CHALMERS

Implementing Composite Design Extension to Improve CFRP Design Process

Development of guidelines and evaluation of Fibersim and its impact on the automotive industry of composited

Bachelor Thesis in Design and Product Development

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Gothenburg, Sweden 2018

Bachelor thesis 2018

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Cover: Modified pages from the *Fibersim advanced guideline*, which came as an result of the thesis

Preface

This bachelor thesis is completed within the engineering program Design and product development (180 credits) at Chalmers university of technology and commissioned by the company Escenda Engineering AB. The extent of the thesis is 15 credits and was made during spring 2018.

First, we would like to thank Escenda for giving us the chance to work with this subject. It gave us great knowledge of the automotive industry and where it is heading with composites. Thank you Lars Bösinger for not giving up on us and helping us through the ups and downs during the whole thesis. We would also like to thank Peter Hammersberg for getting us through the hard times when not knowing how to get forward.

We would also like to thank:

- Siddharth Kumaraswamy
- Mats Brodin
- Joakim Ekedorff
- Gustav Danielsson
- Swerea IVF AB
- Everyone who participated in our survey

Emma Saldner & Victor Åkerblom, Gothenburg, June 2018

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Abstract

Carbon fiber reinforced polymer, or CFRP, has long been a researched composite material and its area of use is wide due to low weight, high stiffness and capability to build complex parts. The material has initially entered the automotive industry, but there are still many parameters that need to be solved in the implementation. One difficulty is to find the right competence of the design engineers who will work with it, as it can be hard to understand and predict how the material behaves in manufacturing without hands-on experience. But a software, called Fibersim, has been identified to potentially aid the problem. Fibersim is also considered to be able to influence the whole design process, due to its capability of running virtual draping analysis.

The purpose of this thesis was to evaluate the design composite extension Fibersim and examine and create guidelines as a manual to the software. The thesis was commissioned by Escenda Engineering AB with purpose to help them implement Fibersim in their organisation. It was also investigated whether Fibersim could be a stepping stone to improve the design process of CFRP parts in automotive industry in any way, for Escenda and their partners.

The outcome was a comprehensive guideline, called Fibersim advanced guidelines, which describes the most important tools and actions the program provides. To capture the possible gap of composite knowledge of the users, a detached introduction was made to ensure that the user understands the fundamental terms that are processed. The guideline and the introduction will be used by employees at Escenda and hopefully give the user enough knowledge to be able to use Fibersim on their own as a basic tool in future work. It was also found that Fibersim could improve the design process by reducing the number of mistakes made in the concept design work. As well as, due to its ability to merge data and generate complete outputs, ease the information flow throughout the process.

Keywords: CFRP, composite, design process, fibersim, guideline.

Table of Contents

1 Introduction 1

1.1 Background . . . 1
1.2 Purpose . . . 2
1.3 Objectives . . . 2
1.4 Delimitations . . . 2

2 Theoretical reference frame 3

2.1 Carbon fiber . . . 3
2.1.1 Creating a CFRP part . . . 4
2.2 CATIA . . . 4
2.3 Fibersim . . . 4
2.3.1 Ply book . . . 4
2.3.2 Draping analysis . . . 5

3 Method 7

3.1 Case study . . . 7
3.1.1 Literature study . . . 7
3.1.2 Interviews . . . 8
3.1.3 Kano Model . . . 9
3.1.4 Quality Function Deployment, QFD . . . 12
3.1.5 Design specification for guidelines . . . 13
3.2 Develop Ply Book in Fibersim . . . 13
3.3 Creating guidelines for Fibersim . . . 14

4 Result of case study 15

4.1 Result of literature study . . . 15
4.2 Result of interviews . . . 15
4.2.1 Interviews at manufacturing company . . . 15
4.2.2 Interview with CAE engineer . . . 16
4.3 Result of Kano model . . . 19
4.4 Result of QFD . . . 21
4.5 Result of design specifications for guideline . . . 22

5 Results of ply book in Fibersim 23

5.1 Boundary . . . 23
5.2 Material . . . 23
5.3 Zone and zone transition . . . 23

5.3.1 T-crossing zones 24
5.4 Ply book 26
5.5 Interconnections 27
5.6 CAE analysis 27

6 Results of guidelines for Fibersim 29
6.1 Disposition 29
6.2 Layout 30
6.3 Introduction 31
6.4 Technical verification 32

7 Discussion and conclusion 33
7.1 Evaluation of methods 33
7.1.1 Discussion 33
7.1.2 Conclusion 34
7.2 How the CFRP design process works today 34
7.2.1 Discussion 34
7.2.2 Conclusion 35
7.3 How Fibersim can simplify the design process 35
7.3.1 Discussion 35
7.3.2 Conslusion 36
7.4 How the guideline meet the user demands 37
7.4.1 Discussion 37
7.4.2 Conclusion of guidelines 38
7.5 Sustainable development 38

8 Recommendations 39

Bibliography 41

List of Figures 43

A Interview guide I

B Transcription Interview 1 V

C Transcription Interview 2 XIII

D Kano Questionnaire XVII

E Design specification XXI

Nomenclature

Buttjoint	Edge-to-edge transition between plies
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CATIA	Computer Aided Three Dimensional Interactive Application
CFRP	Carbon Fiber Reinforced Polymer
Dart	Cut made in a Ply
Draping	To shape and crop a material over a tool-surface
FEM	Finite element method
Ply	One layer of material fabric
QFD	Quality Function Deployment
R&D	Research and Development
Staggerprofile	Defines the transition between plies

1 Introduction

Following chapter contains the thesis background, purpose, objectives and delimitations.

1.1 Background

With the new emission requirements on cars, the design and selection of material needs to change for the manufacturers to reach them. It shows that if you reduce the weight of a car by 50 %, both the emission of CO2 and the cost during use would go down drastically (Granata Design Ltd, 2016). One way to reduce the weight to that extent is by changing the steel panels to carbon fiber. Another way to lower the weight is by decreasing the number of components in the car, a construction and design task. Today carbon fiber is often used in smaller production quantities and there is only a few companies that have managed to mass produce parts in CFRP. According to Marie Jonsson at Swerea, this is about to change (Pröckl, 2015). By its low weight and strong material properties, carbon fiber could be the next big thing for future vehicles. The disadvantages are the complexity of CFRP parts and that it is ten times more expensive than steel due to high material cost and the complicated stabilization and carbonization processes required (Matthis, 2016).

Escenda Engineering AB is a consulting company working in the automotive industry. They are currently working with a project of developing a car in CFRP. Escenda has therefore done an overview of which processes will be needed to apply the material into the automotive industry. One problem is to find the right competence regarding composites and how they behave during manufacturing. A possible step in the right direction is to start using a composite analysis program called Fibersim. The company has no earlier experience in it but are aware of the opportunities it could bring. By researching Fibersim and then developing a guideline to educate employees, Escenda believe that they can keep up with the forefront of the industry.

1.2 Purpose

The purpose of the thesis is to investigate how the design process of parts out of CFRP works today. As an example, a car door was used. That information will later be used to evaluate how a composite design extension to CATIA called Fibersim can be implemented and simplify the process. The program and its tools will be analyzed by creating a layup, a ply book and later see how well it cooperates with changes to the input part. The analysis will be summarized in guidelines to Fibersim. The guidelines will be designed to learn future engineers how to use the software and facilitate the creation of composite parts at Escenda and their customers. The guidelines should be general and applied to any creation of composite parts.

1.3 Objectives

The questions addressed in the thesis are the following.

- How does the design process for CFRP work today?
- How can Fibersim simplify the design process for CFRP parts?
- How should guidelines be designed to provide learning of Fibersim?

1.4 Delimitations

The thesis:

- takes place in spring 2018 and is limited to 15 credits per person.
- only looks at Escenda's and their partner's design process.
- carries out in uses CATIA V5 and Fibersim 15.
- only covers the R&D process of the design process, no physical product will be created.
- focuses on Fibersim's ability to simplify the process, not creation of the car door.
- includes no optimization of the layout of the door.
- will not investigate potential saved lead time or money as an affect on implementing Fibersim
- includes no economical considerations.

The guidelines:

- will not be a guide how to design with composite.
- will only describe the most valuable tools in Fibersim.
- require by user with basic understanding of composites.
- should not be specific to a car door but should be general to be applied to any parts.

2
Theoretical reference frame

In the process of implementing CFRP in the automotive industry, it is highly necessary to start with understanding the material and the benefits of its use. It can even be beneficial to understand it when reading the thesis. So, in the following chapter previous research of CFRP is presented, how parts are manufactured, as well as the softwares that will be used in the development process.

2.1 Carbon fiber

A composite is in general a combination of two or more materials that complement each other's properties to create a better material (Damberg, 2001). Fiber composites are often considered a complicated material that is difficult to calculate and expensive due to material cost and advanced manufacturing methods (Matthis, 2016). Nevertheless, it has been used in decades in the aerospace industry. Now, due to new technology, composites are becoming more and more common in industries like sports goods, boats and orthopedic prostheses (Composite, 2018). The properties of composite material may vary drastically in different fiber directions of the material, compared to steel that is an isotropic material. Common for all fiber composites is that they have strong material advantages. Among these are strength, young's modulus, lightweight and design freedom, which means enabled design of very complexed components.

A carbon fiber composite ply consists of two components, a reinforcement material and a binding material (Damberg, 2001). As reinforcement material, fibers of carbon is used. These fibers are thinner than a hair shaft and have three times the strength of construction steel. This is due to how the manufacturing process works. The carbon goes through different sequences of heating and oxidation, which aligns the atoms in planes with strong carbon-carbon bindings. The fibers is later woven into a fabric-like material or placed in unified direction and afterwards combined with the binding material. The binding material is often a thermosetting resin, but manufacturing with a thermoplastic is becoming more common. This change is due to the properties of thermoplastic, its recyclable and has faster hardening time.

