Invoice			Yes - Format file/ capture into new interface	
						Data requested in the future				
						Traceability of products			Yes	
						Notification on delivery time			Yes	

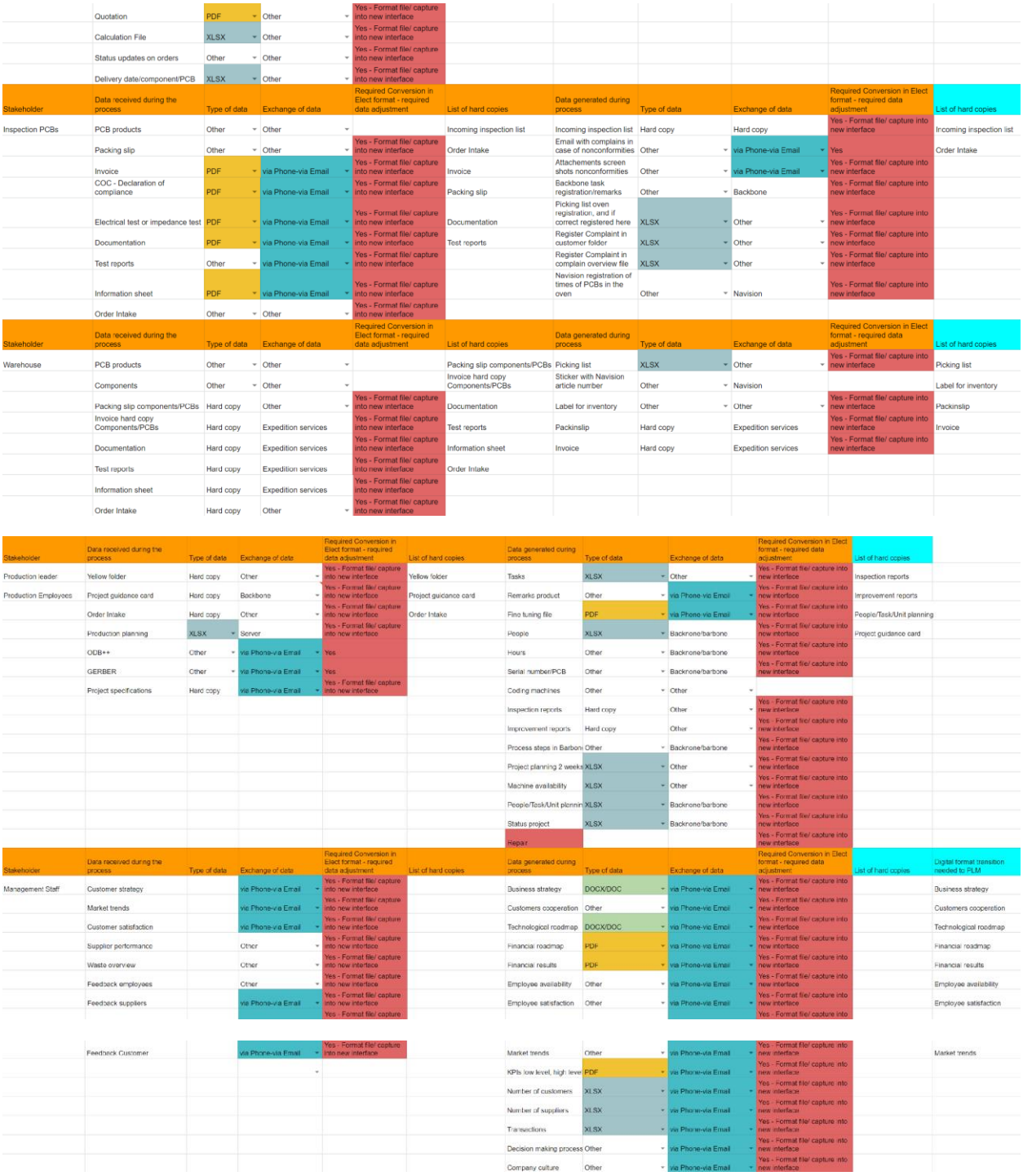
Stakeholder	Data provided by Elect	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies	Data provided to Elect	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies
Supplier PCBs	Emails with RFQ	Other	via Phone-via Email	Yes - Format file/ capture into new interface	PCB info sheet	Quotation/supplier	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	Pre-production approval, changes to Gerber file.
	PCB info sheet	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	Project specifications	Terms and conditions/Supplier	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	Orcer intake
	ODB++	Other	via Phone-via Email	Yes		Pre-production approval, changes to Gerber file.Data of 1 PCB that is panelized	Other	via Phone-via Email	Yes - Format file/ capture into new interface	
	GERBER	PDF	via Phone-via Email	Yes		Order confirmation via email	Other	via Phone-via Email	Yes - Format file/ capture into new interface	
	Project specifications		via Phone-via Email	Yes - Format file/ capture into new interface		Order intake				
	Purchaser order PCB		via Phone-via Email	Yes - Format file/ capture into new interface		Data requested in the future				
						Traceability of products	Other	Other	Yes	
						Notification on delivery time	Other	Other	Yes	

