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Identification of User Needs in Visualisation Tools

A Study Within the Automotive Industry

Master's thesis in Product Development

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Abstract

The successful integration of digital tools in complex product development is highly dependent on understanding the diverse needs of users. As organisations adopt advanced visualisation systems within Product Lifecycle Management (PLM) environments, it is essential to understand how such tools are used across various roles and areas of work to support efficiency, collaboration, and daily work. This study has investigated the user needs associated with three-dimensional (3D) visualisation tools in a complex product development context.

By conducting 17 semi-formal interviews, insight was gained into processes, current issues, and potential areas of improvement. A comprehensive user need list, containing approximately 250 identified needs, has been created to summarise the needs across all roles. The results highlight several recurring themes, including limited knowledge of existing tool capabilities, instances where the same tasks are performed in multiple teams, and varying expectations regarding usability and performance. Despite differences in tasks, many needs were found to be shared between different roles and areas of work; hence a common solution, with possible minor adaptations, will be possible.

Based on the findings, several recommendations are provided that address both functionality and implementation. These include tailoring education based on roles and encouraging skill-sharing to improve user competence, incorporating user feedback continuously to guide development and rollout, and addressing inefficiencies such as duplicated work, manual data handling, and lack of trust in information accuracy. Furthermore, the importance of intuitive design, adaptable tools, and transparent communication was emphasised to ensure smooth adoption and to maximise long-term effectiveness of the new visualisation tool. Although the study was conducted at Volvo Cars, the approach and the insights are considered broadly applicable to other contexts that undergo similar transitions.

Keywords: PLM, Product Lifecycle Management, Visualisation, User Needs, System Implementation, Automotive Industry.

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Aron Eriksson Uggla & Sigrid Wirdheim, Gothenburg, June 2025

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

3D	Three-dimensional
3Dx	3DExperience
AI	Artificial Intelligence
BOM	Bill Of Materials
CAD	Computer Aided Design
CAE	Computer Aided Engineering
EDM	Engineering Data Management
NME	Next Mechanical Engineering, Volvo Cars Project Name
PDM	Product Data Management
PLM	Product Lifecycle Management
QL	Quick-launch
TC Vis	Teamcenter Visualization
VR	Virtual Reality

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1
Introduction

In this chapter, the purpose and objectives of this master thesis are presented. Furthermore, limitations and demarcations are described as well as research questions that the study has aimed to find answers to. Finally, how Artificial Intelligence (AI) have been used during the project is described.

1.1 Purpose

The purpose of this study is to understand the needs different user roles, involved in the development of complex products, have in relation to the use of the visualisation tool. By examining how the current tool is used at Volvo Cars, and interviewing key users, a user needs list can be formulated for a new tool, 3D Experience (3Dx) that will be implemented. In addition, the study aims to provide recommendations for both implementation and workflow, which can improve efficiency and simplify integration.

If a visualisation tool does not align with user needs and workflows, there is a risk that the system will not be used as intended. This could result in inefficiencies, continued reliance on parallel tools, and reduced trust in the system. Understanding the user needs is therefore essential to ensure a successful transition with long-term benefits.

1.2 Objectives

The objectives of this master´s thesis are to deliver;

- A user needs list covering the desired functions of the visualisation tool
- Recommendations regarding the desired functionality of the visualisation tool in 3Dx
- Recommendations about how the implementation of the new visualisation tool should be handled

1.3 Limitations and Demarcations

This study primarily aims to identify user needs related to the visualisation tool Teamcenter Visualization (TC Vis). While tools used in conjunction with TC Vis are not the main focus, existing use cases involving these tools will be reviewed to explore potential new use cases for the new platform. Furthermore, Volvo Cars is a large organisation and this study is carried out within one part of the organisation, which is explained in more detail in Section 2.2.

Due to the early stage of implementation and limited access to the 3Dx platform, this study does not include a detailed mapping or comparison of features and functionalities available in 3Dx.

1.4 Research Questions

Two main research questions were formulated to guide this work. The first questions have four sub-questions that are more focused on the case studied at Volvo Cars.

- What user needs exist for visualisation tools used in complex product development?
  - Who is using the visualisation tool today?
  - For what purposes is the visualisation tool used?
  - How do needs relate between different users?
  - Are there potential new users?
- What are additional problems that could be solved by the visualisation tool in 3Dx?

1.5 The Use of Artificial Intelligence

During the project, AI was used in three different ways. First, the built-in AI transcription feature in Microsoft Teams was used to transcribe interviews. Second, Writefull, an AI-powered tool integrated with Overleaf, was used during the writing of the thesis to provide grammar correction and language enhancement. Third, DALL · E, an AI image generation tool, was used to create an image that was used to clarify a concept explained in the report.

2
Background

This thesis is conducted within an internal project at Volvo Cars, called Next Mechanical Engineering (NME). The project aims to switch one of the PLM systems at Volvo Cars, while this thesis focusses on the visualisation tool in the PLM system. In order to give context to the more in depth introduction of the NME project, this chapter will first introduce the PLM market and its primary actors. Then a more thorough description of the NME project will follow. Lastly, TC Vis, the tool that is used for visualisation at Volvo Cars today, will be presented.

2.1 The PLM Market and Trends

One of the main vendors on the market of PLM systems is Dassault Systéms, who offer the system 3Dx. Dassault Systéms presents 3Dx as a platform that provides companies with a 'holistic, real-time vision of their business activity and eco-system'. You can work 'anywhere, anytime, on any device' and it is stated that it will connect people, ideas, data, and processes on a single, unified platform (Dassault, n.d.). One of these companies is Jaguar Land Rover, a producer of premium vehicles, similar to Volvo Cars. However, when further looking into the Jaguar Land Rover transition to 3Dx, one can find that the journey has not been straightforward and that it has taken 15 years (Grealou, 2024), which indicates that switching PLM systems can be a difficult process.

Another of the main vendors is Siemens, who offer the system Teamcenter. Presented as a 'Reason to use' Teamcenter, it is stated that one can 'Resolve problems before they become real' while using digital twins to connect and optimise processes, for example, within design, software, and visualisation. Furthermore, one can read that companies can connect people across their business, automate and streamline product lifecycle processes, and make innovative product decisions by providing visibility for everyone (Siemens, n.d.).

It is important to note that there are other options in the PLM industry, for example, SAP IPPE, PTC Windchill, and Autodesk Fusion360. The company BMW, for example, uses a combination of SAP IPPE, PTC Windchill and Siemens Teamcenter (Ogewell, 2024). However, the most common PLM systems among brands in the automotive industry seem to be Teamcenter and 3Dx. A mapping of some companies that use each system, carried out in the NME project, can be seen in Figure 2.1.

Figure 2.1: A visualisation of which vendors some big companies have chosen.

Collaboration, connection, real-time, and web-based/cloud appears to be the words trending in the PLM industry when looking at two of the main vendor websites. For example, according to Shilovitsky (2025), companies are believed to be creating unbroken digital threads that will connect all product data, from concept to end of life. In addition, he mentions the use of digital twins, virtual representations of systems that are designed to accurately represent a physical object. Another idea, for example, discussed by Kasper (2024), is that digital twins will shorten feedback cycles and improve product lifecycle management, the core of PLM. Technology will, as has been done before, continue to push the edge of what is possible (Shilovitsky, 2025). In relation to this Shilovitsky (2025) believes that the adoption of Software as a Service and the shift to cloud-based PLM solutions will continue to be important factors in 2025. Furthermore, AI will be used in PLM systems for things like optimising supply chains and design, as well as automating quality control processes and predicting maintenance. The extended use of AI will also lead to the need to prioritise data management, which prepares for AI integration and allows more informed decision-making (Shilovitsky, 2025).

Finally, Shilovitsky (2025) mentions the change management aspect when changing or updating the way of working and systems. Large companies, particularly those who work with complex products, such as cars, must prioritise user adoption and training, as well as maintaining data quality and consistency.

2.2 Next Mechanical Engineering Project at Volvo Cars

Volvo Cars has historically utilised the ‘Best of breed’ strategy, choosing the best software from each vendor when it comes to their computer-aided design (CAD) and PLM systems. For PLM the Siemens system *Teamcenter* is used and for CAD the Dassault Systéms system *CATIA V5*. In a fast-changing industry where new technology is constantly introduced, it is becoming more and more important to have integrated systems that allow for real-time collaboration. This is difficult when using multiple tools, from different vendors, that need to function together. In addition, when vendors update and introduce new features, they do it mainly in their latest software. Therefore, older software is soon becoming outdated. Volvo Cars has therefore started the multi-year project NME with the vision *Unleashing the power of collaboration by bringing data and engineers together*. The goal is to reduce complexity and to be able to use the latest software, which is enabled by decreasing the number of vendors. In order to decide the vendor, Volvo Cars conducted a thorough feasibility study which, for example, included that 140 *Subject Matter Experts* participated in scenarios related to important Volvo Cars processes and tested solutions from the different vendors available. Finally, Dassault Systéms was selected along with their PLM system 3Dx and CAD system *CATIA V6*. The decision was made based on eight criteria with different prioritisations and how well each solution fulfilled the criteria.

The last similar project, or transition, that Volvo Cars went through was in early 2000 when they transitioned from Virtual Product Management (VPM) to Teamcenter, which enabled the transition from CATIA V4 to CATIA V5. That transition was conducted because of pressure from Ford. Their goal was to make all the companies within the group work in the same way, with the same systems. At the time Volvo Cars was at the forefront of visualisation, so Ford wanted to apply Volvo Cars way of working, but with their choice of system; Teamcenter. The transition from VPM to Teamcenter went relatively smoothly, while the transition from CATIA V4 to CATIA V5 took more time and effort. Today, almost 20 years later, some functionalities that Volvo Cars had in the systems they used before are still compromised.

NME is now in the early stages, and the needs different user groups experience in their daily work is investigated, while the possibilities and tools within 3Dx are being examined. The project has been divided into sections that cover different areas. One of these sections is the visualisation within the PLM tool, today primarily solved by the software TC Vis. The use of visualisation is not limited to one user group or department, but instead spans over a large part of the organisation within Volvo Cars with a total of approximately 4500 users and potential for more. The needs of these, both current and potential new users, therefore need to be mapped. As a first step, Volvo Cars aims to reach the same functionality as the one that exists in TC Vis today. However, in the future, it would be of significant interest to expand the use areas. Some of the areas where improvement is expected is *Time to Market*, *Collaboration* and *Accessibility*, as presented in Figure 2.2.

The organisation in Volvo Cars can be divided into two 'circles', where the first circle covers research and development, while the second covers production and maintenance. The NME project will focus on the research and development circle, blue in Figure 2.3. This study is conducted with the base in the Hardware Methodologies & Strategies group within Vehicle Engineering at Volvo Cars. Their focus is to develop processes, methods, and standards for CAD-based work. They support the concept phase, mechanical integration, and detailed design. In addition to creating

Figure 2.2: Areas Volvo Cars expect to see improvement in throughout the NME project.

the processes, they also prepare and arrange educations within the different areas to facilitate a common way of working.

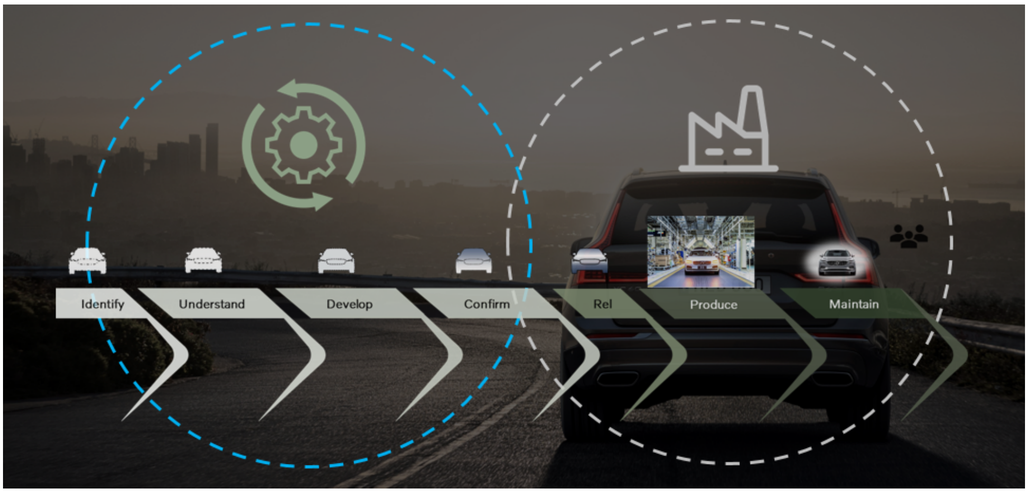

Figure 2.3: A visual representation of the organisation at Volvo Cars.

2.3 Teamcenter Visualisation

In order to provide context for what is found in the interviews, TC Vis, a Siemens-provided tool that is used at Volvo Cars today, will be described in this section. Some of the different tools and functions will be presented, as well as the overall look and functionality of the software. This tool is likely the 'foundation' for the opinions of the interviewees as it is what they work with today.

Layout Overview

Like many other software, TC Vis offers customisation of its layout and appearances. However, upon initial startup, it has a standardised interface, which remains the default configuration for most users. As shown in Figure 2.4, the interface is divided into three main segments: the project workspace (highlighted in red), the 3D viewer (in green), and the tool ribbon (in blue). These three segments together form the core environment in which all work within TC Vis is carried out.

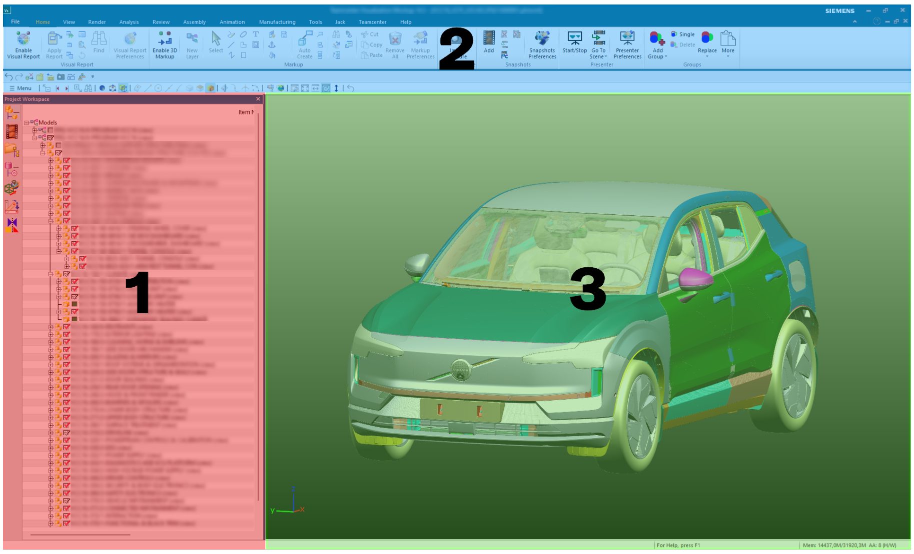

Figure 2.4: The layout in TC Vis divided into three different segments.

Segment 1 - Project Workspace

Project Workspace provides a hierarchical tree structure that represents the loaded models, serving as the main navigation tool within the open files. Users can expand or collapse models, toggle visibility by checking or unchecking boxes, and view the names of individual elements. In addition to navigation, this section also includes a set of tools for organising and preparing geometry for presentation or further work. Among these are the *Snapshot* and *Groups* tools. The snapshot feature allows users to capture and save the current state of their workspace, including all active attributes and tools. For example, a snapshot might preserve the viewing angle, component colour, and any measurements in place at that moment. The *Groups* functions allow the user to save groups of selected components; for example, it can be that you save a *Door* which would be a group that you populate with all the components that are in a door, that otherwise would be dispersed across various areas of the structure such as the frame, isolation, and cables.

Segment 2 - Tool Ribbon

The second segment, highlighted in blue, displays all the tools available in TC Vis. These tools are divided into different ‘ribbons’ correlating to the function of the tool. All ribbons and the key functions located in them can be seen in Table 2.1.

The available tools for the loaded file are shown in colour, whereas the unavailable ones appear in grey, making it easy for the user to see which feature they can access. Certain functions, such as *3D Measurements*, must first be activated before they become available, as shown in Figure 2.5. If one 'hover' over an icon, a description appears. However, it is somewhat underwhelming and sometimes is just the same as the name.

Table 2.1: Table describing the tabs in the ribbon in TC Vis.

Tab	Key Functions
File	Open, save, import, export; manage global preferences.
Home	Visual report (metadata colour coding), markup, image capture, snapshots, presenter, groups.
View	Preset orientations; auto-spin.
Render	Edit colours and transparencies.
Analysis	Single/double measurements; section creation.
Review	Tricolour comparisons of two models (identical/similar/different surfaces).
Assembly	Apply constraints; align parts; part-manipulation mode.
Animation	Kinematic presentation material of the scenes chosen in TC Vis.
Manufacturing	Toggle the Product and Manufacturing Information (PMI) and the Geometrical Dimensions and Tolerancing markup (GD&T) as well as the extent of the visible contents of each.
Jack	The digital human modelling provided by Siemens. It is used mostly for ergonomical analysis, but can come in handy when needing help with sizing the components.
Help	Host Siemens Help website with documentation of the software.

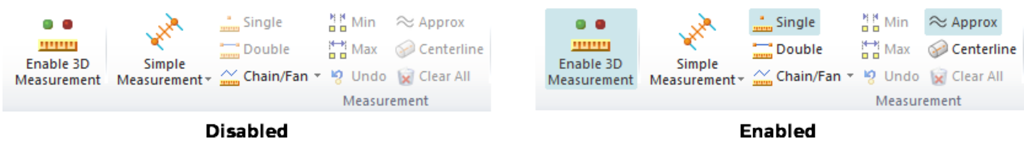

Figure 2.5: 3D measurements in TC Vis toggled off to the left and on to the right.