2.1.1 Creating a CFRP part

Creating a carbon fiber part can be categorized in two different approaches (Damberg, 2001). Either using plies pre-impregnated with the binding material, called prepreg, or adding the binding material after placing the plies in the tool-surface. Using the last mentioned method requires more steps and the mixturing of the thermosetting resin may entail some hazards. After placing the plies in the tool-surface the part gets sealed in a vacuum bag. Through vacuum suction the polymer spreads and residual epoxy is extracted. Later everything is placed under heat and pressure for the part to harden. Using prepreg, the binder is already included and for proper curing sealing, pressure and heat are required.

When placing the composite fabric in the tool surface, wrinkling or bridging can appear if the shape is complex and the fabric cannot adapt to it. This can be fixed by applying darts, like cuts in the fabric, to make it drapable in the difficult shape. The fabric can also be divided into more parts, so that each part is drapable at its local placement.

2.2 CATIA

CATIA, or Computer Aided Three Dimensional Interactive Application, is a world leading CAD program that is actively used for product design in several different industries (Dassault, 2018). CATIA contains tools for composite design, which is used to calculate designs, through FEM, in terms of strength, weight, thickness and volume for example.

2.3 Fibersim

CATIA can cooperate with the composite design extension software Fibersim developed by Siemens. It enables development of optimal design through performed design and analysis in the context of manufacturing (Siemens, 2018). In the design process, Fibersim can be used to analyze the drapability of a composite design, which is linear with its producibility. It can also create a so called Ply book which provides instructions for manufacturing. The software are therefore considered key tools in the R&D process to improve the process of creating CFRP cars, according to Escenda.

2.3.1 Ply book

The ply book is created to help with the communication between design engineers and manufacturing. It gives a visualization of how the plies look on a 2D surface and were on the tool surface they should be located (Bass, 2017). It also includes in what order the plies should be placed, which material and if there are any specific tolerances for each ply.

2.3.2 Draping analysis

Instead of having to practical test if the fabric will wrinkle or bridge it is possible to do a digital draping analysis. This will show how the fabric behaves on the tool surface and if any cuts are needed (Bass, 2017). The analysis indicates how big the deformation of the fabric is and suitable adjustments can be made.

3
Method

To reach the thesis purpose and desired output, carefully considered methods for data collection and analyze were implemented. Overall, the thesis work is divided into two parts:

- Part of investigation
- Part of development

The first chapter, Case study, focuses on investigating how the CFRP design process works today. Furthermore, if and how Fibersim can be used to ease the process, investigation of current guidelines and what methods that were used. The first part of investigation will result in a design specification for the Fibersim guidelines. The second chapter is an investigation on how Fibersim works and cooperates with CATIA. That is achieved by generating a ply book in the software followed by an evaluation of which the most important tools are.

The third chapter then focuses on development of the guidelines, based on collected data from the investigation part. All methods, how they contribute to the outcome and how they were used, are presented in the following chapters.

3.1 Case study

The initial phase of the project was a case study which was made to define the case and to gain profound understanding about what is known today about the CFRP process and the industry. It also examines Fibersim as well as current use of guidelines and how they are designed. The case study begun with a literature study to go through current guidelines, its content and structure. Interviews, KANO Model and QFD were used to collect data from useful sources and to define a design specification for the guidelines. The case study creates a comprehensive basis for following methods.

3.1.1 Literature study

A literature study was made to state what type of guidelines are used in the company today and how they are designed. Access to internal guidelines for software was obtained, read and analyzed regarding communication ways, content and layout.

3.1.2 Interviews

To gain a deeper understanding about the design process for CFRP, interviews were held with persons from different parts of the process chain. That included a CAE engineer who works with the creation of a full CFRP car and a process most relevant to Escenda's. The other interviewed were a production manager and a production worker from an manufacturing company. They were included to understand what manufacturing needs from the engineering companies, which give them all basis for the production of parts.

The interview type was non-structured, which means that it was more of a discussion of a subject, instead of asking questions formulated in advance (Karlsson, 2007). An interview guide was designed and used, divided according to specific interview, as a support to ensure that relevant topics were raised. Interview guide is available in Appendix A. The purpose of the non-structured interview was to capture arguments and wide, describing answers. Follow-up questions could thereby be based on the given answers. That interview type usually gives qualitative data as result. The interview guide was structured to answer following topics:

- How does the design process work?
- Which step in the process works well?
- Which step in the process works bad or less good?

It was also asked about Fibersim in the interviews. Since the CAE engineer had experience of working with the software, it was asked of his opinion on it and its possible implementation in the process. To the production workers, Fibersim and its outcome were briefly described and afterwards asked about their thoughts about it.

All interviews were recorded so that the interviewer could focus on the discussion instead of keeping notes. The recordings were transcribed so that no opinion or data was left behind.

3.1.3 Kano Model

The purpose with the Kano Model was to identify, understand, categorize and prioritize a comprehensive range of customer requirements regarding guidelines in general (Walden, 1993). The method helped to describe how customer satisfaction and needs depend on each other. It also investigates how users value different product features or characteristics.

The Kano Model contains five steps to develop and analyze the survey, presented below.

I. **Develop the questionnaire**
The developed questions were called Customer self-stated importance questions and are two part questions for each potential requirement:
Functional - how the user feels if *feature* is present in product.
Dysfunctional - how the user feels if *feature* is not present in product.
That type of questionnaire contributes the survey with further prioritizing among customer requirements and to avoid providing the user with something unimportant.

II. **Test the questionnaire**
Iterative process of revise and re-test the questionnaire so that it appears unbiased and to avoid unclear statements.

III. **Administer the questionnaire**
Questions were shared in various mediums to reach a wide target group. A log of results was maintained.

IV. **Process the results**
The result was presented and categorized in a Kano Evaluation Table by tabulating the scores for each requirement according to figure 3.1.
Consumer requirement is:

Consumer → Requirements		Dysfunctional				
		1. Like	2. Must-Be	3. Neutral	4. Live with	5. Dislike
Functional ↓	1. Like	Q	D	D	D	O
	2. Must-Be	R	I	I	I	M
	3. Neutral	R	I	I	I	M
	4. Live with	R	I	I	I	M
	5. Dislike	R	R	R	R	Q

Figure 3.1: Calculation model for Kano Evaluation Table

D: Delighter
I: Indifferent
M: Must-Be
R: Reverse
O: One-Dimensional
Q: Questionable Result

V. **Analyze the results**
The result from Kano Evaluation Table was analyzed and satisfaction index (SI) and dissatisfaction index (DI) were calculated. Requirements were defined into five different categories:

Must-be - Expected demands by users, without it no one will use it
One-Dimensional - Not expected by user but increases satisfaction if present
Delighter - Appreciated but not missed if excluded
Indifferent - User does not care if it is present or not
Reverse - Negative interaction with other demand - should be excluded

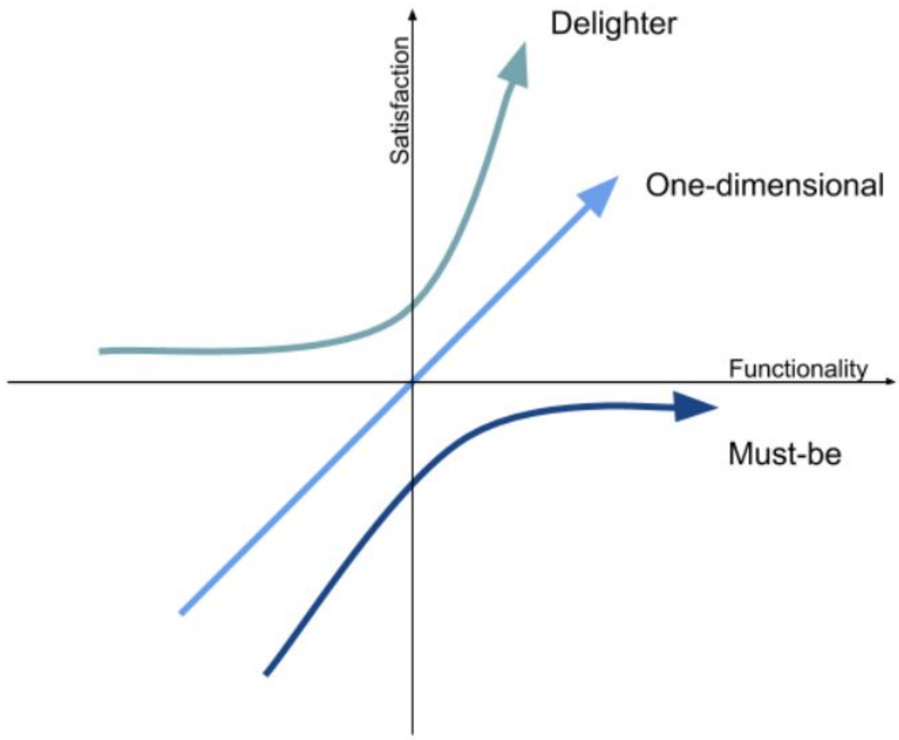


Figure 3.2: Kano Model for the demands Must-be, One-dimensional and Delighters

The equations for satisfaction and dissatisfaction index are shown in equation 3.1 and equation 3.2.