Stakeholder	Data received during the process	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies	Data generated during process	Type of data		Required Conversion in Elect format - required data adjustment	List of hard copies
PCB purchaser	Email from Account manager	Other	via Phone-via Email	Yes - Format file/ capture into new interface	Project specifications	PCB info sheet	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	PCB info sheet
	BOM	XLSX	via Phone-via Email	Yes - Format file/ capture into new interface	Order intake	Emails RFQ	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	Orcer intake
	ODB++	Other	via Phone-via Email	Yes		Decision making points	Other	via Phone-via Email	Yes - Format data/ capture into new interface	
	GERBER	Other	via Phone-via Email	Yes		Supplier selection file - inkoop	XLSX	via Phone-via Email	Yes - Format file/ capture into new interface	
	Project specifications	PDF	via Phone-via Email	Yes - Format file/ capture into new interface		Purchase order PCB	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	
	Purchase order (PO)	PDF	via Phone-via Email	Yes - Format file/ capture into new interface						
	Request for quotation (RFQ)	PDF	via Phone-via Email	Yes - Format file/ capture into new interface						
	Order Intake	PDF	via Phone-via Email	Yes - Format file/ capture into new interface						
	Quotation/supplier	PDF	via Phone-via Email	Yes - Format file/ capture into new interface						
	Terms and conditions/Supplier	PDF	via Phone-via Email	Yes - Format file/ capture into new interface						
	Pre-production approval, changes to Gerber file.Data of 1 PCB that is panelized	Other	via Phone-via Email	Yes - Format file/ capture into new interface						
	Order confirmation via email	Other	via Phone-via Email	Yes - Format file/ capture into new interface						

Stakeholder	Data received during the process	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies	Data generated during process	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies
Components purchaser	Email from Account manager	Other	via Phone-via Email	Yes - Format file/ capture into new interface	Order Intake	Delivery date/component	Other	via Phone-via Email	Yes - Format data/ capture into new interface	Order Intake
	BOM	Other	via Phone-via Email	Yes	Project specifications	Costs information components	XLSX	Other	Yes - Format data/ capture into new interface	Shortage list of materials
	ODB++	Other	via Phone-via Email	Yes		Shortage list of materials	PDF	Other	Yes - Format data/ capture into new interface	
	GERBER	PDF	via Phone-via Email	Yes - Format file/ capture into new interface						
	Project specifications	PDF	via Phone-via Email	Yes - Format file/ capture into new interface						
	Purchase order (PO)	PDF	via Phone-via Email	Yes - Format file/ capture into new interface						
	Request for quotation (RFQ)	PDF	via Phone-via Email	Yes - Format file/ capture into new interface						
	Order Intake	PDF	via Phone-via Email	Yes - Format file/ capture into new interface						
	Order confirmation via email/supplier website	Other	via Phone-via Email	Yes - Format file/ capture into new interface						

Stakeholder	Data received during the process	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies	Data generated during process	Type of data		Required Conversion in Elect format - required data adjustment	List of hard copies
Production Planner	Email from Account manager	Other	via Phone-via Email	Yes - Format file/ capture into new interface	Production planning	Production planning			Yes - Format file/ capture into new interface	Production planning
	Order Intake	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	Order Intake	Orcer book			Yes - Format file/ capture into new interface	Order Intake
					Production guidance card	Production guidance card			Yes - Format file/ capture into new interface	Production guidance card
					Order book	Machine availability			Yes - Format file/ capture into new interface	Order book