In the lower part of the ribbon some smaller icons are available. These are, for example, different filters that decide which type of geometry can be selected when using the different tools. By enabling or disabling these options, you can choose, for example, to make only edges, circle centres, or surfaces selectable. Multiple of these filters can be activated at once to enable selection of different types of geometry. In this lower part, *Leaf Structure* can also be activated. This enables more details in the Tree Structure in segment 1, for example, if the complete emblem previously has been shown as ‘Emblem’, the Leaf Structure will break down the geometry to its smallest parts. It could then consist of ‘Iron Symbol’, ‘Background’ and the different letters in the word Volvo.

Segment 3 - 3D Viewer

The 3D viewer is used to display the models that are loaded into TC Vis. It is also in this window where all the interaction with the model takes place. Here, the user can orient the model and use tools such as a visual report or sections. Several tools can be used at the same time, for example, one can take a section and measure simultaneously, as shown in Figure 2.6.

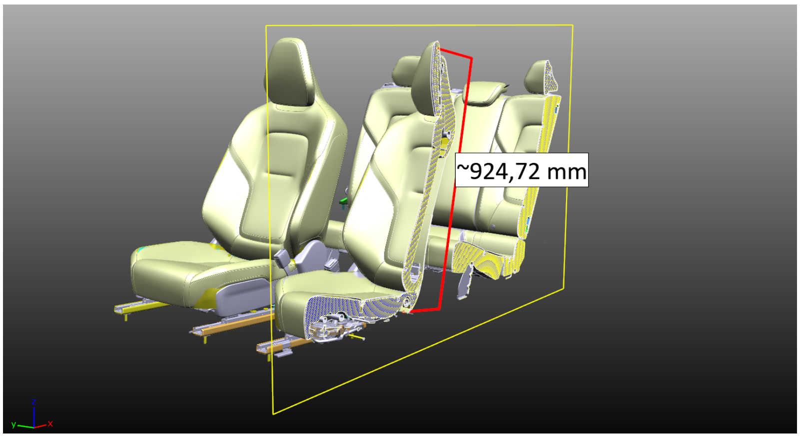

Figure 2.6: Section of seats in EX30 shown in 3D viewer.

3

Theoretic Foundation

This chapter presents the theoretical background relevant to understanding user needs in visualisation tools as well as aspects that could be important for the implementation. The literature studied includes, for example, perspectives on how such tools support product development, collaboration, and decision-making, as well as how they are integrated into existing processes and systems.

The chapter is structured around two main themes. The first focusses on the role of visualisation and PLM systems in engineering work. The second addresses key organisational aspects such as change management, user involvement, intuitiveness, data quality, and knowledge sharing. Together, these areas provide a foundation for analysing the needs identified in this study.

3.1 Visualisation and PLM systems

Understanding user needs starts with the tools they use and how they interact with them. This section introduces key technologies in product development, such as visualisation tools and PLM systems, and highlights how user experience and interface design influence effective use.

3.1.1 Visualisation in Virtual Product Development

Virtual visualisation tools and physical representations have long been used in product development to gain an understanding of a product before it reaches the customer. Over time, the methods of visualisation have evolved from hand-drawn sketches and physical models to advanced digital 3D tools and immersive technologies such as Virtual Reality (VR). In industries such as automotive, clay prototypes remain a common way to visualise the exterior of a product, although they are time-consuming and costly to produce and offer limited functionality (Kirpes et al., 2022).

Today, 3D visualisation tools and digital twins are integral to the product development process. These tools support a comprehensive understanding of a product or its subsystems and are widely used for tasks such as measuring, creating cross sections for analysis, or testing functionality in virtual environments. By embedding metadata into 3D models, it is possible to distinguish between reused and newly developed components, thereby enhancing traceability and design efficiency (Lo et al., 2021). Furthermore, materials and surface finishes can be applied digitally to create photorealistic or semi-realistic renderings, which assist in evaluating design alternatives and making early decisions. Compared to physical prototyping, such visualisation methods offer significant savings in time and cost, particularly in the iterative development phases (Korkut & Surer, 2023).

3.1.2 PLM Systems

In the late 1980s engineers in manufacturing industries saw a growing need to keep track of the increasing amount of CAD files, which led to the emergence of Engineering Data Management (EDM) and Product Data Management (PDM) systems, and later also PLM systems. PLM facilitates the creation, preservation, and storage of information related to companies' products. For example, it created an opportunity to standardise parts, store files, immediately see relationships between parts and assemblies, and more easily have control over revision levels (Saaksvuori and Immonen, 2008).

According to Saaksvuori and Immonen (2008), PLM is a holistic business concept that manages products and their lifecycles. This includes items, documents, and bill of materials (BOM), but also test specifications, change orders, manufacturing procedures, and more.

3.1.3 User-Centered Design and Intuitiveness

For engineers, the focus is usually to create a product as good as possible for customers. A lot of research has been done on, for example, Human Machine Interface (HMI) and information perception to make it as easy as possible for customers to interact with the product. In this thesis, the aim is to give recommendations for a visualisation tool that will be used by engineers; hence the engineers will be the customers. Therefore, theory on topics such as HMI and information perception can be applicable.

Effective information perception in new software relies on how intuitively users can understand and interact with the interface. According to Blackler et al. (2005), intuitive interaction is based on users applying past experience to new systems. An interface that uses familiar symbols, a consistent layout, and meaningful metaphors helps the user recognise functions faster and reduce learning time. Their research shows that appearance, such as shape, labelling, and icons, has a greater impact on intuitive use than feature location. Familiar visual signs enable faster and more confident user interaction, especially for those with less technical experience. Intuitive design principles in new software not only improve usability but also support smoother implementation and better information understanding.

In addition to intuitive design, usability principles from human factors engineering offer valuable insight. According to Nielsen and Molich (1990), factors such as consistency, feedback, and error prevention help reduce user frustration and learning time. Designing interfaces that align with user expectations and previous experiences can make tools feel more predictable and easier to use. These considerations are particularly relevant in engineering, where users range from specialist to occasional users, and where tool complexity can otherwise prevent effective use.

3.2 Implementation of New Methods and Tools

The implementation of new digital tools and methods in product development is often associated with both technical and organisational challenges. It is not only a matter of introducing new functionality, but also of changing established ways of working and ensuring that the tool is integrated into existing processes. According to Rogers (1993), the adoption of innovations depends on factors such as perceived usefulness, ease of use, and compatibility with current workflows. If a tool is seen as complex or disconnected from daily user work, there is a high risk it will not be used as intended.

Introducing new tools in product development requires that they fit well with the way engineering work is already done. As Bergsjö (2009) highlights, one of the key challenges in implementing PLM systems is that disciplines such as mechanical, electrical, and software engineering follow different practices, use different tools, and have different expectations. Each area can have its own methods for version control, data handling, validation, and other procedures. To succeed, a new system must respect these differences rather than trying to force all teams into the same process. Rather than standardising everything, PLM systems should allow different methods to work side by side, for example, allowing step-by-step releases in mechanical design while supporting ongoing changes in software. This requires a flexible structure that can handle differences in the detail, traceability, or development of information between teams. According to Bergsjö (2009), many PLM challenges come not from technical problems but from mismatches between the system and how people actually work in their roles.

Adopting new methods in product development is rarely straightforward, especially in large organisations with diverse roles, tools, and workflows. According to Mallalieu et al. (2024) it is rarely a ‘plug-and-play’ activity. Implementation must align not only with technical processes but also with organisational norms and human behaviours. The author also highlights the importance of contextual understanding and adaptations. Contextual problems vary between different companies and could, for example, be related to linking tools to information or adapting them to already existing ways of working. It is therefore important to understand the individual context where tools or processes should be implemented.

3.3 Change Management and Stakeholder Involvement

According to Moran and Brightman (2000), effective change includes multiple efforts to improve, in different areas such as *improving and managing work processes* or *strengthening employee involvement*. Change efforts in one area can create the need to initiate change efforts in other areas. They state that there is no right answer, but that multiple efforts are required for companies to achieve the changes they want to, in order to remain competitive in the future. Furthermore, they mention that changes must be made both top-down and bottom-up. By this they mean that one single part of an organisation can not conduct a change on their own, but the whole organisation needs to work in the same direction, towards a common vision. By working top-down to provide structure and a common vision, and bottom-up to get support and encourage participation in the change, the best opportunities for success can be created. Effective collaboration among individuals and groups is critical for organisations in order to achieve goals. Effectiveness comes from both processes, people, and organisational culture (Burnes, 2017). Hence, a holistic perspective is needed.

According to Ford and Ford (2010) ‘everybody knows that people resist change’, and therefore it has become socially acceptable for managers to blame resistance when changes are not going as planned. This is also mentioned by Mallalieu (2024) who states that it is ‘human’ to resist adoption. One of the most effective strategies for overcoming resistance is the inclusion of organisation members directly in both the planning and the implementation of change. Including those who will be affected by the change can increase the likelihood that their needs are taken into account, which can make people more committed to the change. In addition, people resist change once they are uncertain about the consequences that may come from the change. It is important to communicate properly, both before and during the change, since lack of proper communication can lead to speculations, rumours, and resistance towards the change (Cummings and Worley, 2008). Ford and Ford (2010) also mention that those who are outspoken about objections are often the same people that care about getting things right, and see possible pitfalls. This goes in line with what Cummings and Worley (2008) states; that members can help identify possible pitfalls and barriers that could hinder the implementation of change. The following quote from Ford and Ford (2010) highlights how important it is to listen to those who will be affected by the change;

> ‘The process of working with individuals and groups to change systems and practices has no simple recipe, but people’s objections, worries, and fears are likely to contain valuable information that can be used to accelerate and smooth the process.’ - Jeffrey D. Ford & Laurie W. Ford

A mistake often made by managers is the ‘overselling of changes’. By exaggerating the benefits that will come while understating the possible downsides, the risk of employees feeling tricked, or that an agreement has been broken, increases. When these promises are broken or deadlines are not followed, it will be more difficult to follow through with the changes (Ford and Ford, 2010).

3.4 Data Quality and Handling

High-quality data is a key requirement for effective use of digital tools, especially within PLM environments. The integrity, completeness, consistency, and accuracy of the data affect how product information is interpreted, shared, and used throughout the different stages of product development.

Product data, such as 3D geometry and metadata, is used by many departments across an organisation. It is therefore important that the data are structured in a way that enables cross-functional use. According to Saaksvuori and Immonen (2008), it is not only the geometry of a component that is important, but also the information connected to the geometry. Attributes such as material, revision status, or supplier must be available and correct for the data to be useful in downstream applications. Redman (1998) states that poor data quality can lead to significant inefficiencies in organisations, including unnecessary rework, delays, and incorrect decisions. Therefore, the effort put into ensuring high data quality is often justified by the long-term benefits. This includes having clear procedures for naming conventions, standardising metadata formats, and ensuring that the most recent version of the data is accessible to everyone who needs it.

Another important part of ensuring high data quality is to establish a single source of truth. As product information is often spread across several systems, such as CAD, simulation, and document management, it becomes critical that these systems are connected and kept up-to-date. A single source of truth means that users get access to the correct and updated data, regardless of which system it comes from originally. Gopsill et al. (2024) describe how this can be achieved through the use of a digital thread, where changes are shared between systems to maintain consistency. This enables users to feel confident that the information they are working with is current and that different teams base their work on the same data.

As the use of simulations, automation, and AI tools increases in product development, the quality of input data becomes even more important. These tools rely on structured and correct data in order to function properly. If incorrect or outdated data are used, the results of simulations or calculations can be misleading, which can affect decision making and delay the development process. Thus, ensuring consistent and high-quality data through digital thread practices is essential to effectively support these modern technologies (Gopsill et al., 2024).

3.5 Knowledge Sharing and Collaboration

In organisations, it is important that knowledge is shared and integrated to a collective level. When individuals share their knowledge with a group, they can realise the value of knowledge. It is therefore important that individual knowledge is systematically shared and integrated at higher organisational levels, from teams to the entire organisation. By doing this, effective use of knowledge can be enabled (Okhuysen and Eisenhardt, 2002). Knowledge sharing can, for example, help increase productivity and make employees more innovative and creative (Razak et al., 2016).

As Okhuysen and Eisenhardt (2002) point out, there is an important distinction between sharing knowledge and integrating it. Sharing involves making information accessible and transferring it between people, for example, by explaining or communicating expertise. Integration refers to the process of drawing on that shared knowledge and combining it. Both knowledge sharing and knowledge integration are important in teams: sharing provides access to information, while integration ensures that the knowledge is used effectively.

Attitudes and social norms can significantly influence people's willingness to share knowledge (Razak et al., 2016). According to Bock and Kim (2001), people are more likely to share knowledge in an environment where a mutual give-and-take attitude exists. Furthermore, they state that those who believe that what they know can contribute to the success of the company's performance also are more likely to share their knowledge.

According to Nguyen et al. (2018), four key mechanisms exist when it comes to coordination within companies, *formalisation*, *informal networking*, *shared vision* and *lateral relations*. All of these mechanisms can positively affect the cross-functional knowledge sharing, but the authors especially emphasises the importance of the last three mechanisms and their impact on improving cross-functional knowledge sharing. They explain that informal relationships can be created through various activities, for example company events or parties, but also through mutual understanding, or when the formal relationships are not enough to solve a task. These informal relationships can then positively affect the cross-functional knowledge sharing and collaboration between different areas of the organisation. A shared vision is an important aspect when it comes to cross-functional knowledge sharing. According to the authors, people with a shared vision are more likely to share and exchange resources and learnings since the shared vision promotes both cooperation and willingness to share information. Cross-functional connections in the lateral direction can reduce the risk of conflict between different parts of the organisation. Furthermore, it can facilitate knowledge integration and make it easier to work towards common goals. Ruggles (1998) states that knowledge is difficult to manage. He argue that even though technology and formalisation can help, the challenge of knowledge management is primarily about content and context, and those who can put the pieces together. It is therefore more about people than about technology and formalisation, which goes in line with what Nguyen et al. (2018) states about the mechanisms.

Companies should have a shared vision, encourage a culture of teamwork and build strong lateral connections throughout the organisation. Formalisation can help, but the people, relations and attitudes are more important.

4

Research Approach

In this chapter, the methods used in this project are described in detail. This includes motivations for the methods selected, the procedures followed, and any adaptations made throughout the process. The methods are discussed with reference to their relevance and contribution to the study. An overview of the process can be seen in Figure 4.1.

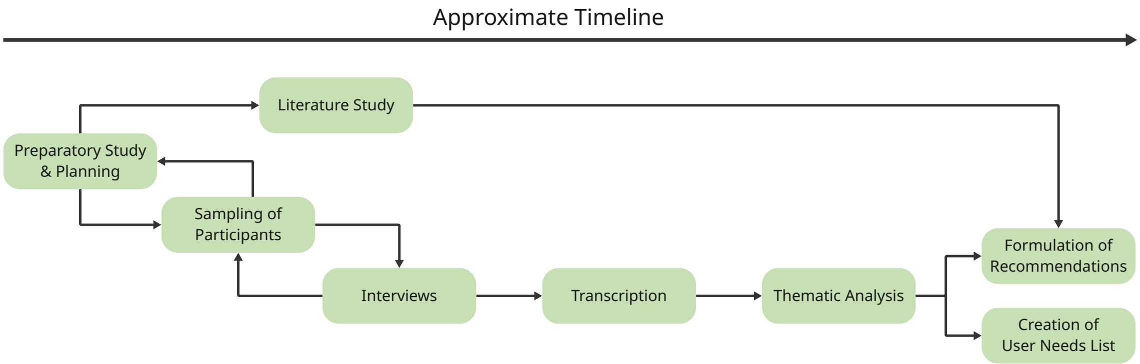

Figure 4.1: A visual representation of the study approach.

4.1 Literature Search

Literature was found using keyword search in mainly Google Scholar, but also Google. In addition, a snowball approach was used, in which references in the literature already identified were reviewed to uncover other relevant sources (Greenhalgh and Peacock, 2005). Articles and books suggested by the project supervisor were also studied. The literature studied consisted of peer-reviewed articles and publications, books, and some other sources that were found to be relevant.

4.2 Review of Internal Courses

To understand the minimum level of knowledge that employees are expected to have about the visualisation tool and to see what is taught, internal courses in TC Vis were attended. The aim was that this would help to see correlations and understand the problems that could be described during the interviews. The courses exist on different levels and are aimed at teaching methods and skills used in TC Vis.

4.2.1 Teamcenter Viewer

The most basic course that one can take is *Teamcenter Viewer*. This course was attended during an ordinary course instance as participants. However, during the course, notes were taken regarding what was taught, how it was taught, and other things that were deemed relevant. After the course, the notes were compared and summarised. Another course that exists, but was not attended during this project, is *Teamcenter Author*. Teamcenter Author covers Teamcenter more thoroughly, but has the same TC Vis content and hence was not deemed relevant. It is mandatory to take one of these courses to get access to Teamcenter, and which course one has to attend depends on what type of access you need. Neither of the courses are focused on TC Vis, but both include some introduction.

4.2.2 TC Vis Level 1 & 2

In addition to the mandatory courses that one has to take to receive access to Teamcenter and TC Vis, there are two voluntary courses in TC Vis available. Instead of attending both of these, which are not held often, the courses were combined into one day, where one of the teachers went through the content of both courses. During this, it was an open discussion in which the teacher went through the course material and demonstrated the different functions that they teach how to use in each of the courses. Usually the course also contains practice exercises; however, these were skipped to fit all content in one day. During the course, questions were asked about both the content and what people who take the course are usually interested in or ask about.

4.3 Preparatory Meetings

In order to get a deeper understanding of the problem and what the situation looks like today, several informal interviews were held. The people who participated in these interviews were experts and knowledgeable persons from different areas within Volvo Cars. Some of these individuals were met with regularly throughout the project, while others were only consulted once. The aim was to have a free-flowing discussion, but in case that would be difficult, questions were prepared to serve as support to get the discussion going.