$$SI = -\frac{D+O}{M+O+D+I} \tag{3.1}$$

$$DI = -\frac{M+O}{M+O+D+I} \tag{3.2}$$

These indices is later plotted in a Customer satisfaction diagram to evaluate each requirements importance. Dots were placed in the diagram depending on the calculated index values. They represent each question with the Dissatisfaction index on the x-axis and the Satisfaction index on the y-axis. The diagram was split into four zones which represent different importance values. Example of a Customer satisfaction diagram is shown in figure 3.3

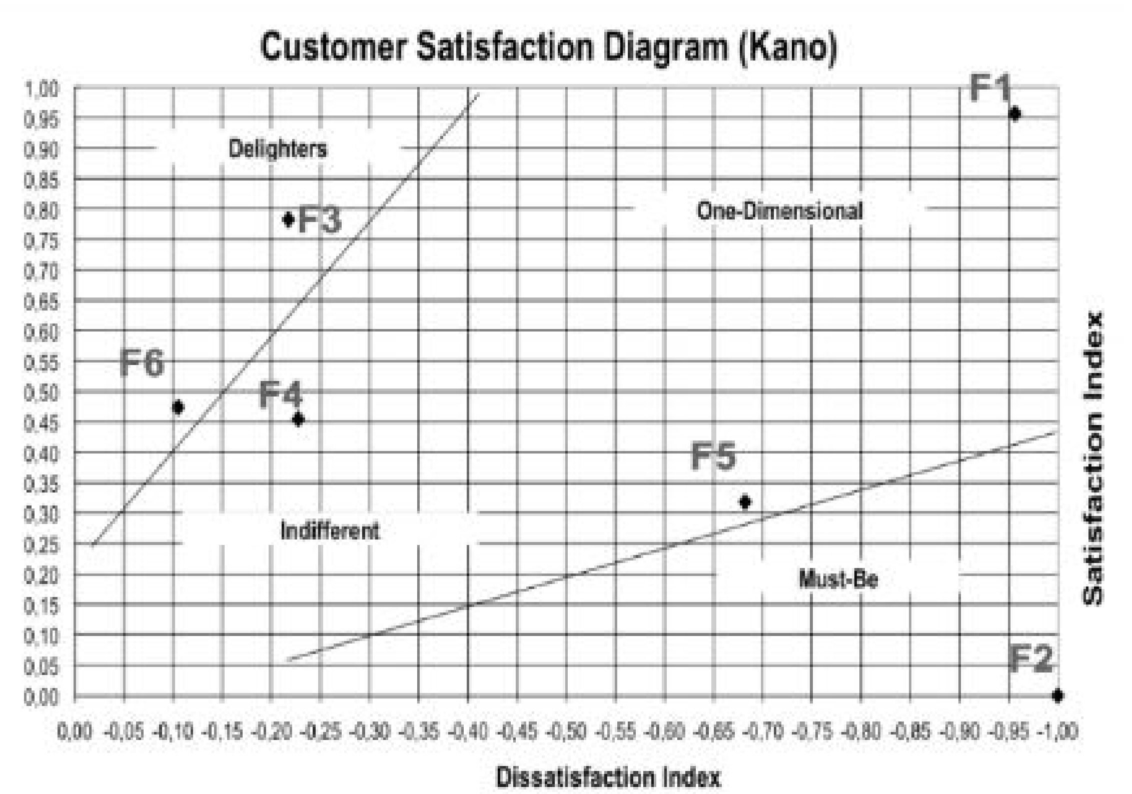


Figure 3.3: Customer Satisfaction Diagram with plotted satisfaction indices

After following the five steps in the Kano survey, based decisions could be made on what requirements should be included in the guideline design. Afterwards, the requirements were carried forward to a Quality Function Deployment.

3.1.4 Quality Function Deployment, QFD

The purpose of using Quality Function Deployment (QFD) was to systematically translate customer requirements and requests into design specification (Johannesson, Persson, & Petterson, 2004).

When using the method, information is structured in a matrix, called the House of Quality, figure 3.4. It contains customer demands, with the importance factor calculated in Kano, and measurable product attributes that can solve the demands, retrieved by analysis of earlier guidelines at Escenda.

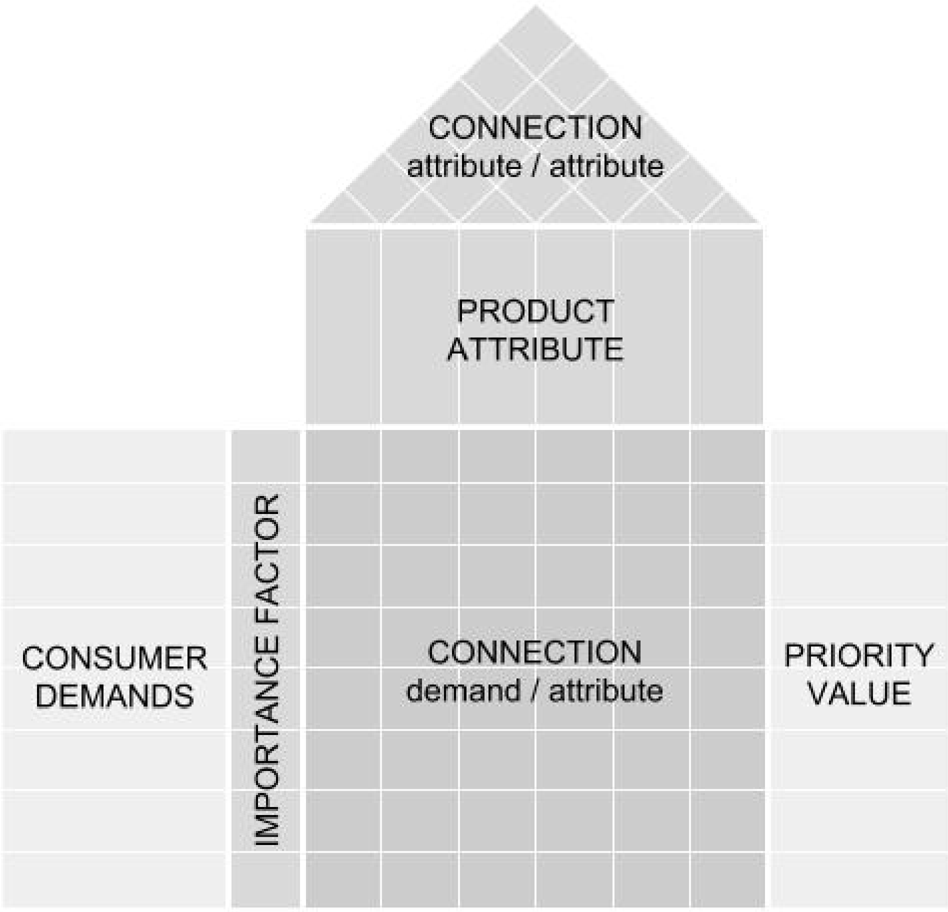


Figure 3.4: House of Quality

In the roof of the House of Quality and in the middle, connections between them were stated. The connection between attribute and attribute were filled by plus (+) or minus (-) representing:

(+) = positive connection
(-) = negative (counteractive) connection
empty square = no-existent connection

The connections between demand and attribute were graded by 1 to 9 representing:

9 = strong connection
3 = medium connection
1 = weak connection
empty square = non-existent connection

After filling the matrix, priority value (PV) was calculated as equation 3.3 shows.

$$PV = \frac{Totalconnectionvalue}{Numberofconnections} xImportance \tag{3.3}$$

The result provided specifications that were measurable and traceable for further development process. Given product attributes can be included in the final specifications for the guidelines.

3.1.5 Design specification for guidelines

Result from the case study methods were summarized into design specifications for the guidelines to verify how they should be designed to create the best possible learning tool for the company (Johannesson, Persson, & Pettersson, 2004). The specifications included user demands on which features the guidelines should contain as well as constraints from Escenda to simplify the implementation specific to them. The design specifications were used in the creation of the guidelines to ensure that the users, and Escendas, demands were met.

3.2 Develop Ply Book in Fibersim

It was given from the company that the most important and relevant actions Fibersim can do is draping analysis and generate ply books. To gain understanding on what utilities that were crucial for these actions to be possible, a ply book for a car door was developed in Fibersim. By creating a ply book, a wide variety of tools were used and considerations on its importances were made. To ensure that the ply book was developed right according to structural regulations, simulation tests were repeatedly made by CAE engineers at Escenda.

3.3 Creating guidelines for Fibersim

Based on results from case study and experience from developing Ply Book in Fibersim, a guideline was developed. The user of the guidelines will be design engineers at Escenda with a basic knowledge about composites and how the material behaves during manufacturing. It was given from Escenda that if the guidelines work well, it will be used by a much larger audience at the company and also its customers. The guidelines were created to teach the employees on how to use the program and its most important tools, which came forward in the case study and during development of ply book.

The creation of the guidelines were an iterative process where technical verifications were performed regularly to ensure that the guidelines content and structure were accurate (Hammersberg, 2018). The persons who verified were two employees at Escenda, to make sure it met their desires and one engineering student with fundamental composite knowledge. The student participated due to they could be the future user of the guidelines and have a related knowledge and solution-oriented thinking. Also two persons with no connection to the project verified the guidelines, to get impartial opinions on the guidelines structure and layout. By testing the guidelines during the process, changes based on feedback were made and regular comparisons to the design specification ensured that the user requirements were met.

4
Result of case study

The case study resulted in insight of today's design process for CFRP parts, where Fibersim possibly could be implemented, the design of existing guidelines and design specifications for Fibersim guidelines. The results will only be summarized in this chapter and complete support can be found as appendix and are referred to continuously in the text.