Stakeholder	Data received during the process	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies	Data generated during process	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies
Account Manager	Email or phone call information	Other	via Phone-via Email	Yes - Format file/ capture into new interface		Tasks internally	Other	via Phone-via Email	Yes	Order Intake
	BOM	Other	via Phone-via Email	Yes		Orcer Intake	PDF	via Phone-via Email	Yes	Quotation
	ODB++	Other	via Phone-via Email	Yes		Quotation	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	Order book
	GERBER	PDF	via Phone-via Email	Yes		Overview request for quotation file	Other	via Phone-via Email	Yes - Format file/ capture into new interface	
	Project specifications	PDF	via Phone-via Email	Yes - Format file/ capture into new interface		Calculation File	XLSX	via Phone-via Email	Yes - Format file/ capture into new interface	
	Purchase order (PO)	PDF	via Phone-via Email	Yes - Format file/ capture into new interface		Customer communication	Other	via Phone-via Email	Yes - Format data/ capture into new interface	
	Request for quotation (RFQ)	PDF	via Phone-via Email	Yes - Format file/ capture into new interface		Order book	Other	Hard copy	Yes - Format file/ capture into new interface	
	Montly forcasts	PDF	via Phone-via Email	Yes - Format file/ capture into new interface						
	Quality dashboards	PDF	via Phone-via Email	Yes - Format file/ capture into new interface						
				Yes - Format file/ capture						



	Quotation	PDF	Other	Yes - Format file/ capture into new interface
	Calculation File	XLSX	Other	Yes - Format file/ capture into new interface
	Status updates on orders	Other	Other	Yes - Format file/ capture into new interface
	Delivery date/component/PCB	XLSX	Other	Yes - Format file/ capture into new interface

Stakeholder	Data received during the process	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies	Data generated during process	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies
Inspection PCBs	PCB products	Other	Other		Incoming inspection list	Incoming inspection list	Hard copy	Hard copy	Yes - Format file/ capture into new interface	Incoming inspection list
	Packing slip	Other	Other	Yes - Format file/ capture into new interface	Order Intake	Email with complains in case of nonconformities	Other	via Phone-via Email	Yes	Order Intake
	Invoice	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	Invoice	Attachements screen shots nonconformities	Other	via Phone-via Email	Yes - Format file/ capture into new interface	
	COC - Declaration of compliance	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	Packing slip	Backbone task registration/remarks	Other	Backbone	Yes - Format file/ capture into new interface	
	Electrical test or impedance test	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	Documentation	Picking list oven registration, and if correct registered here	XLSX	Other	Yes - Format file/ capture into new interface	
	Documentation	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	Test reports	Register Complaint in customer folder	XLSX	Other	Yes - Format file/ capture into new interface	
	Test reports	Other	via Phone-via Email	Yes - Format file/ capture into new interface		Register Complaint in complain overview file	XLSX	Other	Yes - Format file/ capture into new interface	
	Information sheet	PDF	via Phone-via Email	Yes - Format file/ capture into new interface		Navision registration of times of PCBs in the oven	Other	Navision	Yes - Format file/ capture into new interface	
	Order Intake	Other	Other	Yes - Format file/ capture into new interface						

Stakeholder	Data received during the process	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies	Data generated during process	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies
Warehouse	PCB products	Other	Other		Packing slip components/PCBs	Picking list	XLSX	Other	Yes - Format file/ capture into new interface	Picking list
	Components	Other	Other		Invoice hard copy Components/PCBs	Sticker with Navision article number	Other	Navision		Label for inventory
	Packing slip components/PCBs	Hard copy	Other	Yes - Format file/ capture into new interface	Documentation	Label for inventory	Other	Other	Yes - Format file/ capture into new interface	Packinslip
	Invoice hard copy Components/PCBs	Hard copy	Expedition services	Yes - Format file/ capture into new interface	Test reports	Packinslip	Hard copy	Expedition services	Yes - Format file/ capture into new interface	Invoice
	Documentation	Hard copy	Expedition services	Yes - Format file/ capture into new interface	Information sheet	Invoice	Hard copy	Expedition services	Yes - Format file/ capture into new interface	
	Test reports	Hard copy	Expedition services	Yes - Format file/ capture into new interface	Order Intake					
	Information sheet	Hard copy	Expedition services	Yes - Format file/ capture into new interface						
	Order Intake	Hard copy	Other	Yes - Format file/ capture into new interface						