These discussions were also part of the refinement of the protocol, which will be further described in Section 4.4.2, for the semi-formal interviews that would later be held. Participants were asked if there were any topics they thought were relevant. Furthermore, at the end of each discussion, the protocol was presented with the aim of receiving feedback.

4.4 Interview Study

The main data collection method has been interviews. The interviews were conducted at Volvo Cars in Torslanda. A semi-formal structure has been used and the interviewees have been encouraged to freely elaborate and mention things even though they are not explicitly asked about them. A total of 17 interviews were conducted over a five-week period.

4.4.1 Sampling of Interviewees

The primary method of participant selection was purposeful sampling, which is a non-probability sampling strategy designed to identify and recruit participants who are especially knowledgable or experienced in the visualisation software TC Vis (Creswell, 2014). To find the first interviewees, former colleagues, acquaintances, and the Volvo Car supervisor were consulted. All potential interviewees were listed.

To ensure the appropriateness of the participants, the following three inclusion criteria were established:

1. **Relevance to the study** Participants must work within research and development at Volvo Cars. In addition, participants were required to either have direct knowledge related to the use of visualisation tools or be potential new users.
2. **Availability and willingness to participate** Participants must be available within the study time frame and willing to participate in an interview.
3. **Diversity of perspectives** To capture a wide range of points of view and use cases, the study included participants of varying backgrounds, roles, and contexts relevant to the research.

The purpose of the sampling was to include a diverse range of roles and departments to comprehensively map all needs within the development process, which is shown in a simplified version in Figure 4.2. In addition, the sample aimed to capture participants in various stages of development and with various educational backgrounds. This was done to determine whether visualisation needs and functions change through the different stages of development. To expand the pool of participants, the snowball sampling approach was used. In this process, the interviewees were asked to recommend other potential participants who could also meet the study inclusion criteria (Denscombe, 2018). The snowball approach is particularly effective in reaching people with relevant experience and unique perspectives who may not be identified through direct outreach alone (Säfsten and Gustavsson, 2020).

Figure 4.2: Simplified visualisation of the development process at Volvo Cars.

Given the qualitative nature of this research, the objective with the sample size was to reach data saturation. Data saturation occurs when no new significant themes or insights emerge from fresh data (Creswell, 2014).

4.4.2 Interviews

As mentioned above, a total of 17 interviews were conducted. Each interview was between 45 minutes and one hour long and the interviews were recorded. Before each interview, an invitation with location and time for the interview was sent to the interviewee. In this invitation, some demographic questions were also included. This was done to allow for the interview time to focus on questions regarding their use of the visualisation tool rather than basic questions about the interviewee. At the beginning of each interview, the interviewee was asked if they wanted to add or clarify anything about the demographical questions.

A standardised protocol, as suggested by Creswell (2014), was used for the interviews. The protocol was created and refined with an iterative approach. Firstly, the basic format was brainstormed, based on suggestions from Creswell (2014). This version was then revised and refined on the basis of feedback from the supervisors and the input from the preparatory meetings. During the interviews, one asked the questions while the other acted as secretary and took notes in the protocol. The protocol contained instructions for the procedure to keep the interviews standardised, an introduction presenting us and the project, followed by the interview questions, and probes for follow-up questions. During the interviews, the secretary highlighted interesting areas in the protocol, and at the end of the interview the secretary asked further questions regarding these areas. Säfsten and Gustavsson (2020) suggest that when creating an interview guide, one should first make a list of the themes that the interview should cover, this process was followed. The questions were both about how the interviewee had been introduced to TC Vis, what they use it for, and if there is anything they would like to improve or miss in the current tool. The main focus was to get an understanding of what they use the tool for and thereby also what functions and information in the tool they use or wish they could use. The protocol template can be found in Appendix A. Throughout the study, some minor adaptions were made to the protocol and some questions were reformulated, but no major changes were made.

During interviews, the question *Could you describe your work briefly?* was used as a way to gain insight into the daily work of the interviewee. The interviewer took notes on the themes that the interviewee mentioned that could be used as prompts to get the interviewee to think and elaborate on the question *Is there any specific metadata that you use often/wish were available?*. Having prompts, adapted to the interviewees' work, on this question was suggested by one of the experts that participated in the preparatory interviews.

4.4.3 Transcription

To record and transcribe the interviews, the Office online meeting system Teams was used. Teams have an AI-based built-in transcribing tool in the meeting recorder, in order to make the transcription procedure more efficient, it was decided to use this tool. However, when using AI-based tools, there is always a risk that the content contains faults. Therefore, all transcripts were read while listening to the recording and correcting possible errors. This process was especially critical for the interviews held in Swedish, as the tool was not as efficient at recognising Swedish. During this process, all the things that the interviewee said were marked in bold to clearly differentiate what the interviewer and the interviewee had said.

During one interview, only the transcription feature, and not the recording, was accidentally started. The procedure of going through this transcript therefore varied from the rest. Instead of listening to the recording while checking the transcript, the transcript was only read and compared to the notes, while trying to understand the parts that were not correct. Shorter summaries of what had been discussed were then written in the transcript to accommodate the sometimes not so understandable transcript.

4.5 Analysis

The analysis was carried out with an exploratory approach. In order to be as open minded as possible, no specific categories of findings were defined prior to analysis.

4.5.1 Analysis of Transcripts

As a first step in the analysis, all transcripts were read individually. During this first read, interesting or important quotes and topics were highlighted. In some cases, a complementary comment was also added to clarify the thoughts. As a next step, a pairwise comparison was conducted. The two copies of the analysed transcripts were placed next to each other on a TV, as shown in Figure 4.3. During the review of the transcripts, all markings and comments were discussed, compared, and analysed. During this process, the extracts from the transcripts were transferred to Miro, a tool used for online post-it boards, to prepare for the thematic analysis.

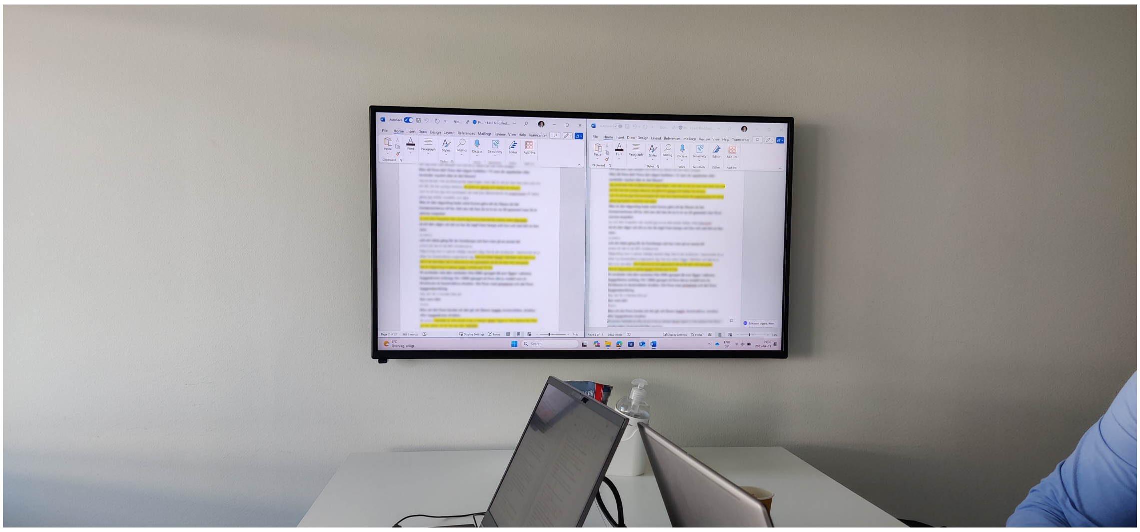

Figure 4.3: How the analysed transcripts were compared.

4.5.2 Thematic Analysis

When the highlighted sections were transferred to Miro, they were coded, divided into different categories, or themes, labelled with a term (Creswell, 2014). Each category was assigned a colour on the post-it to clearly visualise the different categories. These categories were decided and created continuously during this part of the analysis process. For each extract, it was discussed whether it fits into any of the already created categories or whether a new one would be needed. For some extracts, two post-its in different colours, corresponding to different themes, were created.

Each post-it also received a tag with a number, corresponding to the interviewee. This was done to keep track of where the extracts came from, if more context would be needed at a later stage of the analysis. As a first step, all extracts were placed in groups, based on the interview from which they came, which can be seen in Figure 4.4. This was done to visually show how many extracts came from each interviewee. At this stage, all extracts in a cluster came from the same interviewee and thereby also had the same tag. Once all extracts had been transferred to post-its, they were clustered into the created themes, hence the colour of post-its where the same in each cluster, and the tags differed.

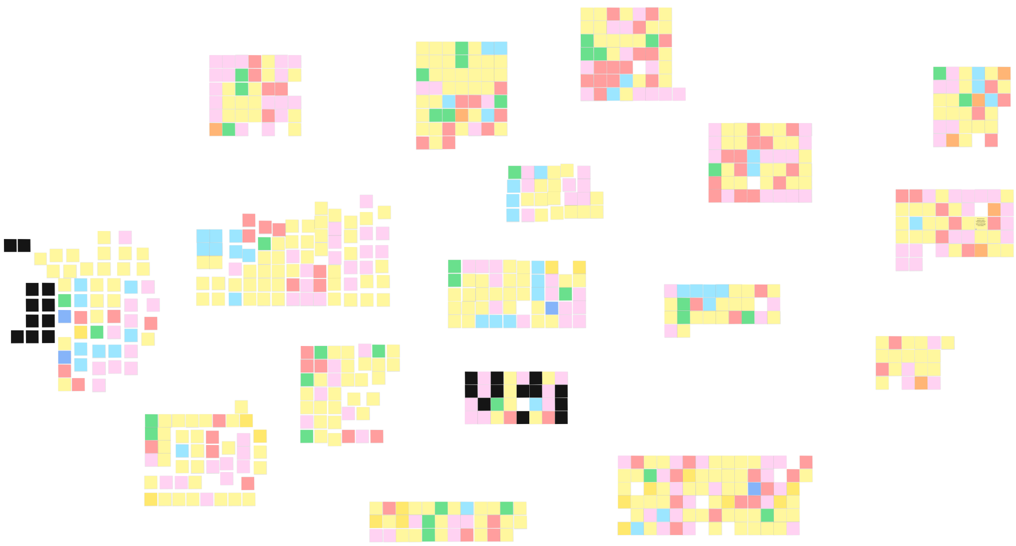

Figure 4.4: The extracts at the first stage, organised by source.

Afterward, each cluster was reviewed and further divided into sub-categories. This procedure was similar to when the extracts were first clustered, with categories emerging throughout the process. In order to define the sub-categories and arrange the extracts into them, each extract was discussed and matched toward the already existing clusters. The creation of the sub-categories was an iterative process where some categories changed name throughout the process in order to accommodate, and describe, the extracts within each cluster. In the bigger clusters, some sub-categories were further broken down into smaller, even more specific, categories.

During this process, the category for some of the extracts was re-evaluated, and the colour of the post-it was then changed to match the new category. Furthermore, one of the categories only had four post-its, and all extracts were judged to fit other categories as well. Therefore, that category was broken up and the extracts were put in different clusters.

4.5.3 Structuring Identified Needs

Depending on the nature of the extracts, they were handled differently in the next step. Firstly, a spreadsheet for a user needs list was created. In this sheet, all extracts that could be directly connected to the functionalities in the visualisation tool were written down. The subthemes that had emerged during the analysis were used in the user needs list as categories. The needs related to each other were connected in a parent-child-like structure.

One of the themes consisted of all needs that were directly related to the visualisation tool, after going through this theme, the other themes were partly used to verify that all needs had been added to the spreadsheet. If procedures were described in which a need that could be fulfilled by the visualisation tool could be interpreted, this need was added to the list. Furthermore, a text document was created for the extracts that was not possible to interpret as concrete needs that the visualisation tool should fulfil. These extracts had a more general, or way of working nature. The different themes were studied one by one and discussed. The different extracts were summarised, analysed, and combined and descriptions were written in the document. Based on these descriptions, recommendations were formulated that will be presented in Chapter 7.

4.5.4 Clarification of Bias

Even though the analysis was carried out with the objective of having an open mind, the analysis was carried out by the same people who had conducted the interviews. Because of this, some ideas and thoughts had started to form before the analysis was conducted. In an attempt to minimise this bias, the exploratory approach was chosen as a way to remain as open as possible to new ideas and themes that could emerge during the analysis.

4.5.5 Ethical Considerations

All participants were informed about the purpose of the interviews and the study. Participation was entirely voluntary. Both authors have signed a confidentiality agreement regarding the protection of personal data within Volvo Cars which is available in Appendix B. All personal data from the interviewees were handled according to the agreement. Before each interview, all interviewees signed an agreement regarding their consent to participate in the study, recording the interview, and handling their data.

5

Findings From the Preparatory Study and Analysis Process

This chapter presents the findings of the preparatory study, excluding the literature study, with a primary focus on the results of the internal TC Vis courses. Furthermore, it presents the results of the sampling of participants for the interview study as well as the analysis.

5.1 Preparatory Meetings

The preparatory meeting helped establish the context for the study and served as a starting point for the identification of the initial participants for the interviews. One of these meetings also inspired the idea to use prompts based on the interviewees' job description when discussing metadata. In addition, insights were collected on how the most recent PLM system transition had been managed. Finally, some of the experts also offered valuable guidance that helped shape the direction of the study.

5.2 Review of Internal Courses

Attending the internal courses gave a good idea of both the minimum knowledge that the different employees who use TC Vis should have and the educational opportunity available to employees. It was also learnt that the voluntary, more in-depth courses, TC Vis Level 1 and TC Vis Level 2, rarely are held because the interest in them is low.

In addition to the courses that were attended, *TC Vis Zoom-in – In Customized* is offered. This course is created based on specific needs from departments or different groups of users who want to learn or refresh skills within specific areas of TC Vis. Both the content and the duration of this course are decided on based on the needs of those requesting the course.

5.2.1 Teamcenter Viewer

As mentioned in Section 4.2.1, the most basic course is *Teamcenter Viewer*. It is a one-day course aimed at those who need to look at the data in TeamCenter. This is evident in the course, since the topics being handled are the fundamentals one needs to know in order to be able to open and find information in Teamcenter. As mentioned earlier, one has to take this course to get access to TC Vis. Hence, this is also the minimum level of knowledge that people, at Volvo Cars, working in TC Vis have. In total, there were seven participants and one teacher. The course is conducted with a mix of theory and practice tasks.

During the first half, the focus was more on what virtual development is and what Teamcenter is used for. Some reasons why things are done in a certain way were presented, and the relationship between the physical car and its part numbers, as well as the virtual car and its 3D geometry, was explained. In addition, sources on the intranet, the Volvo Cars private Internet portal, where one can find methods or seek help if one encounters issues, were also presented. In relation to this, the teacher also mentioned that they like to emphasise where one can find instructions and methods themselves to be able to work more independently.

In general, the course is very pedagogical. It was an applied learning process in which the teacher showed and talked about something first and then everyone got to try it themselves on the practice tasks. Throughout the course, many examples were used and the teacher continuously checked in and asked things such as ‘does anyone work with this?’ to make sure that the content was adapted to the participants. During the TC Vis demonstration, the instructor asked things such as ‘what happens if you do this?’ to encourage participants to experiment and try the tool themselves. Furthermore, they used a ‘notation’ tool to draw arrows and circle important things they showed on the projector that helped to follow. The course is very general and shows the basic tools and methods available.

5.2.2 TC Vis Level 1 & 2

These courses focus solely on TC Vis and usually last one day each. However, as mentioned earlier, for this project a combined version of the courses was attended, specifically held for the purpose of the project. During Level 1 the basics from Teamcenter Viewer is partly repeated, when it comes to organisation and preparation of geometry, one learns about how to create snapshots, groups, and how to save TC Vis models. It is also shown how one can add more columns with information to the structure, segment 1 in Figure 2.4, and that ‘Leaf Structure’ enables measurements that will update if objects are moved. Furthermore, how to perform clearance checks and ‘Neighbour Search’ are presented, as well as the differences between different variants of these functions.

It is introduced how one can search for instructions in the tool. However, this search function takes you to the Siemens website and is not specific to the variant of TC Vis that is used at Volvo Cars. The teacher therefore warns that you might not always be able to find what you want and that it can be a bit difficult to use it.

During Level 2 'Visual Report', which was described in Section 2.3, is introduced. It is also shown how one can find predefined rules to use in Visual Report. The teacher highlights that there are a limited number of licences to Visual Report and that it is very important to turn of the tool when not using it. Level 2 is also mentioned to be more adaptable and possible to tailor to the needs of participants.

5.3 Sampling of Participants

In the beginning, the sampling was a bit slow, which is often the case with the snowball approach. But after a few interviews the number of suggested interviewees quickly increased, and thus also the number of people who agreed to be interviewed. The result of the snowball sampling is shown in Figure 5.1, as mentioned in Section 4.3, some preparatory interviews with experts were held and some of these people were also found using the snowball method, marked in grey in the figure.