4.1 Result of literature study

Reading and analyzing current guidelines resulted in both do's and don'ts for further development. Guidelines as well as exercises and analysis guides, obtained from Escenda, were investigated. It was found that many lacked clarity and a perspicuous structure. Some steps in the tool reviews was omitted, probably due to an assumption that the user is familiar with certain tools from before. Although, most of the guidelines included many print screens which created recognition for the software that was trained.
Also through the literature study it showed the importance of starting with describing what will be processed and reconnect to it in the end. It creates an insight about what will be learned and an opportunity to afterwards ensure that it became so. The obtained guidelines can unfortunately not be referenced since they are classified as proprietary.

4.2 Result of interviews

The non-structured interviews resulted in a broad, qualitative and comprehensive knowledge about the design process at an engineering company and a manufacturing company. All interviews were recorded and transcriptions can be found in appendix.

4.2.1 Interviews at manufacturing company

Two workers at a manufacturing company were interviewed, one production worker and the production manager. Both participated in the same interview because of time constraints. Despite that, they contributed with different angles of view and gave combined broad and qualitative information regarding their process and its pros and cons.

Summarized, the process varied depending on which customer they worked with. Often they got a laminate plane and work instructions about how the manufacturing should be done. In some instructions, one of the requirements could be fiber alignment which means that the edges between two plies would have the same fiber spacing and angle. This costs a lot of time due to the fact that the angle and spacing through the whole fabric may vary and the production worker as to find an area in the fabric where this occurs.

Sometimes a work instruction was not obtained, which resulted in that the company had to spend time to create its own. It then was an iterative process to find the right cutting files, draping origin and to document it so it can be manufactured again. Repeatedly it came forward that a lot of time is added due to hand lay-up of the laminates and that the first batch has to be tried out manually because of the inadequate work instructions from the customers. The hand layup was the most time consuming step when looking at the whole process. It also entails to a lot of waste material, which results in unnecessary expenses.

By discussing the most problematic parts of the process it seemed that Fibersim could save a lot of time and money for the company, since trying out cutting files manually is not necessary if automated in the software. The ply book generated from Fibersim includes cutting files, also called flat patterns, which was the most time and cost consuming step to pursue in the process today. It would also include more specific work instructions than the ones given today from consumers. This due to the ply book informs about layup origin direction which gives the production workers a guide of how the part should be manufactured. The whole interview can be found in Appendix B.

4.2.2 Interview with CAE engineer

The CAE engineer interviewed, who also was responsible for the properties of the CFRP car, had years of experience from composites as well as Fibersim. He therefore had a lot of insight in the design process that also is Escenda's. The interview resulted in knowledge of how the companies design process for composite parts work, as well as requests on where Fibersim could be implemented to ease the most problematic parts of the process.

The current design process

The current design process was then compiled into a process map shown in figure 4.1. The design process starts in the concept work, were designers create a design surface for the specific CFRP part. Afterward, a CAE loop is proceed by testing the concept design and is send back for design changes until part design is complete. It is then send to suppliers who create the part, to be able to run physical tests on it. The part then goes through a cross functional team where it is discussed whether the part can be assembled, if equipment is good and if tolerances are fine. Problems are often encountered and that creates a loop back to the concept work. When the cross functional team has accepted the design, it is packaged to specific CAE teams: durability, safety and NVH (noise, vibration, harshness). They make sure the whole assembly fulfilled their department requirements.

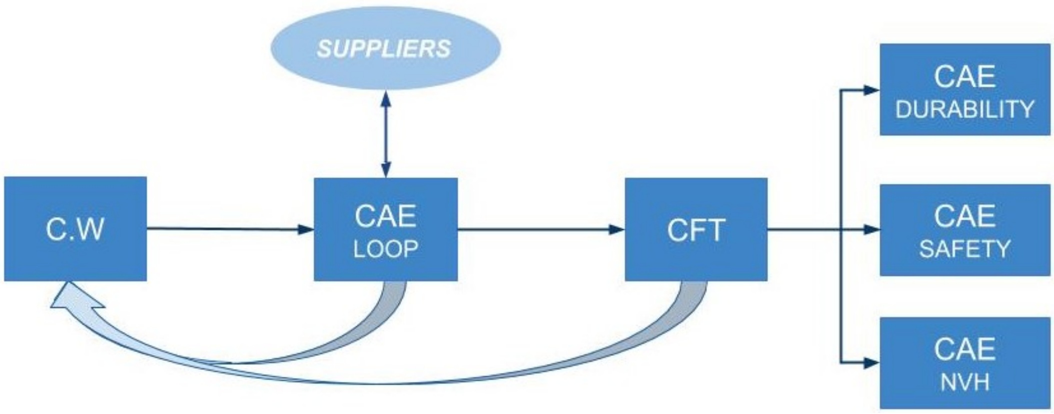


Figure 4.1: Map of design process for CFRP parts

The process is as many other design processes, an iterative one. The concept design step was discovered to be the most problematic, because it turned out that many concept designs were not possible to manufacture. This was due to the designers inexperience of composite material, in other words, the human factor. The information flow, based from concept work to CAE and further to suppliers, was therefore suffering. Inefficient, worse: inaccurate information forces the process to undergo several iteration loops, it gets more time consuming which results in additional costs for the company. Therefore the concept work and information flow is where the process could be more efficient. Also design efficiency, when it comes to composite parts, can contribute to information efficiency as a consequence. Which could lead to an improved process in the whole.

Design process with Fibersim implemented

As shown in figure 4.2, Fibersim could suggestivelly be used between *concept work* and the *CAE loop*. The CAE loop controls the concept work to make sure it is reproducible. The amount of loops between them could be minimized if concept workers could do certain analysis steps (drapability utility and opportunity to study packaging space) by themselves. This is one of the things Fibersim offers. Therefore it could work well in that loop. Fibersim could also be included to ease the information flow between *CAE loop* and *manufacturing suppliers*, through the ply book generator, so that the information is accurate and comprehensive between them. Then, it is very important that the same information is sent to the three CAE departments, which together generate the official attribute reports for the car. The CAE parts were emerged as a part of the process that are relatively sorted out. They already have the ability to proceed relevant tests and calculations for its areas: durability, safety and noise vibration harshness, combined representing the car experience.

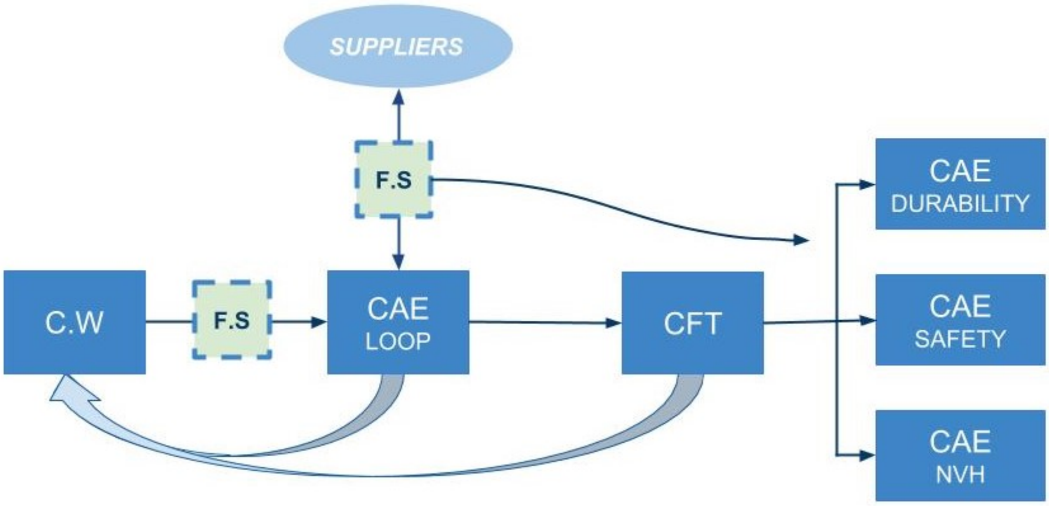


Figure 4.2: Map of design process for CFRP parts and where Fibersim could be implemented

The outcome of the interview was that Fibersim has a link between design tool and CAE tool and could therefore contribute to a more automated information flow, through its ply book generator and draping analysis utility. Complete interview is available in Appendix C.

4.3 Result of Kano model

The result of the Kano Model is presented in the same structure as in the method.

I. A questionnaire was created around seven customer requirements that were based from the interviews, literature study and from personal experience. Every requirement was questioned from a functional and dysfunctional perspective. There was also room in the questionnaire for the participant to write thoughts of their own regarding the demands.

II. The questionnaire was revised and re-tested before sending it out in different mediums. Five independent persons were then asked to go through the questionnaire, so that the questions would not be leading but give complete conditions for the participant to provide personal answers.

III. It was then sent out in different mediums. In total there were 38 responds and each result was analyzed separately. Every question in the questionnaire can be seen in Appendix D.

IV. The answers for all questions were merged in the Kano evaluation table. As the result shows in fihure 4.3, the requirements regarding *describing images, interface, professional layout* and *clear structure* all resulted in Must-be and were therefore prioritized when creating the guidelines. The two Delighters, *Overall understanding* and *exercises*, were taken into consideration during the process. Although the quantity of them were limited by the thesis extent. The requirement about *repeated review of tools* resulted in indifferent and was thus not be included in the design specification for the guidelines.