Stakeholder	Data received during the process	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies	Data generated during process	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies
Production leader	Yellow folder	Hard copy	Other	Yes - Format file/ capture into new interface	Yellow folder	Tasks	XLSX	Other	Yes - Format file/ capture into new interface	Inspection reports
Production Employees	Project guidance card	Hard copy	Backbone	Yes - Format file/ capture into new interface	Project guidance card	Remarks product	Other	via Phone-via Email	Yes - Format file/ capture into new interface	Improvement reports
	Order Intake	Hard copy	Other	Yes - Format file/ capture into new interface	Order Intake	Fine tuning file	PDF	via Phone-via Email	Yes - Format file/ capture into new interface	People/Task/Unit planning
	Production planning	XLSX	Server	Yes - Format file/ capture into new interface		People	XLSX	Backbone/barbone	Yes - Format file/ capture into new interface	Project guidance card
	ODB++	Other	via Phone-via Email	Yes		Hours	Other	Backbone/barbone	Yes - Format file/ capture into new interface	
	GERBER	Other	via Phone-via Email	Yes		Serial number/PCB	Other	Backbone/barbone	Yes - Format file/ capture into new interface	
	Project specifications	Hard copy	via Phone-via Email	Yes - Format file/ capture into new interface		Coding machines	Other	Other		
						Inspection reports	Hard copy	Other	Yes - Format file/ capture into new interface	
						Improvement reports	Hard copy	Other	Yes - Format file/ capture into new interface	
						Process steps in Barbon	Other	Backbone/barbone	Yes - Format file/ capture into new interface	
						Project planning 2 weeks	XLSX	Other	Yes - Format file/ capture into new interface	
						Machine availability	XLSX	Other	Yes - Format file/ capture into new interface	
						People/Task/Unit plannin	XLSX	Backbone/barbone	Yes - Format file/ capture into new interface	
						Status project	XLSX	Backbone/barbone	Yes - Format file/ capture into new interface	
						Repair			Yes - Format file/ capture into new interface	

Stakeholder	Data received during the process	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies	Data generated during process	Type of data	Exchange of data	Required Conversion in Elect format - required data adjustment	List of hard copies	Digital format transition needed to PLM
Management Staff	Customer strategy		via Phone-via Email	Yes - Format file/ capture into new interface		Business strategy	DOCX/DOC	via Phone-via Email	Yes - Format file/ capture into new interface		Business strategy
	Market trends		via Phone-via Email	Yes - Format file/ capture into new interface		Customers cooperation	Other	via Phone-via Email	Yes - Format file/ capture into new interface		Customers cooperation
	Customer satisfaction		via Phone-via Email	Yes - Format file/ capture into new interface		Technological roadmap	DOCX/DOC	via Phone-via Email	Yes - Format file/ capture into new interface		Technological roadmap
	Supplier performance		Other	Yes - Format file/ capture into new interface		Financial roadmap	PDF	via Phone-via Email	Yes - Format file/ capture into new interface		Financial roadmap
	Waste overview		Other	Yes - Format file/ capture into new interface		Financial results	PDF	via Phone-via Email	Yes - Format file/ capture into new interface		Financial results
	Feedback employees		Other	Yes - Format file/ capture into new interface		Employee availability	Other	via Phone-via Email	Yes - Format file/ capture into new interface		Employee availability
	Feedback suppliers		via Phone-via Email	Yes - Format file/ capture into new interface		Employee satisfaction	Other	via Phone-via Email	Yes - Format file/ capture into new interface		Employee satisfaction
				Yes - Format file/ capture					Yes - Format file/ capture into		
	Feedback Customer		via Phone-via Email	Yes - Format file/ capture into new interface		Market trends	Other	via Phone-via Email	Yes - Format file/ capture into new interface		Market trends
						KPIs low level, high leve	PDF	via Phone-via Email	Yes - Format file/ capture into new interface		
						Number of customers	XLSX	via Phone-via Email	Yes - Format file/ capture into new interface		
						Number of suppliers	XLSX	via Phone-via Email	Yes - Format file/ capture into new interface		
						Transactions	XLSX	via Phone-via Email	Yes - Format file/ capture into new interface		
						Decision making process	Other	via Phone-via Email	Yes - Format file/ capture into new interface		
						Company culture	Other	via Phone-via Email	Yes - Format file/ capture into new interface		

Figure 69 Data centralization

12 Appendix Solution principle

IDEATION PHASE

Ideation phase integrates parallel development stages of the prototype. To broaden the solution principle of this thesis project it was agreed by Company X and the thesis supervisor to proceed further with a parallel phase that integrates the research and development activities of student groups enrolled in the academic year 2019/2020 of the PLM course. The initial employee and customer analysis was used as input data for the design brief (Appendix X). The design brief was used to initiate the student groups into the project. The assignment consisted of four main topics:

- Customer communication
- Management dashboard
- Purchase and production
- System and interfaces

First and foremost, the aim of this educational collaboration is to touch upon other areas of research and development of PLM systems so that Company X can create a better rationale when choosing the features and system capabilities. Considering the broad research topic, this collaboration aimed at covering a more extensive area of research and ideation.