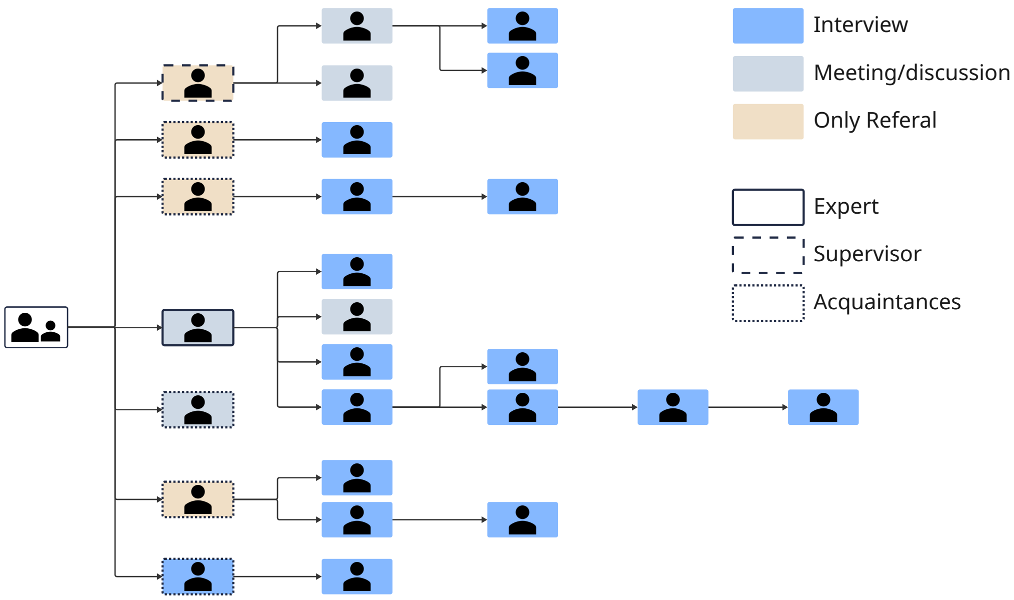

Figure 5.1: A chart visualising the result of the snowball sampling.

A list of roles and the corresponding area of work of the participants can be found in Table 5.1. Both the mean age and the median age were 45 years old. The youngest participant was 29 years old while the oldest was 59 years old. In total, 15 participants were men while two participants were women. This is in line with the fact that 92% of the recommended people from the snowball method were male.

Table 5.1: A table displaying the different roles as well as area of work of the participants in the interview study.

Role	**Area of Work**
Senior Concept Engineer	Mechanical Integration
Senior Calculation Engineer	Vehicle Dynamics
Robot Technician	Pilot Plant
Architect	Vehicle Test & Integration
Test Object Preparer	Part Specification
Method Developer	Concept Engineering
Virtual Car Manager	Vehicle Test & Integration
Senior Analysis Engineer	Perceived Quality
Block Leader	Mechanical Integration
Senior Technical Leader	Car UX
Product Owner	Product Simulation
Simulation Engineer	Process Design & Investigation
Senior Visualisation Expert	Product Simulation
Engineering Manager	Mechanical Architecture & Concept
Senior Analysis Engineer	Product Ergonomics
Design Engineer	Interior Trim
Group Design Leader	Exterior Front & Rear

5.4 Analysis

During the first step of the analysis, described in Section 4.5.1 and 4.5.2, eight themes, presented in Table 5.2, emerged. All extracts, sorted into these themes, can be seen in Figure 5.2.

As mentioned in Section 4.5.2, some of the larger categories were further divided into smaller categories. For example, in *Way of Working* and *Requirements for the Software* some sub-categories, such as *Use Cases* and *Analysis Functions*, were further broken down into smaller, even more specific, categories. The final state of the KJ-Analysis can be seen in Figure 5.3. Furthermore, regarding the category *Sidequest*, it was learned that these features were supposed to be covered by another tool, hence the category was dismissed, while the category *CAE* was broken up into other categories.

Table 5.2: Explanations of the different themes that emerged during the analysis process.

Requirements for the Software	Concrete functions or things interviewees described that they wanted to be able to do in the visualisation tool.
Way of Working	Descriptions of how the interviewees worked today, especially in relation to the use of visualisation.
Implementation	Aspects that was judged to be important when implementing the new visualisation tool.
Education	Extracts related to people's knowledge about the visualisation tool, as well as information about how they had learnt what they know.
General	Things that covered larger aspects, for example, dilemmas interviewees described or pros and cons with TC Vis.
Metadata	Concrete information that interviewees mentioned they want connected to 3D geometry in the visualisation tool.
CAE	Things explicitly related to Computer-Aided Engineering (CAE); this category was later removed.
Sidequest	Aspects related to a potential new use of the visualisation tool, which was then found to be covered by another tool.

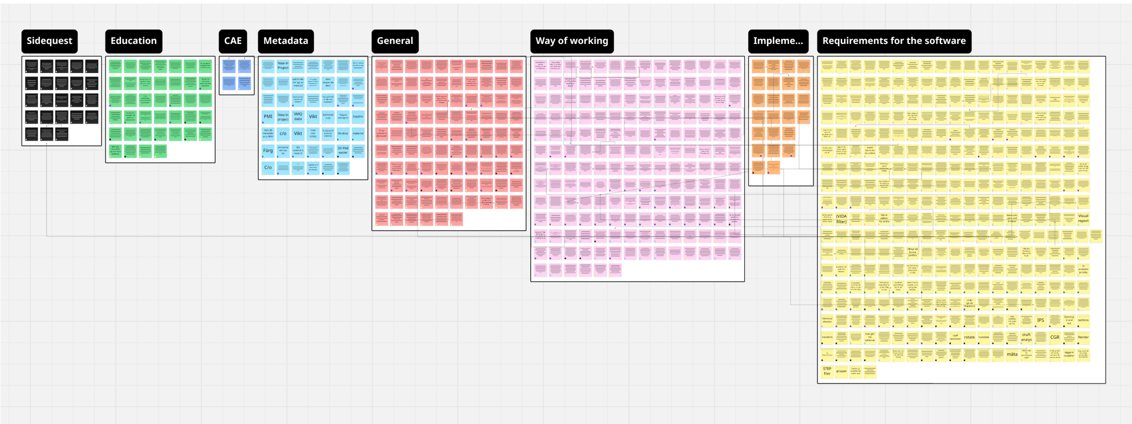

Figure 5.2: The extracts organised by theme.

Figure 5.3: All extracts after finalised KJ-Analysis.

5.4.1 Structuring Identified Needs

All extracts in *Requirements for the Software* were direct needs applicable to the visualisation software. As described in Section 4.5.3, these needs were transferred into an excel list and structured in parent-child-like relationships, as visualised in Table 5.3.

Table 5.3: An example of parent-child relationships between needs related to the appearance of the geometry.

14	Basic Analysis Functions
...	
14.9	Change Appearance of Geometry
14.9.1	Change Colour
14.9.2	Change Transparency

In Chapter 6, the situation today will be described. This description is based mainly on what has been found in the categories *Way of Working* and *General*. Furthermore, the user needs list that has been created will be presented, and some of its categories will be described further, while the complete user needs list can be found in Appendix C. In Chapter 7, the Strategic Recommendations and Practical Implications that have been formulated and identified will be presented. These are based on how the situation today has been described and the issues that have been identified, primarily, these have been based on the categories *Education*, *Implementation* and *Way of Working* combined with the findings of the literature study.

6

The Situation Today and Identified User Needs

In this chapter, the situation today and findings directly related to the software will be presented. These findings stem from the results of the analysis process, presented in Section 5.4. In Section 6.1, the opinions expressed by the interviewees about the current tool, TC Vis, and the situation today will be described. In Section 6.2, findings related to data quality will be presented. In Section 6.3, the user needs list that has been created based on the category *Requirements for the Software*, described in Table 5.2, will be presented.

6.1 The Situation Today

The following insights are based on the 17 interviews that have been conducted with employees at Volvo Cars. Overall, people appreciate TC Vis. For example, it is described as a nice visual way to find information. But opinions also vary, even for the same person, because they experience that one aspect can be really good, while other functions have room for improvement. Some quotes about TC Vis from different interviewees are presented in Figure 6.1.

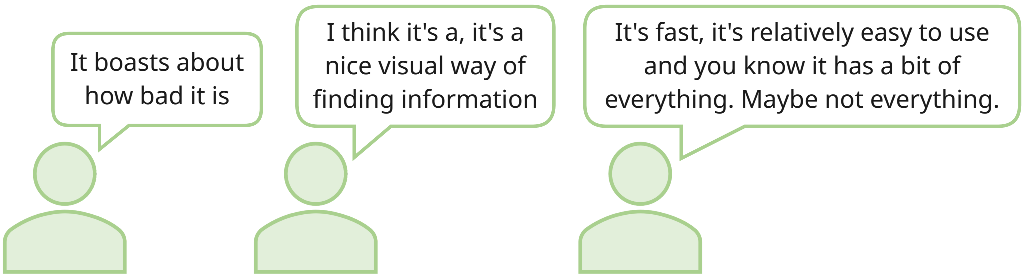

Figure 6.1: General opinions on TC Vis from different interviewees.

Visualisation is used to a large extent at Volvo Cars, as one interviewee stated it; 'usually the arguments come with a picture'. People prefer visuals in discussions and meetings and believe that it makes it easier to communicate. The opinions vary a bit about whether presentation slides or presentation directly in the visualisation tool are the best option, but in general 3D seems to be preferred, as exemplified by the quotes in Figure 6.2.

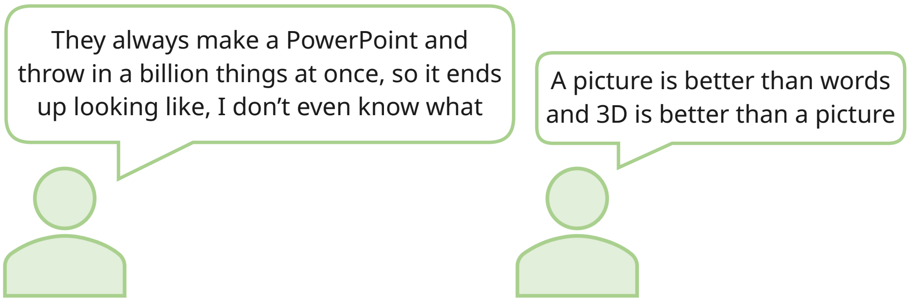

Figure 6.2: Quotes about 3D being the preferred way to present.

When it comes to what tools are used for visualisation, one of the interviewees described the situation today as a mix of TC Vis, other solutions, and gaps where no solution exists. Another person mentioned that if there are things that are missing in TC Vis, they have solved it, at least for now, by using other software. Although most people seem satisfied with the way things are today, there is potential to improve things and make processes more effective.

As mentioned, TC Vis is complemented by multiple various tools and software in order to fulfil all visualisation needs that exist today. By introducing a new, more powerful visualisation tool, some of these could become obsolete when more tasks can be performed in the same tool. However, people are used to the different tools today, so if the new visualisation tool is going to replace some of these tools, it must cater to all needs those tools fulfils as well.

6.1.1 Problems

During interviews, many problems were mentioned, especially when the interviewee was asked what they would like to improve with TC Vis. One of the main problems seems to be that there is no single source of 'the truth'. Today, Quick-Launch (QL) files of different cars and variants are generated every night. This means that already when you look at the 3D geometry, it can be old. Furthermore, many interviewees mentioned that data are stored in many places such as Teamcenter, spreadsheets and other computer tools, which means that it is not always easy to find and can even differ between sources. In general, the quality of the data can often be questioned.

A recurring issue that was mentioned was the availability of information. The path to the needed information was not always straight or intuitive. One person who was interviewed said that they wished that the weight of a component could be viewed directly in TC Vis and that this was not the case. When viewed in TC Vis the weight was missing or 'off by a multitude'. They showed how the car was estimated to weigh eight tonnes in the current configuration, which is clearly wrong. The workaround is to look for the weights in Teamcenter, and if they by any chance are not applied there either, then you need to look in Konstruktionsdata Personvagnar (KDP; English: Construction Data Passenger Cars), an internally developed component database. This is, according to the interviewee, not an easy process. The quote in Figure 6.3 came from one of the interviewees that mentioned this topic. Because of this, you do not always know what is true and what is not, especially since it is not uncommon that the different sources contain different information. Furthermore, it was also mentioned that the data sometimes are fed from the wrong source, leading to incorrect data. Another aspect that was mentioned to contribute to the quality of the data is the naming convention and structure currently in place. One component may go under several different names or part numbers depending on the colour and project it is part of. This inhibits the traceability of the parts and creates confusion in many cases. This makes it difficult for those who consume the data downstream and results in people needing to 'hunt' the correct information of the part. This is a fault in the system according to one of the interviewees since the human factor plays a role in whether the correct information is linked and uploaded or not. According to them there is a lot of 'fribble' that the system should hinder from happening.

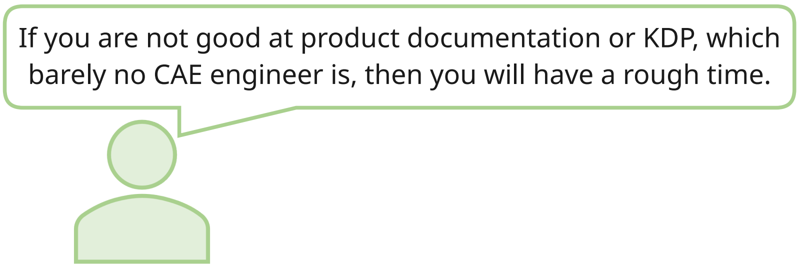

Figure 6.3: Quote from one of the interviewees about the struggle to retrieve the correct information.

Another issue that was raised is the lack of a real connection between the test results and the design outcomes. The analysis data and the design data are disconnected, which contributes to the challenge of establishing a single source of 'the truth'. This lack of traceability often leads users to wonder 'What happened here?' or 'How did it end up like this?'. One participant highlighted the need for more time to freely explore the system, become familiar with the geometry, and follow along with changes. However, they observed that time constraints often cause users to skip this critical step. Establishing a stronger link between analysis and design would make it easier and quicker to understand the changes being made to a component.

The way in which a TC Vis session is run locally is also mentioned as a problem. An interviewee mentioned that they always have to go early if they are going to have a meeting in another building to prepare there, instead of preparing at their desk. The reason was that issues appear when the computer loses connection to the Internet or changes the internet connection, which sometimes happens when you move between different buildings.

Some of the geometries in the system are modelled in a way that does not fulfil all needs. Some are structured as undivided 'black boxes', lacking clear internal segmentation. This complicates the application of materials during visualisation, as users cannot differentiate between parts. The design team often has to resort to other software like CATIA to break these units into more detailed structures.

As mentioned in Section 2.3, one can hover over an icon in TC Vis to see information.

However, usually it is just the name of the function, or in some cases, one or two additional words, that is shown. An interviewee talked about this and mentioned that it would be beneficial if a couple of sentences were displayed to give more information about the tool. However, there should not be too much information, because then it would instead become overwhelming. The interviewee described the functionality today as obsolete and unnecessary.

6.1.2 Compromises

There is a challenge to balance time and quality, and often cost plays a big role as well. Today, some procedures might be cancelled because of the double work required to cover the variants. An interviewee, for example, mentioned not being able to load 13 variants and check all of them. This creates a risk of one of the variants having an issue that passes by unseen until very late stages of the project. This compromise of time vs. quality could be avoided if the system could manage easier switching between variants. Platform-based and modular product development is often effective and makes it possible to offer many variants of the product. However, even though interfaces are common and it is, in theory, easy to just switch out a module, they can come with complications. For example, those working with perceived quality might want to check how all variants are perceived and that everything looks fine. But this will be very time consuming when, as the person mentioned, there are 13 variants.

In terms of time, it was also mentioned that even though tools and processes have improved, which has led to far greater efficiency than before, the number of projects and their complexity have increased. As a result, time limitations are still considered an issue. It was also mentioned that TC Vis is a tool that takes too much time to start and load for people to actively want to use it.

6.1.3 Dilemmas

There appear to be some dilemmas where it will be important to examine these more closely and decide how these things should be handled. Some of these aspects could probably be handled within departments, while for some it will be important that there is a company-wide agreement.

An interviewee mentioned the dilemma that, when you can do something quicker, you can either shorten the lead times or make more iterations, as seen in Figure 6.4. It will be important that the company is on the same page when the opportunity arises. Relating to the expected improvements presented in Section 2.2, the most likely answer, in the Volvo Cars case, will be to shorten the lead times and improve 'time to market'.

Another dilemma that was mentioned was about cost prioritisation. An interviewee talked about pre-production vehicles and how expensive they are to build. According to the interviewee, you can probably buy 100 AR-headsets for the same price as one pre-production car. If this is the case, it could be relevant to look into the

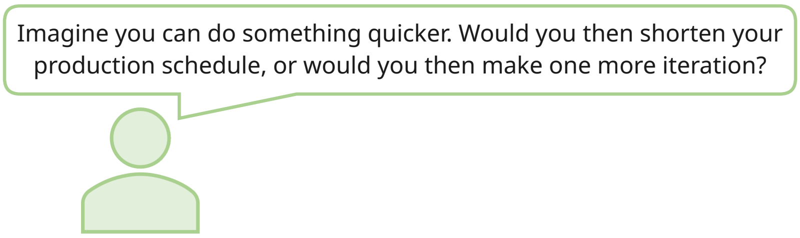

Figure 6.4: Quote from one of the interviewees about a dilemma regarding lead-times and iterations.

possibilities of conducting more tests through, for example, VR and AR.

The level of secrecy when it comes to what is possible to visualise could be a dilemma. An interviewee mentioned that a previous design manager was of the opinion that things should barely be visible at the design office. Another manager had believed that the best way was to be transparent towards larger parts of the organisation. The opinions vary on whether it is good that many employees can see new products, or if it should be difficult to access that kind of model to hinder the visualisation of complete new vehicles on 'every other screen in the office area'. It will be of importance that it is possible to adapt the visualisation tool and who has access to what, based on changed views from management.

One interviewee mentioned that it is not allowed to assign preliminary materials to a component, something that has been allowed before. It was also mentioned that there is a vision to select the correct material as early as possible to obtain quotes for the components. However, the same person also mentioned that too much development, for example regarding material, happens throughout the project, so it is very difficult to set the material early. This creates a dilemma when it comes to, for example, CAE calculations and other areas that need to know what material components will have. It could be worth reevaluating the decision about not assigning preliminary materials if 3Dx allows a way to handle it in an intuitive way. It will be important that it is clear that it is a preliminary material, so it is not seen as the truth. This could improve the situation for downstream data consumers. Another interviewee, working with CAE, mentioned that they aspire to be in a situation where they can do calculations and simulate early in the process, and then they need some kind of material information. The CAE calculations can then be started with the preliminary material, and if the final material ends up having different properties only the affected areas can be recalculated, but probably the preliminary material will be somewhere in the right 'area'. This will be a balancing act between the contradictory needs of receiving information as early as possible and having as much time to develop as possible.