	Question	M	O	D	I	R	Q	Total	Grade
Overall understanding	1	7	5	13	10	2	1	38	D
Exercises	2	6	5	16	10	1		38	D
Repeated review of tools	3	3	3	4	15	11	2	38	I
Describing images	4	22	2	7	5			36	M
Interface	5	22	2	6	7		1	38	M
Professional layout	6	13	2	13	10			38	M/D
Clear structure	7	16	5	12	5			38	M

Figure 4.3: Result of evaluation of Kano

V. The result of the Kano evaluation table was calculated into *Satisfaction index (SI)* and *Dissatisfaction index (DI)*. The result of the calculations can be seen in figure 4.4.

Question	SI	DI
1	0,51	-0,34
2	0,57	-0,30
3	0,28	-0,24
4	0,25	-0,67
5	0,22	-0,65
6	0,39	-0,39
7	0,45	-0,55

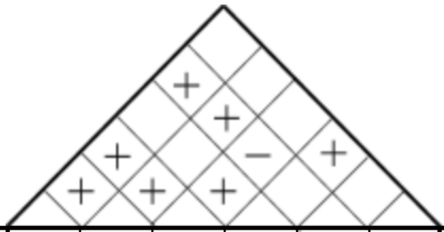
Figure 4.4: Calculated satisfaction indices

For better understanding, all indices were plotted in a *Customer Satisfaction Diagram*. As seen in figure 4.5, question four and five got a value of 0,8 and will therefore be the most important when creating the guidelines. Question three resulted in a low value in the *Customer Satisfaction Diagram*, which confirmed its relevance to the guidelines.

Figure 4.5: Visualization of Customer Satisfaction indices in a diagram

4.4 Result of QFD

The six resulting consumer demands were placed in the QFD, for translation and connection to product attributes.



Custumer demands	Importance	Product attribute	Pictures	Examples	Icons	Structure	Practical background	Table of Content	Priority value
Intuitive interface	0,8		9	1	9	3		3	4
Concise information	0,8		9		9	9		1	5,6
Exercises	0,6		9	9	3		1		3,3
Structured workflow	0,6				1	9		9	3,8
Create overall understanding	0,6		1	3			9	9	3,3
Professional layout	0,6				3	9		3	3

Figure 4.6: Result of QFD in a house of quality

As seen in figure 4.6 all attributes are in some way linked to at least one other attribute. If an attribute is present, or excluded, it will have an impact on other parts of the guidelines, both negative and positive. The priority value shows that the guidelines should mainly focus on having *concise information, a intuitive interface* and a well *structured workflow*.

4.5 Result of design specifications for guideline

The structure of the design specification was originated from Kano and the same three categories of demands were used: Must-Be, One-Dimensional and Delighters. All the customer demands from the QFD were included, due to the relative high importance of each. The requirements given from Escenda were added. Among these were required export file format, their own logotype and the language of the guidelines. The language should be English to enable all employees at Escenda, regardless of nationality, to be able to use the guidelines. Demands like including icons and having an index for easy searchability originated from the two interviews and experience from literature study.
To trace the source of all the demands, an origin column was also included in the specification. That gave a good overview and easy navigation through the demands. The whole resulting design specification is available as Appendix E.1.

5
Results of ply book in Fibersim

Following chapter described the findings from the development of a ply book in Fibersim. The advantages of having Fibersim as extension to CATIA was shown to be one of the key utilities. This allowed Fibersim to use every line, point or surface created in CATIA as analysis elements. When changes were made to the part, the data in Fibersim changed as well due to the link between the programs. By using the advanced application in Fibersim instead of the basic, the process became more adjustable to changes on both the part and to the composite design.

5.1 Boundary

When setting the outer boundaries of the surface, it was important to include the cutouts that weren't going to be laminated. When not included, Fibersim would analyze the cutout as part of the surface and would therefore create a laminate on it. On the other hand, this feature can be used when creating a part with holes that is going to be made after the laminate process (e.g. through holes).

5.2 Material

During the drapability analysis process of the laminate, it was possible to choose what type of material that will be used, which allows for realistic end results. The most important material property available is the sheer look angle. This property is key to getting a realistic result in the drapability analysis.

5.3 Zone and zone transition

One tool that the advanced application allowed was to create zones and zone transitions. This allowed for better connection to design changes and control of the overlap between the zones. The key factors when creating the zones were the origin point of the zone and placement of the zone boundaries. The origin point indicates where the draping analysis for each zone should start, representing the laminate layup origin in production. Depending on its position, relative to e.g. double-curved surfaces, the result may vary drastically, as seen in figure 5.1.

By testing it came forward that placement of the boundaries should be around double-curved surfaces or when the part changes direction. This will help with dra-

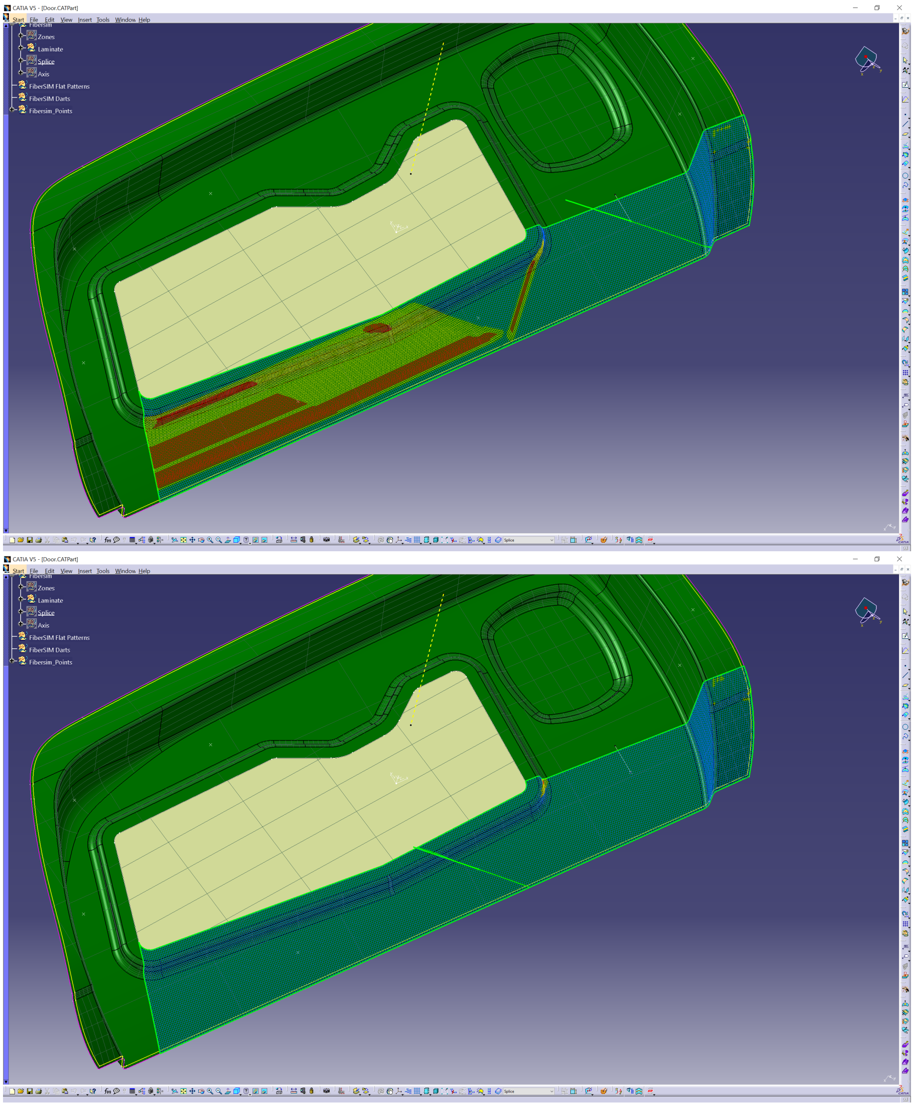


Figure 5.1: Image of different origin points and draping analysis on the zone. Blue is good, yellow is warning and red is bad

pability and the tension on the fibers will be reduced. It will also reduce the amount of darts needed on each ply.

With the zone transitions the designer can control the stagger profile between the zones. It can be set to standard settings, such as symmetric or decreasing. It can also be customized to the designers choice. This becomes practical when a part has specific regulations regarding construction stiffness. For example, the first laminate can have an overlap of 10 mm while the other laminates have edge-to-edge transitions, called butt joints.

5.3.1 T-crossing zones

A problem that occurred when using zones and zone transitions was the inability to create zones with a T-crossing. The problem occured when two of the zones had an increasing/decreasing transition while the third zone had the opposite. If two of the zones have a decreasing transition it will create a gap, as shown in figure 5.2 and when they have an increasing transition it will create unwanted overlaps and thicker areas.