Secondly the intention is to capture diverse perspectives regarding functionality and challenges that come along with a PLM system. Also this can eliminate some of the research and development biases of this thesis project and of course can provide a great source of inspiration when forging the mock-up in a final version. Additionally the benefit of associating the PLM course to this thesis is that it provides scale and flexibility of the concept development. A final benefit of this collaboration is that it helps identifying and addressing potential operational risks when thinking about developing and implementing an internal PLM system within Company X.

As mentioned earlier, there are four study cases proposed for this collaboration and two to three student groups assigned to tackle each study case. Each study group delivered a concise report and a prototype that addressed the four proposed topics.

Parallel to the student assignments, another prototype was developed to serve students groups as inspiration and as a guiding mechanism in the ideation and designing phase.

The final prototype incorporates an optimized solution principle that merges functionalities determined by student groups and the ones developed during this thesis process. The intention is to produce a coherent representation of the functionalities that address the pain points that Company X is facing.

13 Appendix Bottleneck prioritization

Table 1 Bottlenecks Prioritization

Po.	No.	Problem definition	Rationale
	1	Inconsistent Status & updates about product information at different stages. Minimum of notifications Customer & Supplier Communication	
1	a	Employees request a notification system regarding statuses, updates or any other changes to the product data, respective to the project. Not having a clear notification system in place it leads to slow operational response and awareness.	Partially urgent. This aspect is important because it addresses the speed of operational response in product data. By addressing this element Company X as well as the stakeholders can benefit of a clearer collaboration.
1	b	No real time control of production processes, no notification if there are any updates on the product/process.	Partially urgent. This aspect is highly important for stakeholders and customers because it often provides traceability and transparency which is highly desired by them.
1	c	Customers require notifications, status and updates at each product/process development step for a better transparency.	Partially urgent. This aspect is highly important for stakeholders and customers because it often provides traceability and transparency which is highly desired by them
1	d	The cost structure sometimes is not clear and concise and when there are changes, it happens that customers are not notified about those changes.	Urgent. The cost structure is highly important because the

			customers are becoming frustrating if extra costs are added without being notified.
	2	Manual file manipulation & repetitive work	
1	a	High set-up time and indirect hours because of repetitive work that encompasses manipulation of typically offline (transition offline to online) file by different employees.	Urgent This results in high costs for the company. It is because of poor data management.
1	b	The purchasing time is increasingly high because of the highly increase manual search that needs to be done while purchasing components	Urgent Currently the supplier databased connection is missing which results in increased manual search for components.
1	c	Important changes in the physical products or parts are captured on paper that can result in lag of the virtual counter-part product, additionally in extra human effort, energy, materials and incorrect information.	Urgent. The process should be as much as possible paperless and capture information in one system
	3	File format	
3	a	Manual production scheduling done in excel.	Not urgent This aspect does not affect the overall data management process.
1	b	Suppliers and customers are providing different file formats that implies for employees a high intensive file formatting work that can lead to loss of information, incorrect data processing, long duration processes.	Urgent This has an influence on the outcome of product data and now is one of the main pain points that exist in Company ecosystem.
1	c	The EBOM to MBOM file conversion is a tendinous process that takes a lot of time due to different file	Urgent

		formats that Company X receives from different customers.	This has an influence on the outcome of product data and now is one of the main pain points that exist in Company ecosystem. Long conversion process.
1	d	File computation and editing is missing from a wide range of PLM vendors	Urgent This aspect directly impacts the performance of product data thus it is highly relevant
	4	*Information exchange (via Email or phone)*	
1	a	Data exchange presents a low degree of automation and is usually spread across multiple interfaces.	Urgent This will prevent the manual manipulation of data thus will lead to less errors. Systems are not interconnected at the moment.
1	b	The exchange of information between internal employees and stakeholders is done verbally, via email or phone which can result in loss of information while the decision making process is not capture at its essence.	Not urgent This aspect is not urgent but it influences how product data is defined.
1	c	**Data automation** - There is a specific need in improving the level of automation in terms of data exchange and processing.	Urgent This will prevent the manual manipulation of data thus will lead to less errors.
	5	***Decision rationale, data and product traceability***	
1	a	Traceability of product data and statuses both internally and externally is inconsistent and where is done is dispersed across multiple systems	Urgent At the moment the statuses of product data are not displayed in any platform and are not coherent
1	b	No clear and transparent information/data flow internally	Urgent Employees would