A critical factor influencing the performance is the type of QL-file being loaded. QL-files loaded with KDP data tend to be particularly heavy, often leading to slow load times. This presents a dilemma, since there is a wish from the users to store more information on the geometries so that it can be reached from the visualisation software. However, this can lead to even longer loading times, which will further hinder the workflow. This is already experienced by users as many people mentioned that the software has become increasingly slow as details and quality of the data have improved. This problem is partly worsened by the fact that not all users have the same hardware. Many managers use lightweight laptops not designed for heavy processing tasks. Their computers already struggle with normal QL-files. This creates a usability gap, where only users with powerful workstations can work efficiently, limiting access to high-quality data.

6.1.4 Waste

During the study, different areas of waste were identified. Waste that is mainly due to both ways of working and technical restrictions. The identified waste will be presented here.

Information availability

As mentioned in Section 6.1.1 the availability of information is an issue. The current situation, which involves needing to search for information or even working with incorrect information, is a waste of time and might lead to faulty results, which can cost a lot of money. In some cases, data must be modified before it can be used, such as the ‘black box’ example also mentioned in Section 6.1.1. This ‘data washing’ is a wasteful, time-consuming, and avoidable task that does not add real value.

Remote access

TC Vis depends, as mentioned above, on being connected to the Internet, which means that if you lose connection, your session will crash. Today, if you need to show something in TC Vis in a meeting, you need to go early to the meeting and load the session on the local Internet. Hence, many resort to screenshots in an PowerPoint instead, which is a waste of time and frankly a lesser way to present than utilising the available 3D visualisation tools.

Export JT

The file format used by TC Vis is JT, an ISO-standard lightweight file format that is not the standard format in many other software. As a result, converting JT files to more compatible formats such as FBX often requires additional conversion tools. This conversion can be done in many different ways; one popular option that design often utilises is converting the JT within VRED. Since VRED licences are expensive and pay for by use, this workaround is not only time consuming but also expensive. Additionally, interviewees mentioned that JT files are frequently poorly stitched, requiring improved stitching quality and higher fidelity in lightweight geometry. The reasons behind this are unclear, but it could be because of the different tools used today and that the file format is continuously changed, according to one person.

Automotive development today relies more heavily on simulations than in the past, resulting in a significant increase in the number of people who work with simulations on a daily basis. During interviews, it was noted that manual data export was not a problem when only a few people handled simulations. However, with many users now involved, having each person manually export data has become inefficient and time consuming. It was suggested that there should be a unified database for exports.

Dead files

In many departments, the software in use does not support live data feeds from Teamcenter, partly due to the mentioned incompatible file formats. This leads to a bunch of issues, such as not knowing if geometry is the latest and correct one. This was especially a problem for one interviewee who uses geometries from various departments and ‘freezes’ them by downloading them and effectively ‘killing’ the file. So, when someone is late to the deadline and has not uploaded the correct data, they are not captured in the freeze, and the process needs to be re-done. In some cases, the missing files can be taken out separately and entered, but this is time consuming.

Material and metadata

The management of applied material also suffers from inefficiencies. Incorrect or incomplete metadata is a recurring issue. Design decisions, such as colour selections for components, are frequently recorded in external documents like Excel files, rather than being applied directly to the geometry. This disconnection forces downstream engineers to spend time tracking the correct information, often needing to call colleagues. It is a system flaw that is rooted in a process that is dependent on individuals to remember to properly link or upload data. According to several interviewees, there is a lot of ‘fribble’ going on.

Several downstream software systems are used today that do not directly feed Teamcenter but instead rely on ‘dead surfaces’. For these software, it is a manual process where the user needs to read in Teamcenter or CATIA which material is applied and then pick them one by one. These processes are ineffective and increase the risk of errors. Many people said that each time you need to resort to manually picking surface by surface or exporting materials one by one, it is a complete waste of time. An interviewee expressed it as: ‘It is completely insane to sit and pick a surface like this’.

Lastly, this has also been mentioned that it becomes an issue during development when assessing the total weight of the vehicle, and someone forgets to include a material. You may progress to the next development phase, only to suddenly discover that an unexpected 100 kg has been added. This extra weight needs to be managed, and if balancing has already been done, it must be re-done. An interviewee stated that ‘Stirring the pot again like this can take anywhere from 4 to 6 months before everything is fully settled.’

Downloading complete vehicle

During the study, it became evident that the workflow of several people consists of them starting each session by loading the entire vehicle. This so that the files will be stored on the RAM and be fast to navigate afterwards. This is a waste of time if the intended work does not involve the complete vehicle. One of the interviewees mentioned that the clearance search is so slow that this way of working is faster. It was understood that this procedure was done because of the unintuitive structure. This way of working becomes especially slow when working within the support structure, which might be populated with all kinds of data.

6.2 Quality of Data

During the interviews, the importance of data quality was often mentioned. According to many of the interviewees, the usability of a digital part is highly dependent on the quality of the data, which is in line with the discussion in Section 3.4 about the importance of correct and accessible information. If the component lacks correct metadata, then it will not be as useful in other downstream applications, which is highlighted by the quote in Figure 6.5. As mentioned, metadata are often missing, or even incorrect. This was often mentioned by many as a great source of annoyance and affected to what extent the software was used. Features utilising attributes such as 'New in project', which should indicate if a part is carryover or not, could not be utilised or trusted to 100 percent since not everyone assigns the correct status on the parts. The reason for the low quality was often blamed on laziness and that other departments were careless in applying the correct metadata, which is discussed in Section 7.3.3. One user even said that they wished that it would not be possible to release components that are incomplete in relation to the connected data. Although it may seem tedious or even excessive, manually applying each piece of metadata can pave the way for future automation, ultimately saving time.

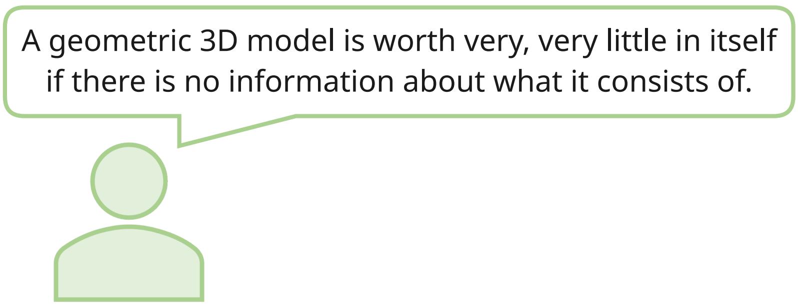

Figure 6.5: Quote from an interviewee regarding the importance of metadata on the 3D geometry.

Although human error is a contributing factor, it is not the sole reason for poor data quality. Some components are inherently limited in how their metadata is structured. For example, the digital representation of wires or cable harnesses is intended only for packing purposes. They do not include detailed modelling of the copper strands or insulation, as seen in Figure 6.6. As a result, critical simulation attributes, such as mass, centre of gravity, or moments of inertia, may be inaccurate.

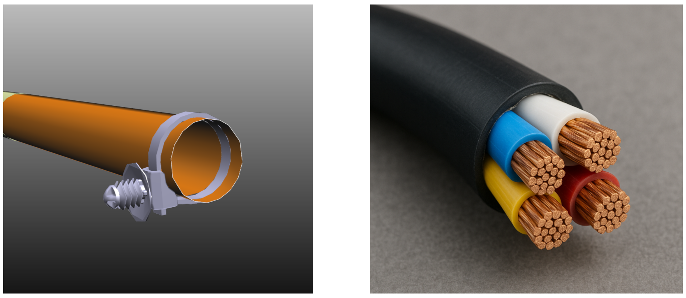

Figure 6.6: Section of a cable in TC Vis to the left and a AI generated image from DALL · E via ChatGPT of an cable with strands and isolation to the right.

6.3 User Needs List

In total, almost 250 needs were identified. These needs were divided into 21 different groups, presented in Table 6.1. Some groups of needs will be presented in more detail here, while the complete user needs list can be found in Appendix C.

Table 6.1: The categories in the User Needs List.

1. Metadata /Attributes	The metadata that should be connected to the 3D geometry and related functionalities.
2. VR & AR	Virtual and Augmented Reality features and related needs.
3. Rendering	What rendering features that should be available, as well as settings related to rendering that should exist.
4. Collaboration	Collaboration aspects.
5. Issue Mgmt	Functionality related to the handling of issues.
6. Save	What, and how, to save 3D geometry.
7. Export	File formats and tools it should be possible to export to.
8. Import	Things that should be possible to import into the visualisation tool.
9. User Roles	Needs related to different roles that could be defined within the visualisation tool.
10. Filter	Which filter that should be possible to apply in order to display the geometry you want to see.
11. Structure	The different structures the 3D geometry should be organised into.
12. Search	Options to search for 3D geometry and other information in the tool.

13. Models	Type of 3D models that should be possible to visualise.
14. Analysis Functions	Analysis functions and tools that should be available in the visualisation tool.
15. Assembly Sim	Functionalities related to assembly simulations.
16. View	Other things that should be possible to view in the visualisation tool, in addition to the 3D geometry.
17. Organise /Prepare	Ways to organise and prepare 3D geometry, for example for presentations.
18. Manoeuvrer	How to manoeuvrer in the tool.
19. Adaptability	How the tool should be possible to adapt to accommodate extra, or future, needs.
20. Intuitiveness	Aspects related to the intuitiveness of the tool.
21. Performance	How the performance of the tool should be.

6.3.1 Issue Management

One area that would benefit from having a seamless connection to the visualisation tool is the issue management system. Today, it is partly handled by another tool, MIP, which has links to TC Vis. However, it was found that everybody does not use MIP. Some interviewees mentioned that they mainly use 'Teams chats' to communicate issues with affected people. The needs that was identified related to issue management are showed in Figure 6.7.

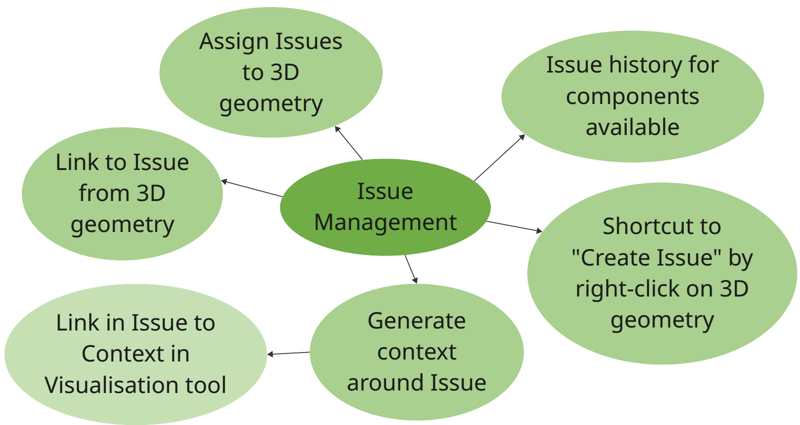

Figure 6.7: The different needs related to issue handling in the visualisation tool that was found.

Another need that was found was that it should be possible to 'hover' over an issue and then see a preview of the context. This is a functionality that probably will not be implemented in the visualisation tool but solved in the issue management system, and therefore the need is not presented in the user needs list. However, it is still related to the visualisation tool that should feed the context to the issue management system.

6.3.2 User Roles

The need for different user roles was something that was mentioned by many of the interviewees, and the identified needs are shown in Figure 6.8. The purposes were different, but the desire for an adapted tool depending on the user was common. As mentioned in Section 6.1.3, there can be differences in who is allowed to see what. By having different user roles in the tool, the models you have access to can be adapted based on your role, so that, for example, everyone can not see the latest design models. It was also found that it could be helpful if the interfaces and dashboards were adapted based on different roles, for example, a manager role with more basic visualisation and less analysis functionalities. However, it was also mentioned that it is important that you can switch to roles that have other functions, or search for and add functions to your dashboards and toolkits.

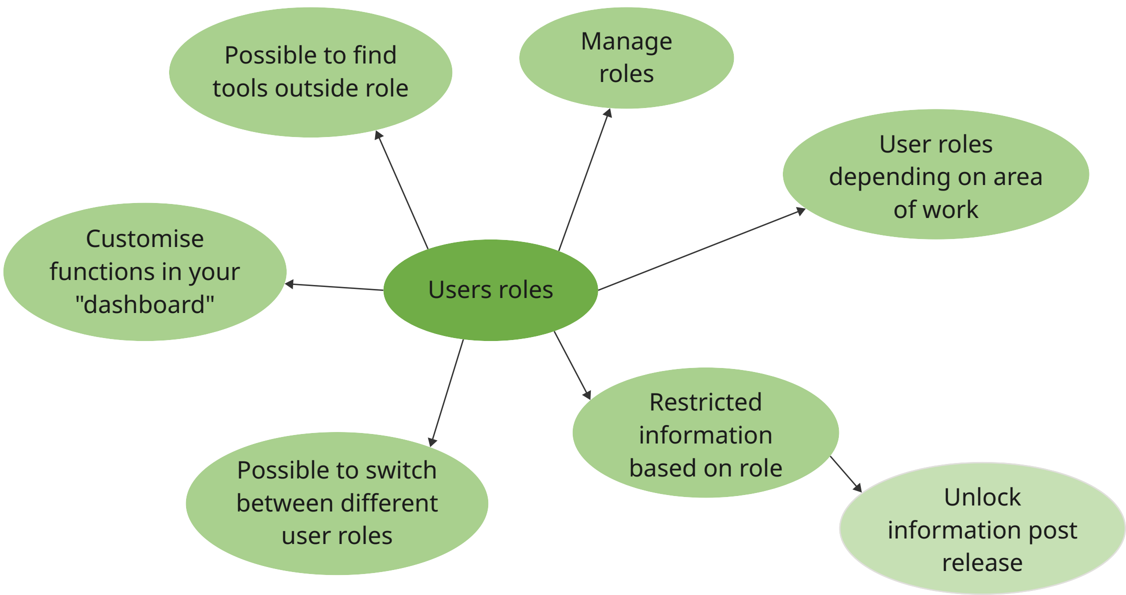

Figure 6.8: The identified needs related to user roles.

6.3.3 Filters

One thing that multiple interviewees mentioned was the possibility of easily filtering what you see. These filters could be applicable both to find components within one or multiple cars, but also to compile the exact car variant you want to look at.

Filtering Components

It was expressed that sometimes you might just want to look at some of the components and not a complete vehicle. By implementing filters such as weight, material

Figure 6.9: The different types of filters that should be available in the visualisation tool in 3Dx.

or carryover you could then limit the visible components. For example, if you only want to see plastic components that weigh between 20 to 60 grams, or all brackets that are made of sheet metal, then you could select this in the filter, and only the components that fulfil these criteria will be visible.

Another useful filter could be those that hide all the components that are not relevant to you. Examples of this could be that aerodynamics only need the exterior components, or those working with perceived quality only those that are visible to the eye. By then deactivating all other components, one could decrease the file size which then can lead to quicker loading times or better performance when using, for example, VR. All needs related to filters are presented in Figure 6.9.

'VIDA-Filters'

VIDA is a computer programme used in after-market workshops for Volvo cars. In VIDA it is possible to filter step by step to see a specific variant of a car, with the filters shown in Figure 6.10.

One of the needs related to filters is 'VIDA Filters'. This filter would be used to decide which car you want to see, not to filter within visible models. The idea is that incompatible options will be deactivated when certain other options are selected. This will make it easier to visualise every possible vehicle. Today, there is something called the DMU Garage, or Digital Mock-Up Garage, in which one can find QL-files of prefiltered cars. However, this significantly limits what options or

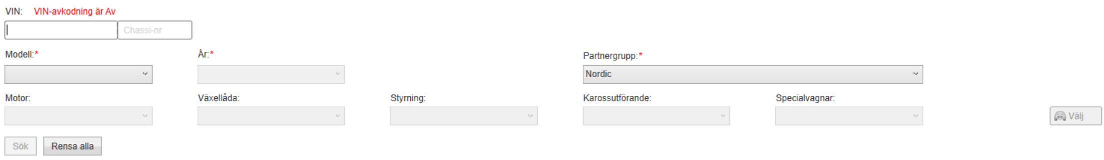

Figure 6.10: A screenshot of what it looks like in VIDA when one wants to select a specific car variant.

variants you can see. It is very time-consuming to filter variants in Teamcenter, so therefore only some variants are offered in the DMU garage. By implementing a convenient way of doing this in the 3Dx visualisation tool, it would significantly ease the process while creating the opportunity to easily visualise all possible variants. An example of what this kind of filter could look like, developed based on the findings of the study, and what the filter in VIDA looks like, is shown in Figure 6.11. In the figure the button *Only compatible options* exist, by de-selecting this one could see car configurations that are not offered to the customer and therefore not a realistic variant, for example, a fuel tank on a completely electric vehicle. This could be used, for example, in packaging to try new combinations of components.