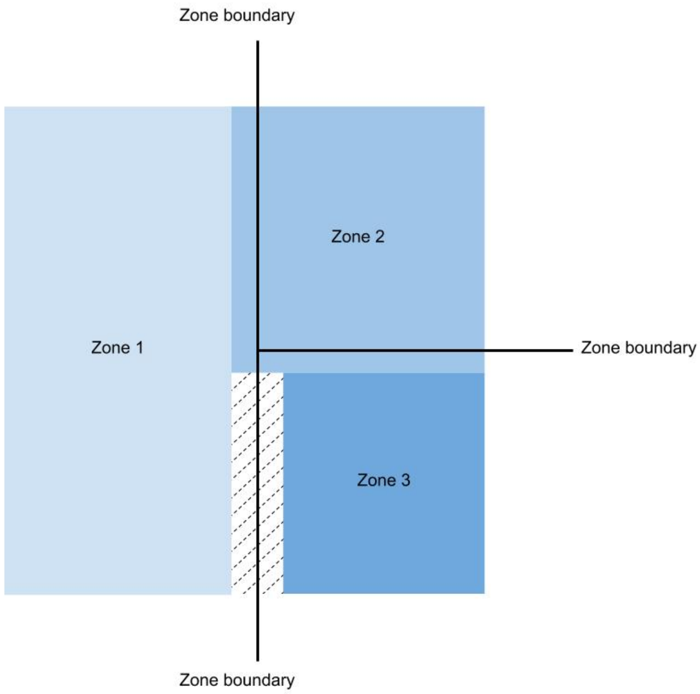


Figure 5.2: Image shows the gap created when Zone 1 and 3 have a decreasing transition while Zone 2 has a increasing

One way of solving this problem was found out to be the tool Splice. Figure 5.3 shows how the tool splits one zone into two plies. As a result, the two new plies have the same transition towards the surrounding zones and create an internal transition between the two plies. The new transition has the same design freedom as the zone transition utility. By doing this the gap and the unwanted overlaps can be avoided.

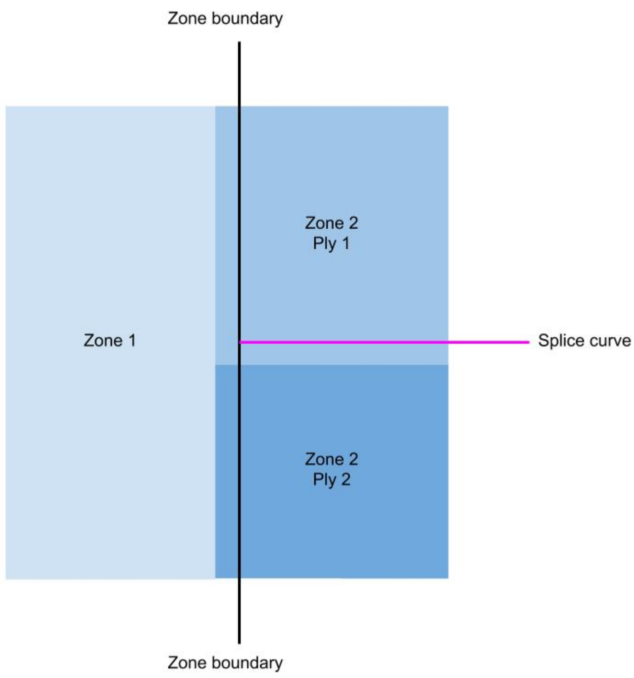


Figure 5.3: Image shows how the outcome would look like when using splice to split a zone into two plies and have different transitions between the plies versus between the zones

5.4 Ply book

The tool for generating the ply book links the plies to the geometry of the CATIA part and plotts it on a template drafting sheets in CATIA. This sheet can include tables, texts and tolerances. Information from Fibersim, such as Step, Material and Ply orientation, can be linked to the table or text. This enables an automated generation of each sheet, with individual information of each ply on each sheet. That also makes it possible to show where on the part each ply is located and a visualization of the flat pattern can be made. This is done by adding different views to the sheet and then link it through Fibersim.

5.5 Interconnections

As figure 5.4 shows, all the tools used when creating a ply book are connected. Those are Laminate, Rosette and Material Specification, which represent the basic settings for the design surface. The tools regarding Zones, Zone transitions and Layers are the most interlinked. They define the zones, its transition and stagger profile as well as the layers, which in turn is linked to the ply that draping analysis can be performed on.

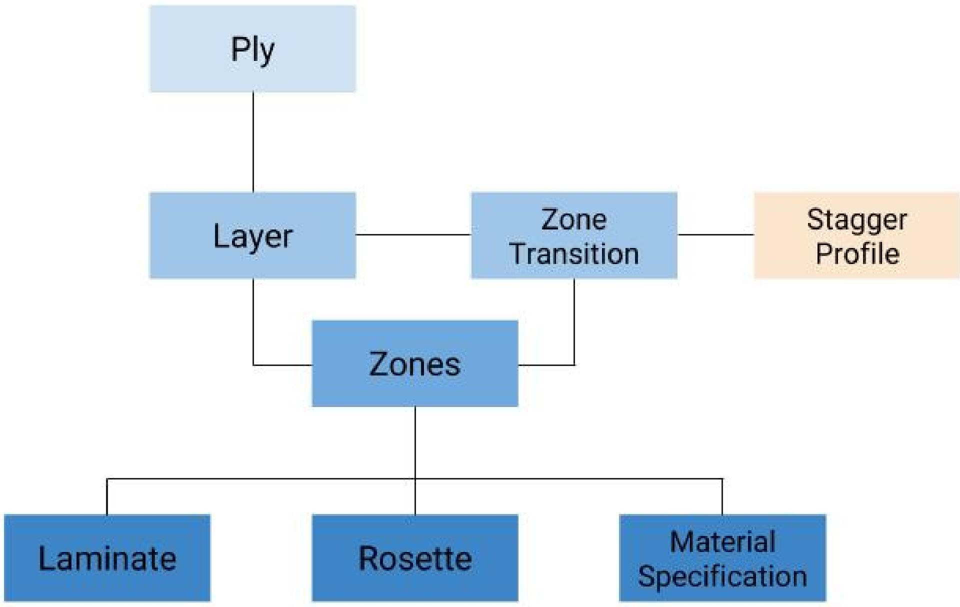


Figure 5.4: Interlinked tools in Fibersim

5.6 CAE analysis

The simulation tests performed by the CAE engineer showed promising results. The exported file contained accurate definitions of fiber angles. When opening it, the CAE engineer could automatically define the element orientation instead of manually define them which can be very time consuming. He could also successfully automate the zone based laminate definitions. It was not possible to evaluate the draping analysis, but it was visible that darts had been made to the plies.
With good definition of darts and laminate, the CAE analysis will result in a simulation of exactly how the part would be structured on a ply level. The good result from the CAE shows that the course of action, when creating the ply book, could be applied to the creation of the guidelines.

6

Results of guidelines for Fibersim

The iterative creating process resulted in a 50 pages long guideline named *Fibersim Advanced Guidelines* with a detached introduction of 5 pages. The guideline describes detailed how to do draping analysis on a design and how to use each necessary tools. It later describes how to generate a complete ply book.

6.1 Disposition

The guidelines follows a chronological order of which the tools are to be used. This is due to the big amount of interlinked tools, so to avoid going back and forth between the utilities, a thorough disposition was made. The disposition is as follows:

- Preface
  A quick description of Fibersim and what the guideline will process.
- Process
  Description of overall process and the structure of the guideline.
- Interlinked Tools
  All interlinked tools is described in a tree diagram for broader understanding.
- Input
  The required inputs before starting Fibersim are stated.
- Creative tools
  How to use all creative tools are described in detail.
- Draping Analysis
  Description on how to run draping analysis and how to interpret the result.
- Ply book
  Detailed description on how to generate a ply book from created data.
- Export
  The export files relevant to run CAE analysis are stated.
- Postface
  A short text about what has been processed during the guidelines.

6.2 Layout

The guideline has a constant use of images, icons and print screens from the software. The workflow is numbered on each page and arrows and boxes are used to highlight what the user should pay attention to. Bold text represents that it refers to a term in Fibersim and italic text refers to the operation that are to be made. To create a consistent structure and make it easy to relocate in the guideline, there are linked tags at the bottom of each page that follow the process and can be pressed to switch chapters. See figure 6.1

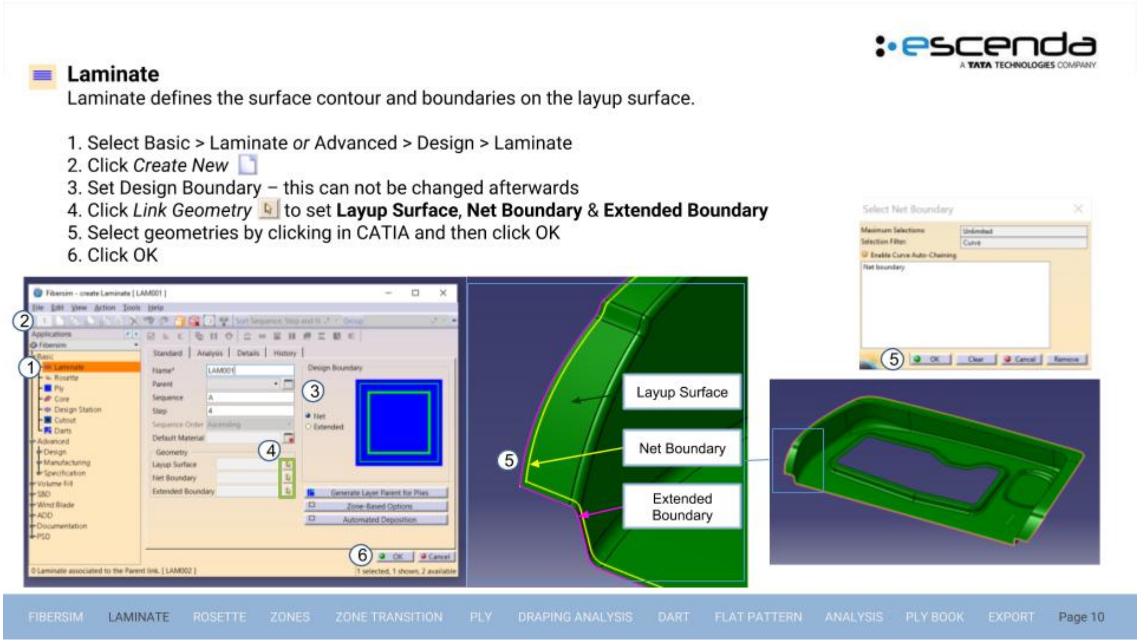


Figure 6.1: Sample of the guideline layout

All colors used were related to Escenda´s own color palette which included blue, orange and green among others. The logo is present on each page and together with the recognized palette, it should create a connection between the user and its employer. Also it could make the guideline perceive trustworthy due to it. The color on the boxes was determined to be green because it indicates that something is "right", like a traffic lights where green light indicates "go". Arrows were colored depending on the object it points to, to make the differences as clear as possible.