1	c	There is no documentation or traceability of decisions/ rationale (because decisions are often made verbally and are therefore not digitally stored) There is no traceability of delivery status regarding products or components that are delivered by suppliers.	Urgent This might lead in production delays thus it is essential to tackle it.
1	d	Customers desire full traceability regarding each project in each phase (quotation, preparing, production and delivery). There is no clear data transparency and product traceability.	Urgent Project traceability aside from product and component traceability is a requirement often mentioned by customers.
1	e	Customer platform and product traceability is used by the most competitive companies, while Company X lacks these features	Urgent Company X should keep their customers involved and offer them tools that facilitate an easy communication
	6	Testing and development	
1	a	Due to lack of testing tools and capabilities there are problems that arise during prototyping and production (e.g. DFT,DFX), problems that can account for long stand-by periods of the production line, implicitly delays in satisfying the delivery date of the product/service.	Urgent Company X and customers need early engagement of both parties in the early stage of product development.
3	b	Developing **testing capabilities** without engineering by the customer and developing technical capabilities such as DFT, DFM, DFL, DFC, etc.	The issues are not falling under the objective of this thesis
3	c	Advising service for customers to conduct functional tests	The issues are not falling under the objective of this thesis
3	d	Extending services capabilities such as assembly, wire-bonding and **introducing** repairing services which are on high demand.	The issues are not falling under the objective of this thesis
3	f	Overall competitors are promoting the same production technologies while about one third of the companies are	The issues are not falling under the objective of this thesis

		more innovative and technologized, providing extended manufacturing, testing and repairing services.	
	7	*System interconnectivity, interfaces and data storage*	
2	a	**Digital continuity** between Company X and its customers is a requirement from customers for future collaborations.	Not urgent Digital continuity is a necessity however this aspect is too broad to be directly addressed by the scope of this thesis.
1	b	Barbone/backbone and ERP are not connected thus product data is stored across multiple systems and none of them provide the singular source of truth.	Urgent This is addressed because it directly influences the outcome of product data.
1	c	API connectors are missing for supplier and customer data base access.	Urgent This also influences the outcome of procuct data. Aside from that it can bring more accuracy in terms of BOM conversion and component data.
1	d	Component purchasing process requires long processing time due to missing API connectors	Urgent This also influences the outcome of procuct data. Aside from that it can bring more accuracy in terms of BOM conversion and component data.
3	e	ERP system is not used at its entire potential because its features are partially unknown or not well developed and integrated within Company X systems architecture.	The issues are not falling under the objective of this thesis
1	f	Companies with a centralized platform to conduct data exchange and trace each project are perceived as being more qualified.	Partially urgent Build customer trust by showing initiative in improving collaboration

1	g	Missing open BOM reflecting costs of individual components	Urgent Missing Open BOM structure results in biggest bottlenecks in the existing process
3	h	Competitors present quotation, contact form and price calculator integrated in websites and/or platforms.	The issues are not falling under the objective of this thesis
2	i	Intuitive interface design is missing in existing PLM interfaces	Not urgent
8		Working methodology	
2	a	Different working methodologies that are used by Company X employees for the same tasks result in confused customers.	Urgent Standardization of processes is important and at the moment this is lacking in the environment of Company X
2	b	Experience employees might fall ill or might leave the company and their experience is not captured in a meaningful way so that the next person can accommodate faster to the tasks and responsibilities of the job.	Not urgent Training of employees in manipulating product data is essential.
	9	KPI dashboard	
2	a	Not sharing KPIs risk alienating and frustrating the company's employees and other stakeholders who are unable to see the direction in which the organization is heading. At the moment the managerial strategy and vision is not fully visible to important stakeholders in Company X's ecosystem	Not urgent
	10	Market analysis	
3	a	Low branding visibility - Website design and branding improvements are required for Company X to compete with some of the main competitors.	Not urgent Does not fall under the scope of the project
3	b	Low marketing promotion - Social media, newsletter, blogs tools are some of the main features used by the best rated companies to promote and marketer	Not urgent

		themselves. It is important to notice that Company X superficially making use of social media platforms while the rest of marketing tools are not in use.	Does not fall under the scope of the project
3	c	Companies have a competitive advantage compared to Company X by multiple technological adoptions while Company X is having a biased opinion regarding its own competitive advantage in the market.	Not urgent Does not fall under the scope of the project