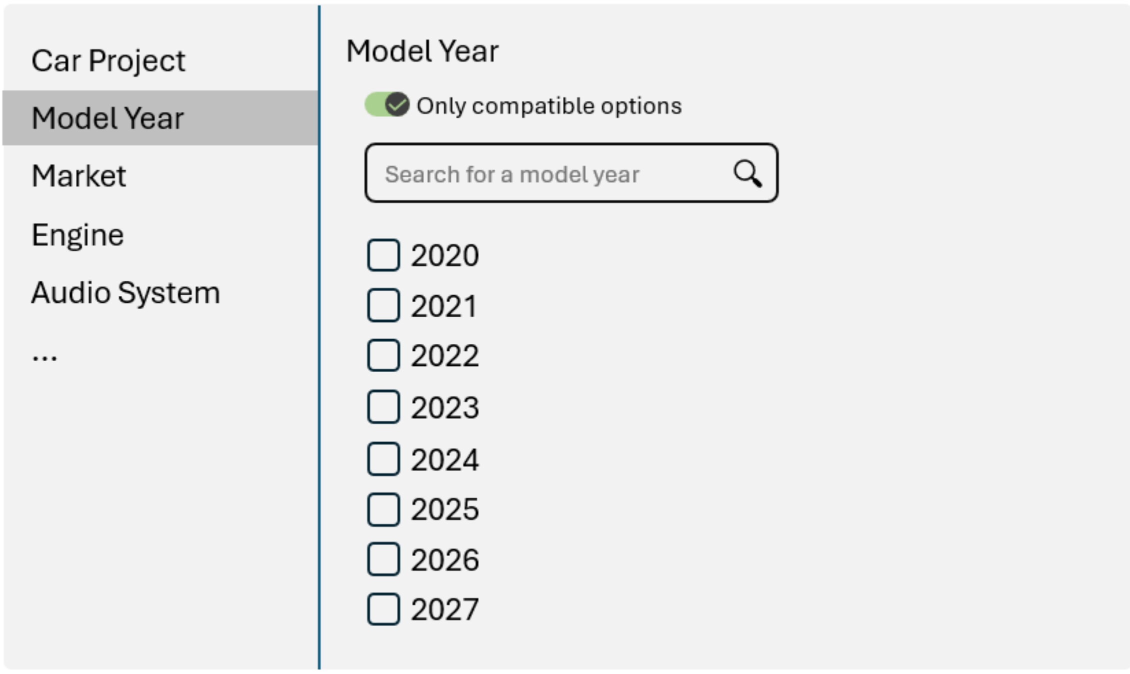

Figure 6.11: An example of what a VIDA-inspired filter setup could look like.

6.3.4 Structure

One person explained that as of now the structure of the vehicle is arranged on the basis of a project rather than component-based. This means that, for example, the wiper stock or other component that can exist in multiple vehicles looks different in the structure. For example, in an XC60 and XC90 the component will be structured differently even though it is the same component. This once again goes to the fact that users long for alternative structures. Many people said they wish there was a QL-file that was structured in an an alternative way, more suitable for their work. For example, when you want to select the door today, you need to pick first the speaker, the 'Body In White', the isolation, etc. Instead, people want it to be organised as a 'left front door'.

In addition, the structures currently in use are not as self-explanatory as they could be. In conversations with users, few were able to distinguish between the different structures of QL-files currently in use. This is an issue according to one person because people are using the wrong structure, which is creating problems downstream.

6.3.5 Analysis Functions

Many people use the visualisation tool for different types of analysis, for which they need different functions, presented visually in Figure 6.12. The most mentioned functionality was to be able to measure things, and it would also be appreciated if some more advanced measurement tools could be implemented. An example of a more advanced measurement tool could be the possibility to measure gaps, both the length and the different distances throughout the gap.

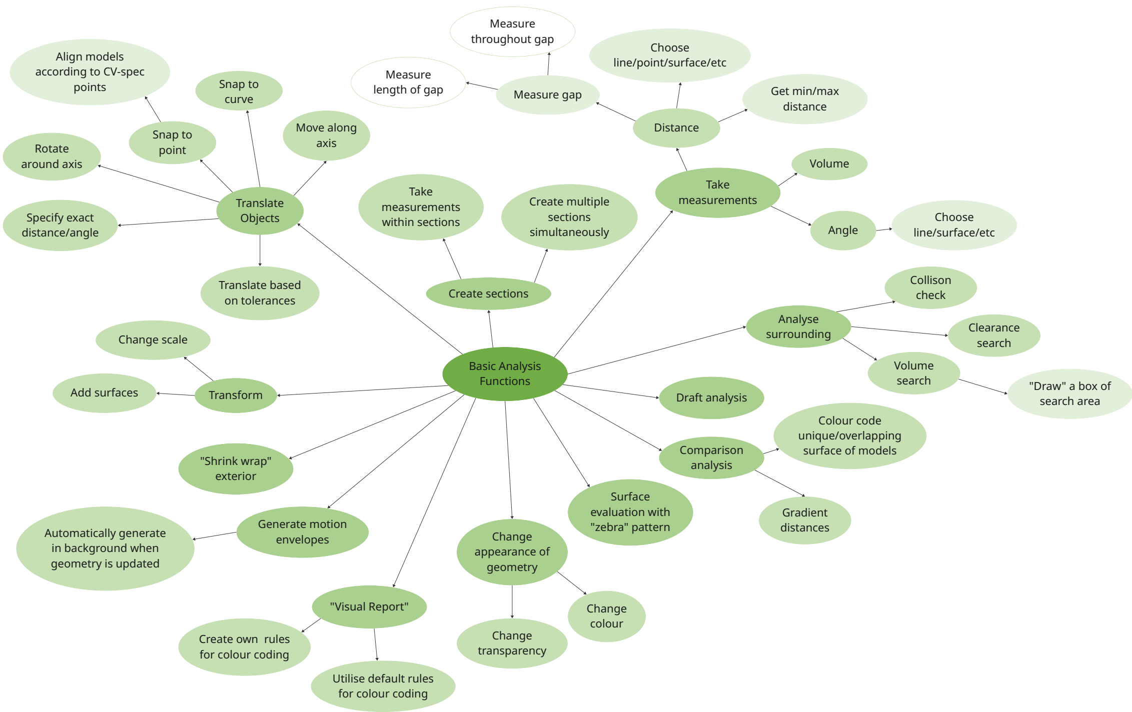

Figure 6.12: Analysis functions that should be available in the visualisation tool.

Another functionality that could improve workflows is the generation of motion envelopes within the visualisation tool. Motion envelopes are geometries that represent all the positions a component can reach, whether it is intended to move, like wheels, or moves unintentionally due to external influences such as vibrations. The front wheels, for example, can turn both ways to a certain angle but can also move up and down with the suspension. To ensure that these components have the ability to

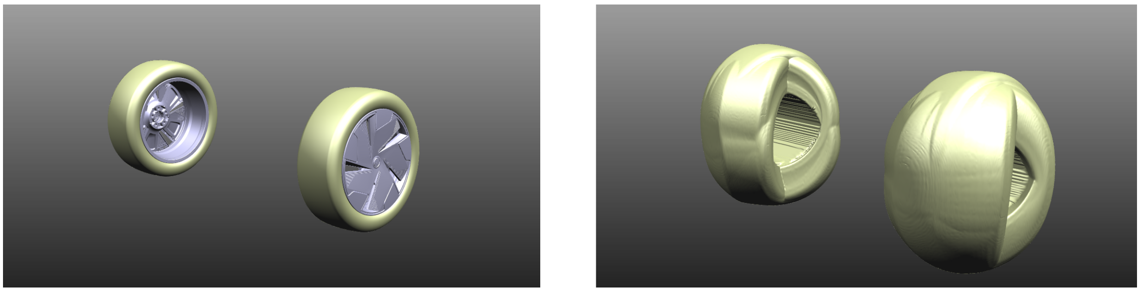

Figure 6.13: The 3D geometry of the wheel to the left, compared to the motion envelope of the wheel to the right.

move and that no other components will interfere with movement, motion envelopes are generated and then used to support the packaging. An example of a motion envelope for a wheel is shown in Figure 6.13

One of the most mentioned and appreciated features of TC Vis was ‘Visual Report’, which is described in Section 2.3. A similar functionality, that allows the user to colour code geometry based on metadata, must exist in the new visualisation tool. In this tool, it should be possible to use ‘default’ rules, but also possible to create your own rules and share them. In the user needs list in Appendix C, metadata that should be available have been listed, the 3D geometry should then, in an easy way, be possible to colour code based on these parameters.

6.3.6 Adaptability

Some interviewees mentioned the adjustment of tools in order to fit their desired way of working, while others mentioned the possibility of changing the way people work to adapt to new tools. Primarily, people seem to want the tools to be adjustable, and they appreciate the tools that can be tailored to their needs. It should therefore be possible to code your own solutions in the tool. It was mentioned that a commonly known programming language should be used, preferably Python. Furthermore, it was also mentioned that it should be easy to ask for adaptions from the supplier if one cannot code themselves.

6.3.7 Intuitiveness

Many users expressed concerns about the intuitiveness of the current software, TC Vis. It was perceived as not user-friendly or easy to navigate. According to the literature studied in Section 3.1.3, intuitive interfaces are critical for efficient user interaction. A common desire among the interviewees was for the new software to be more intuitive, allowing users to get started without requiring extensive training. Several people emphasised that using the programme should not require attending a multi-day course just to perform basic tasks.

There was also a discussion about the design of the interface. Some users preferred an interface similar to CATIA, as it is familiar, which is consistent with what is presented in Section 3.1.3, that an interface that uses familiar symbols and a consistent layout helps the user to recognise functions faster and reduce learning time. However, other noted that CATIA itself is not particular user-friendly or intuitive, showing that familiarity does not always translate into ease of use. One person mentioned that interfaces where actions can be completed with a single button press often feel simpler and easier to use, but may also be more limited. This raised the issue of balancing the number of available tools with the number of clicks required to perform an operation. There appears to be a fine line between having too many buttons that clutter the interface and having too few, which may restrict functionality. This will be important to consider in the new tool.

Furthermore, it was noted that the new software should be accessible even to users without a technical background. This includes managers and others who may not work regularly with CAD or PLM tools. The interface should be logical and intuitive enough for a broader audience to use effectively.

It was mentioned that one source of annoyance with TC Vis is that the rotation and panning functions are not similar to that of CATIA. Furthermore, it was wished that the placement of the functions should, preferably, be similar to that of TC Vis as that is where you will start to look when entering the new software. The wishes of having things similar to both CATIA and TC Vis could be contradicting, and with the case that Dassault Systéms is the supplier for both CATIA and the new visualisation tool, it will probably be more similar to CATIA.

The findings presented on intuitiveness align closely with the research discussed in Section 3.1.3. These play an significant role in enhancing the intuitive understanding and interaction of users with the tool.

6.3.8 Performance

The performance of TC Vis has sparked mixed reactions among users. Some praised it for being exceptionally fast, especially compared to traditional CAD software, while others reported that long loading times significantly disrupted their workflow. The division depended to some extent on what the user was viewing within the visualisation tool. For instance, most users agreed that visualising a single vehicle works smoothly. However, problems arise when multiple cars are loaded simultaneously, support structure is used, or when analytical tools, such as rendered section views, are used.

Several users report that TC Vis often crashes or freezes, especially when large searches are performed or when particularly heavy files are activated. This challenge is similar to what is mentioned in Section 3.2 about technical limitations affecting adaptations of digital tools and that this can affect the perceived usefulness of the tool. Many expressed frustration with frequent slowdowns and instability, stating that these issues disrupt their workflow. However, during the TC Vis course, the instructor pointed out that in almost all cases where the software froze, it was due to user error such as sending the search tool in a loop or attempting to load more data than necessary. This highlights the need for better education or perhaps safeguards within the software to prevent such issues.

As mentioned in Section 6.1.1, there are problems when moving between buildings. It would be beneficial if the sessions could be run in a remote environment. Today, this is done, for example, with CAE calculations and ‘heavy’ realistic renderings. Having the session remote would make it easier to move between buildings and meeting rooms without risking losing things you have prepared.

7 Strategic Recommendations and Practical Implications

The chapter begins with recommendations on education and knowledge sharing, followed by general guidance on implementation. Finally, suggestions on how to improve communication and collaboration will be presented. Although this study was conducted at Volvo Cars, the recommendations in this chapter are based on recurring themes that have emerged both in the interview study and in the literature. The identified challenges and user needs, such as the demand for intuitive tools, correct and up-to-date metadata, and efficient workflows, are typical in organisations that work with development of complex products. Therefore, the following recommendations are presented in a generalised format, with applicability beyond the specific case at Volvo Cars that has been studied.

7.1 Education

A common theme seemed to be the lack of education, or knowledge, about the tool. Multiple interviewees mentioned that they think the tool has more functionality, but that they do not know about it. Furthermore, some interviewees expressed the need for functions that already exist. Another thing that was often mentioned was different workarounds to achieve certain results, but in cases where a tool exists that can create that result. This suggests that there may be a lack of knowledge about the possibilities within the tool.

In general, the interviewees seemed open to learn more about the tool to be able to do more advanced things and use it more. An interviewee also mentioned that many people want to learn, but that if you do not use it in your day-to-day work, it can be a bit abstract and difficult to get used to.

As mentioned in Section 5.2.1, courses today are very pedagogical. When planning and conducting new courses, they should be done in a similar manner. This should be considered both when it comes to applied learning, as well as when the teacher uses 'marking tools' to circle and point to things on the screen.

7.1.1 Introduction to TC Vis

When asked about how they were introduced to TC Vis, the responses varied. Some people said that they had just been put in front of a computer or taught by a colleague. Others had undergone education when Teamcenter was first introduced at Volvo Cars almost 20 years ago. The most common response was that they had attended one of the internal courses *Teamcenter Author* or *Teamcenter Viewer*, which was further described in Sections 4.2.1 and 5.2.1. Neither of the interviewees had attended any of the specific TC Vis courses, TC Vis level 1 & 2.

Several interviewees mentioned having forums or spontaneously sharing knowledge and tips with colleagues. Some had a 'Tips & Tricks meeting' focused on sharing skills, while others mentioned group chats in Teams or simply turning around in the office and talking. This type of informal exchange can be facilitated by, and highlights the importance of, informal relationships and lateral relations, as discussed in Section 3.5.

7.1.2 How to Work with Education

The education when introducing 3Dx will be of importance. For people to feel comfortable with the tool, they need knowledge about it. One person mentioned that a previous tool had been deemed too complicated for some users. It could be suitable to offer various courses based on roles or areas of work in addition to adaptations and user roles within the tool. By doing so, the courses can be kept relevant and cover the important tools. An interviewee explicitly expressed the wish of tailored courses, but also stated that it would be important that Engineering Managers received the same education or at least could acquire similar knowledge about the tool and its functionalities, as their employees, in order to work properly.

In addition, one interviewee mentioned that having an incentive is essential to learn new software. The current level of skill they possessed was attributed to being forced to learn and remain curious in a previous role. It was also noted that, in a line manager position without technical responsibilities, there would likely have been less motivation to engage with the software and learn it. This highlights the importance of creating motivation and perceived usefulness for learning, as discussed in Section 3.2 as well as having a shared vision, as presented in Section 3.5.

7.1.3 Skill Sharing Opportunities

Today, a methods portal exist on the intranet, which some interviewees also mentioned using. In the portal, documents can be found that describe how to perform various tasks in TC Vis. A similar portal will be needed for the visualisation tool in 3Dx and should be up and running when 3Dx is introduced. In addition, a forum where people can share tips and tricks will be beneficial and should therefore be implemented. As mentioned earlier, multiple interviewees mentioned that they have formal or informal ways of doing this today. A central portal could also help limit the creation of 'silos' of knowledge. An interviewee stated that it is important to identify and share specific and deeper knowledge to avoid the creation of silos. This can be done by having effective cross-functional collaboration and systematically share knowledge between people and teams, as discussed in Section 3.5.

Some interviewees mentioned that they had been more skilled previously, but since they often did not use all functions, they forget. It could be a good idea to offer 'refresh-courses' that people can attend, similar to the customisable course offered today, mentioned in Section 5.2. It was also mentioned that you quickly get used to the tools and 'moves' that you usually use and therefore do not seek new or more effective ways to do things.

7.1.4 Technology and Way of Working

One topic that was mentioned by several interviewees was the aspect of relevant education on new technologies and ways of working. An interviewee mentioned that their manager did not really understand the difference between VR and AR. This manager is probably not alone in having this knowledge gap, but to fully utilise the potential of these technologies and make adequate decisions about them, the knowledge gap needs to be closed. As new technologies are made available, it is important to educate employees about them, both the benefits and potential, as well as the possible drawbacks and how to use the technology in a good way. One technology might be suitable for one case, while for the next case another technology is the best choice. VR was explicitly mentioned in this case as a tool that can be really helpful but also, in some cases, risks being misleading. This highlights the importance of proper and targeted education as presented in Section 3.1.1. This is especially important when introducing exciting new technologies that many people might want to try.

7.2 Implementation

As mentioned above, the education of employees before implementing 3Dx will be of significant importance. Sufficient education, adapted for the different user roles, can help set the users up for success, an aspect that is supported by what is presented in Section 3.2, which emphasises the role of user readiness when implementing new technologies. In addition to the education of the employees, some other steps and recommendations have been identified to make the implementation process as smooth as possible.

One of the interviewees suggested that a priority list of the different functionalities should be created. This could help to implement the most important functionalists first. However, the most desirable way, which is also the goal, as mentioned in Section 2.2, would be to achieve the same level of functionality as the previous tool from the beginning.

It will be important to promote 3Dx and the visualisation tool to show the potential, both before and during the implementation process. This will make people curious and hopefully more eager to transfer to 3Dx. When asked if they had tried the VR function in TC Vis, interviewees said no, it was also found that people did not know or had not even thought about using it. This indicates that the promotion of that tool might have failed. Another example is that an interviewee mentioned that even though they knew that new tools had been made available in TC Vis, they had not changed their way of working. They did not elaborate on the reason, but it could highlight the need for education, ‘word-of-mouth’, and awareness raising when new tools are introduced. If people are unaware of what the tools can do, how to use them, or the potential benefits, they are less likely to adopt them or adjust their workflows. This could lead to people being stuck in old, inefficient ways, when, in reality, better ways are available. When 3Dx is introduced, promoting the different functionalities can be a way to get people curious to try it and to get people to reflect on their methods and ways of working, which could potentially lead to more effective workflows. It would also be wasteful to spend time and money on acquiring advanced software and tools if, in the end, they will not be utilised.

7.2.1 Inclusion of Users

It will be of great importance to listen and include users in the implementation process, which also is emphasised in the literature presented in Section 3.3 that discusses the importance of stakeholder involvement. The feasibility study mentioned in Section 2.2 is an example of a step taken to include users. This interview study has been another way to include users and make sure that their opinions are heard.