In order to increase understanding of assumed more difficult tools, these were followed by examples taken from the creation of the car door. To distinguish examples from remaining descriptions, they were presented in a box with orange background and with the heading "Example" followed by the exemplified tool. See Figure 6.2

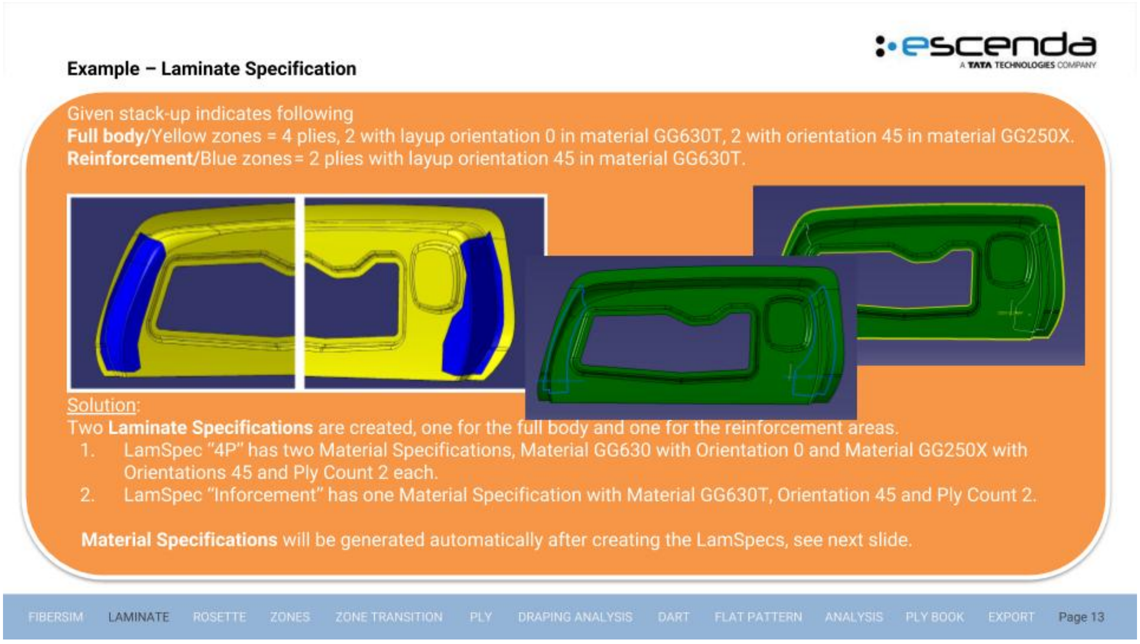


Figure 6.2: Example in box with orange background

6.3 Introduction

The detached introduction was made to give the user basic knowledge about designing with composites and to describe terms used in the guideline. This was done because the user's background knowledge in the field of composites varies. The user is recommended to read the introduction before using the guideline, since the guideline only explains how to use the tools and not the understanding required about why they are used.

6.4 Technical verification

The technical verification of the guideline and introduction resulted in valuable feedback on structure, content and layout. The employees gave linguistic corrections and verified that the required tools were explained and described.

The engineer student tested the guideline together with the program, with no initial information about the subject. That was made to verify the guidelines self-explainability and how well it reconnects to Fibersim through its print screens, boxes and arrows. It also ensured if the structure was easy to follow through. The structure received good response and the only criticism was regarding the print screens and that they did not always show exactly all steps that were processed. This created confusion as to whether the user was doing right or not.

The two independent testers got no initial information about the subject and it was asked for their general opinion of layout and structure. The responses were that the guideline looked “very professional” and had a good structure due to the linked tags on each page. As an improvement, information about what bold respectively italic text specifically meant could be more clearly in the preface.

All constructive data from the verification were then applied to the final guideline.

7

Discussion and conclusion

In the following chapter the thesis purpose and objectives are discussed and conclusions regarding its fulfilment has been made. The methods are discussed in a source-critical manner and a chapter on how the outcome has impact on sustainable development is stated.

7.1 Evaluation of methods

The discussion and conclusion of the used methods in the part of investigation are as follows.

7.1.1 Discussion

The literature study may only represent a one sided perspective of how the guidelines should be constructed. It gives a very detailed description on how Escenda usually design guidelines and might leave out some important aspects. Just because something is done in a certain way does not mean it is the best way.

Doing the interviews gave new perspectives on how the interviewed would like the outputs from Fibersim to be. The result might have been misleading due to the fact that it only included two different companies and only one interview regarding each area of expertise. The structure of the interview gave the interviewed a lot of freedom in their answers, which is believed to give a very qualitative and considerable view on the topic. It might also result in loss of important information due to no specific question about it.

Using Kano as an evaluation method of demands entails some risks. The structure and questions in the questionnaire might be hard for the respondent to understand. The respondent might think that they have to answer with opposite answers on the two questions to get the “right” result. The result from the questionnaire does not seem to be affected by it so much though since the Kano Evaluation Table got a varied result of demands.

The QFD method is mainly based on other profound data, that makes it a credible method. The connections between consumer demands and product attribute was sometimes hard to specify and could therefore be considered more of an estimate than fact. Despite that, it does not seem to affect the result so much and all attributes were taken forward to the design specification not to miss any valuable data.

The design specification can be missing important demands, but only if they were missed in the earlier methods.

7.1.2 Conclusion

By having three different methods for gathering and evaluating information about the demands, regarding the guidelines, results in three different points of view. This combination of different methods eliminates the main problem for both the literature study and the interviews. Combined, they create a wide range of information and can be analyzed together for a justified result. The Kano model adds the knowledge from people not involved in the process and the focus can then be on the creation of the guidelines. By adding the ability to write their own thoughts, important demands that might have been missed were discovered. Using the QFD method gives an easy way to validate the importance of the different demands. It also creates a good visualization of how the demands are connected to properties and how these properties are linked to each other. The conclusion is that the methods are valid and that the design specification will contain verified demands.

7.2 How the CFRP design process works today

The discussion and conclusion of the objective: *How does the design process for CFRP work today?* are as follows.

7.2.1 Discussion

It emerged, from the interview results, how the design process works today. It was shown that there are well working parts and some problematic parts. By only getting the result from one method, it could be questioned whether a comprehensive view has been gathered. But due to the delimitation that only Escenda and their partner's design process would be investigated, the result might not be the optimal process.

7.2.2 Conclusion

It was clear that the process is internally iterative through concept work, CAE analysis, cross functional team and back again. The information flow between the departments is a crucial thing to make it work. Which also applies to the information send to suppliers and back through CAE analysis again.

It was also stated that the part which works well and are sorted out is the CAE analysis. Since they have the ability to proceed relevant tests and calculations for its areas already. The part that emerged to be problematic was the concept work as well as the information flow based from that department. Summarized, the objective is considered answered.

7.3 How Fibersim can simplify the design process

The discussion and conclusion of the objective:*How can Fibersim simplify the design process for CFRP parts?* are as follows

7.3.1 Discussion

The knowledge of how the current design process works combined with arguments from interviews, strengthened by the development and analyzation of the software, resulted into the conclusion of Fibersim´s impact on the design process. It appeared frequently that the more manual work required in the process, the more time, money and mistakes are involved. Which is relevant in both the design phase by engineers as in manufacturing. The errors made at the design table can only be corrected if the designer in question has prior knowledge of CFRP, which is not reality today. Until then, Fibersim seem to be a comprehensive and implementable utility for the necessary simulations currently lacking in the process. This due to its ability to do draping analysis and generate ply books.

The arguments from the Fibersim experienced CAE engineer about how Fibersim can streamline the information flow to a greater extent, was strengthened when the software was tested. Due to all the interlinked tools in Fibersim and its connection to CATIA, it appeared that large amount of data could be bonded and therefore completely automate the creation of a ply book. By the utility to export with the desired file format .h5 it makes it even possible for direct CAE analysis.

Verification of reality
When using computer generated analysis, it can be hard to know if the results will be the same in reality. Even though a software like Fibersim seems to enable realistic analysis, since the user applies material with accurate properties, it can still be hard to truly verify the final result. The program uses a perfect constructed composite fabric, while in production the fiber direction may vary by a few degrees throughout the whole fabric. This can be crucial depending on the demands on alignment of fibers or structural properties.

But since Fibersim is based on the input data that it is given, which is based on true materials and constructions, it should reflect reality to an acceptable extent.

Interlinked tools
The interlinked tools is a crucial advantage of Fibersim which enables that adjustments, in both the CATIA part and internal in Fibersim, are updated between each other. By understanding how they work together, the design process can be simplified. The connection between the two softwares and the design freedom enables good communication between the designers, the manufacturing department and the CAE.

7.3.2 Conslusion

The conclusion is that using a program like Fibersim enables a shorter design cycle due to the possibilities of testing the drapability of every ply digitally. It also simplifies the production chain by generating describing directions with relative information to the production workers, due to the automated ply book. A work that today is made manually which costs a lot of money.