During an interview, it was mentioned that another tool, developed internally, had been very appreciated by those who had the opportunity to influence the development. An interviewee mentioned that they had stopped using another tool as it no longer supported the functionalities they needed. These two cases should be seen as learning opportunities about how this implementation should be conducted. It will be very important to listen to employees about what functionalities they want, and this dialogue must also continue after the implementation to keep people on the platform when their needs or ways of working change. Including the employees that will be affected by the change can lead to more people being comfortable with the new tool and thereby also more willing to use it. Furthermore, this can help both to decrease the amount of resistance and to identify possible pitfalls, as discussed in Section 3.3.

Some of the interviewees were very curious and eager to learn. These people were also enthusiastic about new opportunities. These types of persons in the organisation should be identified when implementing 3Dx. They should receive training and access to 3Dx prior to the main ‘rollout’. There could be multiple benefits by doing this. Firstly, these people would become ambassadors for change in their respective departments. If they talk positively about the new tools and the change, it can help to get more people excited about the transition. Secondly, they could act as knowledge hubs. If people feel insecure or want to learn something in the new tool, it can feel easier to go and ask someone they already know about tips rather than reaching out to a central support group. Lead users could be a way to incorporate an aspect of ‘bottom-up’ work with the change, as mentioned in Section 3.3.

Finally, it was mentioned that when new projects are started or big changes are coming, it is really important that everyone gets to speak. Everyone needs to be provided with information and there should be opportunities to ask questions so that no one is forced into a system they do not understand. This is well aligned with what is mentioned in Section 3.3, that a change must be conducted both bottom-up and top-down; working bottom-up enables the employees to be involved and getting their voices heard, while working top-down can contribute with a common vision, also discussed in Section 3.5, that can guide the implementation.

7.2.2 Risks

One of the main things that could create annoyance among the employees would be if tools or functionalities that have been available in TC Vis or other tools now disappear. To reduce this risk, it is important, as previously mentioned, to include users and educate employees about the tool to ensure that people know how it works. This also relates to what is presented in Section 3.2, that different tools and methods are often used in different disciplines, and that one therefore needs to respect these differences when implementing a new tool or system.

Another risk that was mentioned was the case where functionalities in a tool are removed or changed. One interviewee mentioned that a button for direct export to Industrial Path Solutions (IPS) had been added to TC Vis, but that later the functionality was removed while the button was still visible. They stated that this was very annoying and caused confusion. Hence, it will be important that any changes made to the software, during or after the implementation phase, are properly communicated and that no ‘buttons’ without functionality are visible within the tool.

7.2.3 Expectations and Concerns

One of the most frequently emphasised expectations for 3Dx is improved speed and performance. Users indicated that the efficiency of their workflow is greatly impacted by the responsiveness of the software. Frequent pauses, sometimes as long as 90 minutes, to wait for the object to load significantly reduce productivity. One participant stated that ‘If the speed is improved, you are already taking a huge step towards a better solution’. Interestingly, some highlighted that performance is even more critical than feature completeness. A faster and more responsive tool is preferred to one that has every function but suffers from delays. As mentioned in Section 2.2, the first goal is to achieve the same functionality. However, these findings suggest that this may not be necessary if there is a significant improvement in speed. Independent of the chosen approach, it is important that it is clearly communicated.

Many users discussed the importance of having a centralised, integrated system. The hope is for a platform where historical data, decisions, and associated documentation are easily accessible and clearly connected. This would in turn result in a new opportunity to visualise status, maturity, and other linked information directly in the visualisation tool. This desire points to a broader theme that was mentioned in the interviews, as well as in the literature presented in Section 3.4, which is ‘one source of the truth’. When having one source of the truth, all relevant data is stored in a unified and traceable format, rather than fragmented across multiple systems and stored in layers. Thus, allowing the shift to only one software and making it easier to find information that you can trust.

The expectations of the actual switch from Teamcenter to 3Dx were that it would initially be messy. People are used to their tools and have a straightforward workflow that could easily be disrupted by the need to look for tools or alternative solutions. This was met with both worry and excitement; one user said ‘I think it will be super messy, but that is okay’ and continued to explain that they believe that ‘when you know one software, you usually know all the others’. Furthermore, they mentioned that when you use a new software, you usually learn 80 percent of the function after the first week, 90 percent after a month, and the rest usually takes years.

When using software like TC Vis in a complex product development environment like automotive industry, there will not always be tools that match your workflow. Therefore, companies often make their own solutions in-house and customise how the software works. This was something that several people mentioned they hope would become easier now when the supplier for the CAD and PLM is the same. Before, many functions and capabilities were lost because the two software could not talk seamlessly.

7.3 Collaboration and Communication

The idea of having workshops, or Community of Practice, where similarities in ways of working could be identified was mentioned by one interviewee. They also stated that now, when everyone needs to adapt to a new tool, there is a great opportunity to collaborate to identify similarities in workflows and develop common ways of working. This aligns with Section 3.5, and could help create lateral relations that can improve collaboration. It was also mentioned that this kind of collaboration could also be beneficial, since it would allow for identification of common needs, which can then be presented to the supplier to increase the chance of receiving needed adaptions or updates to the software.

7.3.1 Communication

It was also mentioned that it is not unusual that they use placeholders or educated guesses when visualising the vehicle. It is then important to be transparent regarding which results and surfaces are the ‘real’ and which are just placeholders. Examples could be a mock-up floor if testing interior light to avoid light leaking out, or an estimated door opening angle if that information has not been specified yet. Even if, for example, a door opening angle is based on an educated guess, there can be confusion if decisions are made based on this and the real angle turns out to be different. In these cases, it will be important to properly communicate what are ‘proper’ surfaces and what are placeholders to avoid misunderstandings.

Furthermore, it is important to communicate the purpose of renderings, and what aspects that are realistic and not. One interviewee mentioned that when their team shows other people realistic renderings, people often question them and say, 'But is this how it's going to be?'. They mentioned that even if they use a proper rendering engine, people are often doubting the results. They thought that it could have to do with the fact that people are used to one type of visualisation, for example TC Vis, and that they then have a hard time understanding other types of visualisation with other purposes.

Another interviewee mentioned that if you show too nice visualisations too early in the development process, you might get comments on the wrong things. An example was that people could mention things like 'I think that corner should be a bit rounder', when the purpose was to see how many 'clicks' that were required to perform a certain task on the screen in the car. The interviewee mentioned the importance of communicating purposes, and that when you look at a certain type of visualisation, you do not make comments about some things that are not the purpose of that visualisation.

7.3.2 Trust

The importance of trust and that you can trust that what you are looking at is the correct and latest version was mentioned by many, with some examples shown in Figure 7.1. This ties back to the discussion in Section 3.4 regarding the value of accurate, centralised information and version control. In relation to this, it was also mentioned that if you have to raise an issue about something, it is not good if you have looked at an old version and then go to a team and complain. That can cause unnecessary conflict and bad relations. Furthermore, it was mentioned that those who consume data downstream have to trust that the 3D geometry and data they get from the systems are correct. An interviewee mentioned that they know that it is not uncommon to receive incorrect information. With the systems used today, many people are forced to work with 'dead' data. Because of that, the risk of 3D geometry, or data, being incorrect increases significantly. It would be beneficial if everything was connected to one single source of 'the truth'.

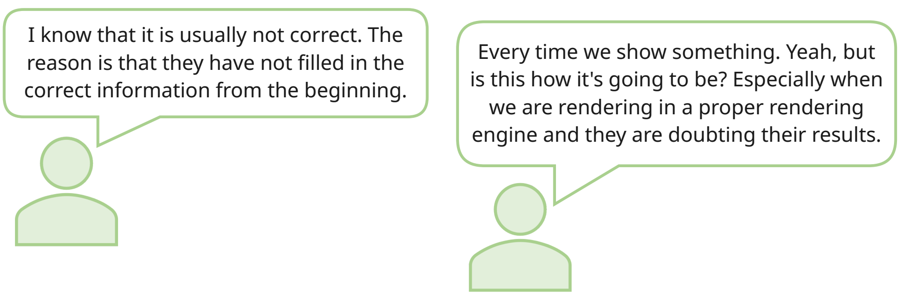

Figure 7.1: Quotes from interviewees regarding trustworthiness of info and the trust in results.

The fact that a lot of development and work is done iteratively and in different phases could also affect the trust of the 3D geometry and data. One person mentioned that they can see that something is incorrect or that there is a collision, but it takes weeks, or months, before the person responsible contacts them about it. The reason they stated was that they are working in a different phase where the position is not the main concern. This can create issues for people who consume the data during this period.

With regard to the education on new technologies, trust also plays an important role. When using unfamiliar technology, there is a risk that you will trust the result, even if it could be misleading. However, there is also a risk of not trusting a technology. An interviewee mentioned that there are cases, especially when working with very realistic renderings, that people rather trust themselves. According to them, people say things like 'This rendering is highlighting it way more than it will be in reality, this cable will not be visible', and then 'you are standing there with a clearly visible cable and people wonder how it happened'.

That the information available in the tools can be trusted is one of the most important things. It will be annoying if the data is missing; however, it can create even bigger problems if the faulty data is interpreted as correct. To increase the level of trust, the verification steps could be incorporated in the different processes throughout development. The problem presented in Section 6.1.1, concerning having one single source of 'the truth', also becomes relevant here. By decreasing the different sources one can find, perhaps contradicting, information about the product in, the available information becomes more reliable.

7.3.3 Attitude

A common theme was that other people were mentioned to not have completed their work, which then caused downstream problems. When talking about these people, the interviewees often described them as careless and that they easily could have done the work correctly, and on time, but just did not care to do it. This was also highlighted by the interviewee quoted in Figure 7.2. It is difficult to say whether this is true or not; however, the attitude from both perspectives is interesting. In general, a lot of people mentioned other departments or groups and stated that what they do is not good enough, which is an interesting phenomenon when it comes to attitude. This could be a barrier when it comes to cross-functional knowledge sharing, also addressed in Section 3.5. Working to improve lateral relationships and encourage informal networking could be a possible way to improve this collaboration.

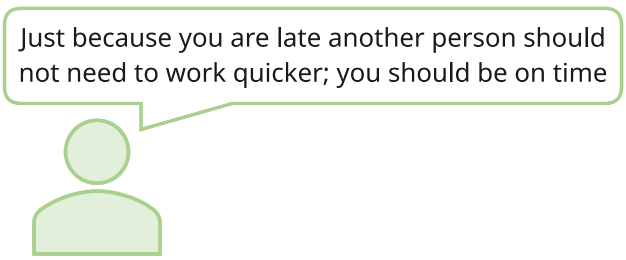

Figure 7.2: A quote from an interviewee mentioning that others should not be affected if one cannot do their work on time.

The dilemma of what is measured with respect to performance was mentioned; for example, one interviewee stated that you can be 'Green across all lists' but that it says very little about how complete the component is. The experience was that what they felt was important to do for the components to be improved was not measured in the same way as other, according to them, less important factors. The interviewee also mentioned the 'not so mandatory' things, such as issue handling and documentation, and that they do not have too much time to do those types of things when they have done 'what we are forced to'. They would rather skip administrative tasks to focus on 'actually improving our detailed design'. Furthermore, it was mentioned that they sometimes do not get complete information about a component, for example, the process of deciding material is not done so they get told to use a placeholder material. They are then blamed by other departments for not assigning the correct material. This could be an issue with transparency in processes and decision making. It can create a lot of frustration and conflict, both when you experience that others do not finalise what they should and when you get blamed for something that you cannot affect. The interviewee mentioned that when people come with a pie chart that shows what is missing, the interviewee roll their eyes in response. This could be because of misunderstandings and that they experience that their work is not valued as much or that they feel like other people do not care about their deliveries and get away with it, but they do not.

In many cases, it was also mentioned that other people are careless when creating 3D geometry and documentation and that they neglect aspects that are not important for themselves, but that then creates problems downstream. An example of this is surface normal. Having the right direction on the surface normal might not create a difference in some cases, but while rendering it becomes important. The requirements for how detailed and what information is needed can also differ between departments and areas of work, and therefore it is important to consider other areas than your own when creating information.

Although there were examples in which people called colleagues or other departments careless or said that they were focusing on the wrong things, there was also clear evidence of understanding between different areas of work. For example, an interviewee mentioned that the status 'New in Project' is not used as it should be, but that they understands that it is manual work, that the human factor affects and that it is probably often done by mistake. Some people also mentioned that they know that other departments, or groups, probably have a lot to do, which could explain why some things are not executed correctly; however, they still felt that it was annoying since it made work more difficult for other people.

These aspects suggest that a more common picture of the development process, and why different things are needed at different stages, could be needed. A more transparent process could help improve the understanding among employees in different areas and potentially help solve this problem. Finally, what was mentioned in Section 6.1.1 about that it is a system issue that people are allowed to deliver unfinished material should also be considered, it could be beneficial to look into solutions that hinder this.

8
Discussion

In this chapter, a deeper discussion is provided on how the methods used and the decisions made during the project could have affected the results. Furthermore, suggested next steps that Volvo Cars could take to continue the work with the implementation are presented.

8.1 Approach and Research Design

In this section, the methods used and how the study was carried out will be discussed. The potential effects of the decisions made will be discussed, as well as how alternative processes could have looked.

8.1.1 Sampling of Participants

While the Next Mech project in its entirety, with a great focus on the transition from CATIA V5 to CATIA V6, is highly targeted toward those working within detailed design, the visualisation tool is widely used in Volvo Cars. Therefore, the wide approach to sampling was deemed appropriate.

The initial sampling plan estimated that approximately 12 interviewees would be sufficient to reach saturation. However, this proved to be somewhat optimistic, and during the data collection phase the number increased to 17 interviews and 4 additional discussions, as detailed in Section 4.4.2. While complete saturation of all possible details was not the objective, primarily due to time constraints, the aim was to gather enough information to understand how needs and requirements vary between different work areas and user roles. Although some new details continued to emerge throughout the interviews, these findings still fit within the broader themes and categories that had already been identified. For example, an interviewee expressed a desire to change the transparency of a component, while another wanted to alter its colour; although these are distinct requirements, both belong to the broader category of 'Change appearance'. This suggests that while additional interviews might reveal further specific requirements, the general categories of needs and requirements have already been sufficiently captured.

Due to the wide sampling when it comes to areas of work, only one or two people have been interviewed within each area. There is therefore a risk that the people who have been interviewed are unique within their area of work and that their needs do not reflect the rest of the people within that area. However, since many needs have been communicated and shared between different areas of work, it is still judged that sampling has been good enough and that an acceptable level of saturation has been reached, even if there is a risk that specific needs in certain areas could have been missed.

As mentioned in Section 4.4.1, only two women have been interviewed. Ideally, more women would have been interviewed; for example, one could have reviewed the information about how many percent of the employees in the engineering departments are female, and aimed for the same percentage of females in this study. When it comes to the age distribution of the participants, presented in Section 4.4.1, it is judged that a wide enough sampling has been carried out. The mean age and median age being the same, while it differs 30 years between the youngest and oldest interviewees, shows that there is a great variation.

Although snowball sampling helped identify relevant participants across departments and made recruitment more efficient, it also carries certain risks. Participants tend to suggest colleagues they know or share similar views with, which can reduce the diversity of perspectives. It may also lead to an under-representation of individuals who are less connected or less vocal. In this study, steps were taken to ensure the variation between roles and areas, but it is still possible that some important perspectives were missed.

8.1.2 Interviews

As mentioned in Section 4.4.2, a standardised protocol has been used for all interviews. There are both potential benefits and drawbacks with this approach. One of the benefits is that the needs found and the described use cases can be easily compared between different interviewees and areas of work. This helps both to verify the findings and to identify similarities and differences in workflows. A drawback could be that if a topic was missed when creating the protocol, it was then missed in all interviews. Another aspect could be that what people express that they need is only ‘the top of the iceberg’ and there could be multiple latent needs that therefore have not been found. There was an idea to let all interviewees demonstrate a typical task they perform in TC Vis to incorporate an element of observation into the study. The hope was that this could possibly help to find eventual needs that the interviewees did not explicitly express, but the described issues with TC Vis being slow made this difficult.

Furthermore, as more knowledge was gained throughout the study, it became easier to ask follow-up questions and encourage the interviewees to elaborate by asking about, or prompting, different topics. This resulted in some of the latter interviews being more thorough and reaching more depth. However, the depth and information of each interview also depended heavily on the personality of the interviewee. The ideal situation would have been if more knowledge had been gained before the interview study, for example, by conducting more preparatory meetings. However, it would have been time-consuming and limiting the number of possible interviewees.

8.1.3 Analysis and Verification

As mentioned in Section 4.5.4 there could be a risk of bias. By choosing an exploratory approach and avoiding predefined categories for the analysis, the goal was to minimise the possible effect of the bias as much as possible. However, it would be ideal if this had been verified by an external party. Furthermore, pairwise comparison and continuous discussions throughout the analysis process were also judged to help minimise the effect of bias by creating opportunities to compare and question ideas and interpretations.

The plan was to verify the identified needs by inviting interviewees to focus group discussions. However, due to time restrictions, this was not possible. As several interviewees expressed similar needs, this provided a degree of corroboration within the study. However, it would have been desirable to include some aspect of verification with the interviewees to ensure that the needs had been interpreted correctly.

8.2 Sources and Results

In this section the selection of sources, and how they could have affected the study will be discussed. Furthermore, the adaption of the internal courses as well as the choice of presenting the needs in a user needs list will be discussed.

8.2.1 Evaluation of Sources

For the literature review, sources were, as described in Section 4.1, mainly peer-reviewed journal articles retrieved through Google Scholar. In addition, a few industry publications and blog articles were included to capture recent trends and perspectives within the PLM market, topics that may not yet be covered in peer-reviewed literature. These non-academic sources were used cautiously, with attention to their intent, context, and credibility.

8.2.2 Internal Courses

The internal courses attended played an important role in improving understanding of the user context and requirements. However, certain considerations must be taken into account concerning how the courses were adapted for this study and the exclusion of practical components.

Since two of the courses were merged into one and were organised exclusively for the study, the instructor was informed that the sessions would be documented and analysed. This may have influenced how the material was presented. It is plausible that a standard session, held under normal conditions, would have been less detailed or inclusive. Nevertheless, this potential bias is considered minimal, as the course content was based on existing presentation materials. Although the presentation may have been more elaborate, the information conveyed would have remained consistent with the standard sessions. These presentation slides are accessible to all users via the intranet, ensuring access before, during, and after the course.

Another factor affecting the content of the courses is the exclusion of the practical segment due to time constraints, as noted in Section 4.2.2. This may have led to certain content being skipped. To address this, the instructor summarised the practical components that normally are a part of the course.

8.2.3 User Needs List

Although the user needs list effectively captures the identified needs, it may not represent the full complexity of user expectations. User needs are often nuanced and may require additional context or explanation to be fully understood. Had the study continued with a verification phase, these limitations might have been revealed more clearly. In that case, the user needs list could have been complimented with a description or context which could support the meaning behind the need.

It is also important to note the difference between a user needs list and a formal requirement specification. Unlike a user needs list, which primary reflects user desire and expectations, a requirement specification defines precise software functionalities and performance criteria. To make the results more directly applicable and actionable for Volvo Cars, the user needs list would eventually need to be translated into a detailed requirement specification.

In the current phase of the NME project, where the focus remains on understanding user perspectives and exploring possible directions, the user needs list is appropriate. It emphasises the motivations and reasoning behind the needs rather than stating specific requirements. However, as the project progresses and the uncertainties are reduced, the transition from user needs to concrete requirements will be important for implementation and development purposes.

8.3 Limitations, Transferability and The Future

In this section, the limitations of the study and how the results could be applied in other contexts are discussed. Furthermore, next steps will be suggested when using the results in this study.

8.3.1 Limitations and Applicability of the Study

Although this study was conducted at Volvo Cars, the challenge of implementing new computer tools in organisations involved in the development of complex products is wide. The resulting user needs list is likely to be relevant to other organisations as well. However, adaptations may be required to reflect the specific characteristics, structures, and workflows of different companies.

One limitation of conducting the study at Volvo Cars is that certain user roles, which may exist in other companies but not at Volvo, could have been overlooked. Furthermore, the setting of the study in Sweden may have resulted in cultural assumptions that affect work practices, which may not be translated directly to other countries or contexts. Therefore, all recommendations might not be directly translated to other countries or contexts. Similarly, it will be important to understand the contextual problems and make necessary adaptations, as discussed in 3.2.

When applying the findings in other settings, it is important to compare the current situation in the target organisation with the description of the current state provided in Section 6.1. This comparison can help identify which elements of the findings are transferable and which may require adaptation to fit the local context.

8.3.2 Next Steps

As mentioned above, the planned steps of verification were skipped because of time constraints. The next step could be to verify the needs. One way could be similarly to what was planned, utilising focus groups with people working within different areas. Another way could be by comparing the needs identified in this study with the needs identified when TC Vis was implemented. However, it is possible that the needs have changed and therefore it could be a risk to use previously identified needs as verification, so it would be necessary to be careful.

In addition, the opportunities within 3Dx should be further examined. By comparing the identified needs of this study with the features available in 3Dx, it will be possible to identify eventual gaps. In order to fill these gaps the options could either be to request additional functionality from Dassault Systéms, or see if one of the other tools used today could continue to fulfil the needs.

As mentioned in Section 7.2.1, it will be important to continue with the inclusion of users and to have an open dialogue. This will both help the implementation of 3Dx and, in the long term, fulfil the needs experienced by the employees as they continue to change.

9

Conclusion

The purpose of this study was to examine the needs that exist in relation to the visualisation tool in the development of complex products. To find this information, an interview study was conducted at Volvo Cars with the objective of answering two main research questions. The first question focused on the needs that exist, aspects people would expect to be solved with the visualisation tool. A total of 17 interviews resulted in a user needs list that contains almost 250 needs. The users of the visualisation tools are spread out across large areas of the organisation, and the purposes vary from physically locating components or conducting packaging studies to realistic renderings and VR simulations. When it comes to how needs vary between different users, they are quite similar. Although the use cases differed, most of the tools used were similar between interviewees, resulting in many shared needs. Finally, there are opportunities for many new users.

The second question aimed to see if there are any potential new areas where the visualisation tool could be used. Primarily, areas where education about the tool was lacking were identified. Many possibilities exist within the tool used today, but few know about them. By educating more about tools and making sure that employees know about their opportunities, there is great potential to use visualisation in more areas. Furthermore, the possibility to use colour-coded visualisations in order to easily get an overview of the status of 3D geometry was widely mentioned as a potential area where visualisation can be beneficial.

Many needs exist when it comes to the use of 3D visualisation in the development of complex products. However, many of these have been found to be common between different departments and roles. With proper education and a continuous dialogue with those affected by the change, the chances of a successful implementation of the new visualisation tool are high.

This thesis also demonstrates how user-centred approaches, grounded in stakeholder inclusion and theoretical models of change, can be valuable in digital transformation efforts. By combining the insights from the interview study with theory, the thesis offers a framework for how similar challenges can be approached in other organisations. The recommendations formulated are general and thereby applicable beyond the Volvo Cars context, as they address challenges that are common in many product development organisations.

In summary, this study has identified specific needs related to the use of visualisation tools when developing complex products. Furthermore, it highlights the importance of understanding users and their needs, promoting knowledge sharing, and involving stakeholders early in the implementation of new tools. Aspects such as training, collaboration, and role alignment have also been identified as highly important. The presented findings are essential not only for local success in the case studied, but also for enabling broader organisational change.

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A

Interview Protocol

Interviewer: Secretary:

Interviewee:
Date:

Thank you for participating in this interview, we will ask some questions about how you utilise TC Vis in your day-to-day work, and you are more than welcome to elaborate and fill in with extra information that we haven't explicitly asked about. If it is anything you mention that you explicitly know is covered by secrecy you can add that so we know, otherwise everything will go through a secrecy check by our supervisor before the information leaves Volvo.

To start with, we want to ask if there is anything you want to clarify or add regarding the questions we sent out beforehand?

Demographic Questions (sent out beforehand)

- Age:
- Educational background:
  - University:
  - Graduation year:
- Current Role:
  - Years in current role:

Icebreaker question(s)

How are you today?

What is your favourite part of your job?

When did you start at Volvo?

Interview questions

How were you introduced to TC Vis and how to use it?

What types of tasks do you use TC Vis for?

Which feature do you appreciate, or use, the most?

What would you like to improve?

Is there anything you miss, that you wish you could use TC Vis for?

B

Confidentiality Agreement

CONFIDENTIALITY AGREEMENT

REGARDING THE PROTECTION OF PERSONAL DATA WITHIN VOLVO CARS

The undersigned, _______________________ (name), employed as Thesis worker by Volvo Cars ("**Volvo Cars**"), having, in such capacity, access to and/or duties in relation to the personal data processed by Volvo Cars (hereinafter „**Personal Data**"), hereby acknowledge the confidential nature of the Personal Data and undertake the below confidentiality obligations:

a) I shall make all efforts in accordance with my job duties, in order to protect the confidentiality of all Personal Data to which I have access and to prevent disclosure of such Personal Data to persons not expressly authorised to receive such Personal Data;

b) I shall not use the Personal Data to which I have access for any other purpose than to fulfil my duties;

c) I shall not give access to the Personal Data to unauthorised persons;

d) I shall not duplicate the Personal Data or make any copy thereof that is not necessary to fulfil my duties;

e) I shall make all efforts as a professional in my field of business, taking into account the technical means available to me, to prevent any fraudulent use, destruction, loss or unauthorised change of the Personal Data;

f) I shall ensure, taking into account the technical means available to me, that I communicate or transfer the Personal Data only through means that can ensure their security;

g) I shall immediately inform the Company of any situation I become aware of, that may threaten the confidentiality of the Personal Data, including without limitation attempts of unauthorised access, malfunctions of equipment used for the processing of Personal Data, as well as any other actual or threatened accidental or unlawful destruction, loss, alteration, unauthorised disclosure of, or access to, Personal Data transmitted, stored or otherwise processed; and

h) Upon termination of my employment, I shall return the Personal Data I have had access to, regardless of their means of storage.

I acknowledge that this confidentiality agreement shall be applicable throughout the performance of my duties within Volvo Cars, as well as thereafter for an unlimited period of time.

Violation of this Agreement will subject Employee to disciplinary action according to Volvo Cars' disciplinary policy, up to and including termination and may result in civil or criminal liability as the case may be.

Signature Thesis Worker

____

Date

____

C

User Needs List

User Needs List	
Number	**Need**
0.1	Seamless integration to CAD
1	Metadata/Attributes
1.1	Link to Information About Quality History
1.2	Link to Change Orders
1.3	Link to History of part
1.4	Possibility to link other metadata than default
1.5	Possibility to display metadata in columns
1.6	Colour coding based on metadata
1.6.1	By different attributes
1.6.2	By missing / not missing attributes
1.7	Right click on model to display Metadata
1.8	Visualisation tool should contain up to date, correct info
1.9	Link to if physical component was / was not used in Pre-series production
1.10	Functionality to summarize metadata of displayed geometry
1.10.1	Revision and history based summary
1.11	Possibility to open context around geometry
1.12	Export metadata to Excel
1.13	Search/filter based on Metadata
1.14	Sync (special) surface material library to new 3D geometry
1.14	Correct and up-to-date Metadata
1.14.1	3D PMI
1.14.1.1	Desired Gap Sizes
1.14.1.2	Rotation axis
1.14.1.3	Thickness of material (sheet metal)
1.14.1.4	Surface Material
1.14.1.5	Texture of Surface
1.14.2	Material
1.14.2.1	Material Definition
1.14.3	XMQ Data
1.14.4	Weldability
1.14.4.1	Coating on Steel
1.14.5	Weight of Component
1.14.6	Principle Moment of Inertia
1.14.7	Center of Gravity
1.14.8	Dimensions of model
1.14.9	Colour
1.14.10	Carryover
1.14.10.1	Previous Contexts (Car Projects)
1.14.10.2	New in Project
1.14.10.3	PMXU Status
1.14.11	Part number
1.14.11.1	Other part numbers the geometry goes by
1.14.12	Function Group
1.14.13	Cost
1.14.13.1	Estimated Cost
1.14.14	Supplier
1.14.15	Owner
1.14.16	Creator

1.14.17	Who released
1.14.18	Status of CAE Verifications
1.14.19	Age of Model
1.14.20	Revision
1.14.21	Part Validity
1.14.22	Current Issue / No Issue
2	VR & AR
2.1	VR functionality
2.1.1	Simpler environments available
2.1.2	Possible to move around
2.2	Lightweight Graphics
2.3	AR Functionality
2.4	Sufficient Education about VR & AR to use it properly
2.5	User Friendly
3	Rendering
3.1	Image Shaders
3.2	High Quality
3.2.1	Surface Material
3.2.1.1	Texture
3.2.1.2	Glossiness
3.2.1.3	Refraction
3.2.1.4	Scanned Material Data
3.2.2	Resolution of Result
3.3	Choose Colour(s)
3.3.1	Neutral "out of focus" material
3.3.2	Highlight colours "focus rendering"
3.3.3	Zebra (surface evaluation)
3.4	Options for mapping, ex. UV-mapping
3.5	Realistic Rendering
3.6	Possible to choose what to render
3.7	Animation
3.7.1	Export renders to PNGS sequences
3.7.2	Key Frame Animation
3.8	Raytracing
3.9	Different Camera Settings
3.10	Equal functionality to V-red
3.11	"Quick" rendering
3.12	Render one/both sides of a surface
4	Collaboration
4.1	Possible to use custom filters made by others
4.2	Live data (3D geometry)
4.3	Centrally stored data
4.4	Possible to share session files or groups
4.4.1	Add/change geometry and send back
4.5	Work in the same environment
5	Issue Management
5.1	Assign Issues to 3D geometry
5.2	Link to Issue from 3D geometry
5.3	Generate context around Issue
5.3.1	Link in Issue to Context in Visualisation tool

5.4	Shortcut to "Create Issue" by right-click on geometry
5.5	Issue History for Components Available
6	Save
6.1	Save changes made in Visualisation tool to CAD file
6.2	Possibility to save Session files (with links to "real" info)
6.2.1	Possibile to sync/update session files to recieve new 3D geometry
6.2.2	Save files in a way that can be sent to suppliers/consultancy firms
6.3	"Freeze" a model to hinder geometry from changing
7	Export
7.1	Export to multiple file formats
7.1.1	STEP
7.1.2	PMXML
7.1.3	CGR
7.1.4	FBX
7.1.5	USD
7.1.6	JT
7.2	Easily Export/Launch directly to different tools
7.2.1	IPS
7.2.2	CATIA
7.2.3	DeltaGen
7.2.4	Unity
7.2.5	Blender
7.2.6	VRED
7.2.7	RDnT
7.2.8	Process Simulate
7.2.9	SPEOS
7.3	Export with metadata
7.3.1	Choose which metadata is exported
7.4	Export rotatable geometry to PowerPoint
7.5	Automated export for PKI pictures
7.6	Choose quality for export (ex. Lightweight for VR)
7.7	Notify when new export/sync is needed
7.8	Automated sync to different tools
8	Import
8.1	Import surfaces from CATIA
8.1.1	Ramsys
8.2	Import from DMU garage ("ready" vehicles)
8.3	Import simulation results
8.3.1	IPS
8.3.2	RDnT
8.4	Surroundings
8.5	Test Object (based on test object order, ex. old revisions)
8.5.1	Import Pre-HPD data
9	User Roles
9.1	User roles depending on area of work
9.1.1	Manager Role (easy to find info)
9.2	Possible to find/search for tools outside your "role"
9.2.1	Add other functions to your "dashboard"
9.3	Possible to switch between different (allowed) user roles
9.4	Settings for which role can see a certain level of info

9.4.1	Allow more people to see more info as the project proceeds / at release
10	Filter
10.1	Only exterior components
10.2	Only Visible Components
10.3	Project
10.4	Revision
10.5	Material
10.6	Weight
10.7	Show all possible configurations / variants of components
10.7.1	"VIDA filters"
10.8	Commonality (when multiple cars are loaded)
10.9	Carryover
10.9.1	PMXU Status
10.10	Standard Components
10.11	Filter on Current Issue / No Issue
11	Structure
11.1	Toggle tree structure
11.1.1	E-BOM
11.1.2	P-BOM
11.1.3	A-BOM
11.1.4	Componets groups (ex. Doors)
11.2	Toggle Leaf Structure
12	Search
12.1	Search Box
12.2	(AI Powered) "Missing components" search
12.3	Previous Solutions Search
12.4	Advanced Search
12.4.1	Filters for metadata
12.5	Associated Items Search
13	Models
13.1	Complete Vehicle
13.2	Accessories
13.3	Restriction Models
13.4	Benchmarking models
13.5	Multiple (Vehicle) Models at Once
13.5.1	Generations
13.5.2	Variants
13.5.3	Design Themes/releases?
13.5.4	Different Programs
13.5.5	Platforms
13.6	Equipment
13.7	Fixtures
13.8	Single models - chosen one by one
13.9	Possible to choose to load in same or new window
14	Analysis Functions
14.1	Take Measurements
14.1.1	Distance
14.1.1.1	Choose line/point/surface/etc
14.1.1.2	Get min/max Distance
14.1.1.3	Measure gap

14.1.1.3.1	Measure throughout gap
14.1.1.3.2	Measure length of gap
14.1.2	Volume
14.1.3	Angle
14.1.3.1	Choose line/surface/etc
14.2	Create Sections
14.2.1	Create multiple sections simultaneously
14.2.2	Take measurements within sections
14.3	Translate objects
14.3.1	Move along axis
14.3.2	Snap to curve
14.3.3	Snap to point
14.3.3.1	Align models according to CV-spec points
14.3.4	Rotate around axis
14.3.5	Specify exact distance/angle
14.3.6	Translate based on tolerances
14.4	Transform
14.4.1	Change Scale
14.4.2	Add surfaces
14.5	Analyse Surrounding
14.5.1	Clearance Search
14.5.2	Volume Search
14.5.2.1	"Draw" a box of search area
14.5.3	Collision Check
14.6	Draft Analysis
14.7	Comparison Analysis
14.7.1	Colour code unique/overlapping surface of models
14.7.2	Gradient distances
14.8	Surface Evaluation with "Zebra" pattern
14.9	Change Appearance of Geometry
14.9.1	Change Colour
14.9.2	Change Transparency
14.10	"Shrink wrap" exterior - Merge exterior to one single surface
14.11	Generate motion envelopes
14.11.1	Automatically generate in background when geometry is updated
14.12	Visual Report
14.12.1	Create own rules for colour coding
14.12.2	Utilise default rules for colour coding
15	Assembly Simulations
15.1	Path Planning
15.2	Colour code construction attributes/requirements
15.2.1	Too close to edge / almost ok / ok
15.2.2	Reachable by tool / not reachable by tool
16	View
16.1	View CV-Spec
16.2	View VIBE
16.3	View Surrounding
17	Organise / Prepare
17.1	Create Groups
17.2	Create Snapshots - Save current setup

17.2.1	Reuse snapshots on other models
18	Maneuverability
18.1	Zoom
18.2	Rotate
18.3	Pre-defined views
19	Adaptability
19.1	Possible to code own solutions
19.1.1	Python
19.2	Easily request "Volvofied" functions
20	Intuitiveness
20.1	Familiar interface
20.2	User friendly
20.3	"Hover" over a button to display 1-2 sentences discribing the tool
20.4	Seamless integration to other SW
20.4.1	Intuitive which SW to change to
21	Performance of the Software
21.1	Quick to load models
21.2	Stop/warn if "faulty" or too demanding action is taken that could lead to crash
21.3	Sessions loaded remotely

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