The ability to export the computed data to CAE analysis will ease that process as well. Even though the software may not have fully realistic results, it mimics reality good enough for it to shorten some of the iterative steps during the design process. So, by using computer generated data from Fibersim, the earlier inevitable human errors can be eliminated.

7.4 How the guideline meet the user demands

The discussion and conclusion of the objective: *How should guidelines be designed to provide learning of Fibersim?* are as follows.

7.4.1 Discussion

The discussion of how the guideline meets the design specification is as follows.

Must-be
The must-be demands with origin from Escenda were concrete and therefore clear with its fulfillment. The guideline is written in English and the file format is available as PDF. Escenda logo is present and the considered necessary tools are described. However, if useful tools are excluded is a question left for further development of guidelines. Evaluation of the tools importance have been made regularly and in consultation with the company. Tools that have been excluded are noted so that the company can investigate their value furthermore. The Must-be demand regarding structure is considered fulfilled with the ease of searchability due to the linked tags, the tree diagram describing interlinked tool and chronological order of guideline. Also the numbered workflow and highlighting with squares and arrows contribute to the structure demand.

One-dimensional
The one-dimensional demands mostly came from the QFD and interviews. Print screens and icons from the software are used to a large extent throughout the guideline to enable intuitive and easy learning och recognition. Table of content is presented in the beginning with ability to press on a chapter or page to come directly to it. An intuitive interface is considered fulfilled through a continuous layout, detailed description on how to proceed and regularly images of what each step should result in. Despite that, the guideline is kept relatively short through simple language and only processing the most crucial steps. Therefore the guideline also fulfill the demands of concise information. Indices, as linked tags at the bottom of each page, enables searchability.

Delighters
The delighters as came from the QFD and the designers themself, were not required to be met but, according to the method results, would contribute to an increased user experience. The demand of including examples, to enable practise and reconnection to tool review, were sequentially included in the guideline. The reviews that were considered needed an additional explanation, was followed by examples. After more basic steps, examples were not included. The technical verification ensured that the stated examples worked well and increased the understanding of the tools, although was not missed in the chapters they were excluded. It can obviously depend on the human factor, whether examples are necessary for all steps or not, but that evaluation is left to the company to investigate.

The designers demand of professional design is considered partly fulfilled. A concise content got more focus than design when it came to prioritizations. Although, a clean and continuous design was considered created. The company's template and color palette were used, which was considered contributing to a professional experience since it creates connection between the user and a known company. The designers still had space to put its personal touch on the design with the tag line, high resolution images and icons and thoughtful color decisions from the given template.

Practical background was a delighter with a difficult balance of what extent it should be. Some knowledge about composite materials is expected from the user but in order to link reality with terms in Fibersim, the introduction is supposed to capture the varied range of users experience.

Technical verification
The technical verifications were performed with two employees at Escenda, one engineering student and two independent testers. The method would increase its credibility if the number of participants were more. But due to the time limit and difficulty of finding testers, the amount is considered valid.

7.4.2 Conclusion of guidelines

Based on the discussion above as well as consultation and discussion with the company, the guidelines are considered to meet the demands in whole. The conclusion is, that it will be a well functioning tool and provide a comprehensive learning of Fibersim for a wide user audience at Escenda with customers.

7.5 Sustainable development

The conclusions can contribute to different aspects of sustainable development. Implementing Fibersim will minimize the number of mistakes made in the concept work and valuable resources as time and thereby money can be saved. It will reduce the frequency of iterative loops between analysis and concept work and make the whole process more efficient. This is a sustainable development for the company and in the long run also the automotive industry.

Furthermore, the question is whether the guidelines is persistent and sustainable. Will it work while a new version of the software may be available? That is left for the company, or further thesis to investigate.

8
Recommendations

Whether Fibersim is a step in the right direction to ease the design process in whole can not be answered in the thesis, due to the time limit. How much affect it will have on time and money in the long run, can not be known until maybe years after implementation.

It is therefore a recommendation left for the company, or further thesis work, to evaluate the guidelines and the true effect of implementing a composite design extension in the CFRP design process.

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List of Figures

3.1 Calculation model for Kano Evaluation Table 9
3.2 Kano Model for the demands Must-be, One-dimensional and Delighters 10
3.3 Customer Satisfaction Diagram with plotted satisfaction indices . . . 11
3.4 House of Quality 12

4.1 Map of design process for CFRP parts 17
4.2 Map of design process for CFRP parts and where Fibersim could be implemented 18
4.3 Result of evaluation of Kano 19
4.4 Calculated satisfaction indices 20
4.5 Visualization of Customer Satisfaction indices in a diagram 20
4.6 Result of QFD in a house of quality 21

5.1 Image of different origin points and draping analysis on the zone. Blue is good, yellow is warning and red is bad 24
5.2 Image shows the gap created when Zone 1 and 3 have a decreasing transition while Zone 2 has a increasing 25
5.3 Image shows how the outcome would look like when using splice to split a zone into two plies and have different transitions between the plies versus between the zones 26
5.4 Interlinked tools in Fibersim 27

6.1 Sample of the guideline layout 30
6.2 Example in box with orange background 31

E.1 Design process for CFRP parts and where Fibersim could be implemented XXI

A
Interview guide

Datum:
Namn:
Företag:

PROCESS (ALLA)

- Hur ser er process ut? (beräkningar, plybook, tester, handarbete, iterativt?)
- Vad är din roll i produktutvecklingsprocessen?
- Vilka steg i processen funkar bra?
- Vilka steg i processen funkar mindre bra?
- I vilket steg tror du att processen kan förenklas?
- Blir resultatet det samma, i praktiken och i teorin?
- Vad är svårt att förutspå innan en detalj ska tillverkas?
- Hur verifierar ni att resultatet stämmer överens med underlaget?
- Fungerar det i praktiken?
  Beskriv Fibersim
- Vad tror du att Fibersom skulle ha för inverkan på processen? Varför?
- Vilka risker tror du finns med användning av Fibersim?

GUIDELINES

- **Använder ni er av guidelines (/manualer/riktlinjer)?**
    - **Vem och när använder guidelines?**
    - **Förklara hur era guidelines används**
- **Vilka krav finns på guidelines för att de ska funka? (kravlista)**
- **Vad avgör om en guideline är bra?**
    - **Hur vet ni att era guidelines är bra?**
- **Vad är målet med guidelines? (att processen går fortare, bättre, inlärning?)**

PRODUKTION

- Hur blev ni introducerade för hur man arbetar med kolfiber?
- Är det viktigt att förstå hela processen när man introduceras för arbete med kolfiber?
- Var det något som fattades i introduktionen?
- Hur mycket har ni lärt er teoretiskt vs i praktiken?
- Hade det förenklat med mer digitala underlag?

CAE

- Hur ser riktlinjer för introduktion av andra områden ut?
- Hur omfattande bör de va? Veta allt eller bara delar?
- Vad är viktigast att få med?
- Hur bör riktlinjer va utformade? Teori, video, praktik?

→ Vilka krav finns på guidelines?

UNDERLAG (OUTPUT FIBERSIM) **(ALLA)**

- Hur ser underlagen ut?
    - Design av plies
    - Placering av plies
    - Darts och snitt
- Hur mycket av underlaget tas fram i programvaror? (Joakim?)
- Hur skulle underlagen kunna förbättras?
- Hur mycket kan ni påverka arbetet? Hur plies ska beskäras t.ex.
- I vilket steg kan processen förenklas?

FIBERSIM

Simulerar hur väl ett kompositlager draperas över en form. Väckbildning och överlappning kan undvikas genom snitt (V/I) och uppdelning tills en producerbar detalj skapats som uppfyller de givna kraven. Vikt, detaljtjocklek beräknas. Output blir en Plybook med flat patterns beskriver hur lagren skall beskäras vid produktion.

-

B
Transcription Interview 1

Datum: Måndag 23/4
Namn: Cecilia, Produktionsarbetare, laminerar
Joakim, Produktionschef
Företag: Aston Harald

UNDERLAG

V: Processen. får ni underlag av kunderna eller hur ser det ut?
E: Hur ser hela designprocessen när ni ska tillverka kolfiber
J: Varierar från kund till kund. Koenigsegg har laminatplan som innehåller exakt vilka material och en arbetsinstruktion som förklarar i detalj exakt hur man ska göra. Finns inte det gör vi en egen arbetsinstruktion men inte förens efter 2-3 skottet som vi bestämt och dokumenterat hur vi ska göra.
C: Vi provar oss då fram men oftast har de exakt bestämt hur det ska ligga.
J: Vissa kunder har skärfiler men oftast inte. Vi har det oftast inte förens efter 2-3 skottet. Först efter tredje skottet är vi fullstackade.
C: Första delen görs för hand, sen sparas mallarna och ändringar görs. Sen skickas de upp och görs till skärfiler, ändring igen och först vid tredje funkar det.
V: Ni skulle säga att det är den delen i processen som är mest problematisk?
C: Ja, mest tidskrävande om inte annat. När delarna väl finns på plats går det smidigt.
J: Då är det även lättare att sätta det i händerna på någon som inte är lika erfaren. Det första momentet är det långt ifrån alla som klarar.
C: Alla delar ska mötas i radier och inga fibrer får flyttas innan man lägger på och drar det. Kunden vill även se första grejen och godkänna eller göra designändringar efter hand. Ofta går det inte lägga en hel bit även fast du velat det, utan man får lägga flera bitar och då behövs en överlapp eller möte som ofta behöver flyttas för att den andra sidan är mindre synlig.
J: Normalupplägget är att vi gör en, oavsett hur många de beställer, och få ut en tidigt i processen så att kunden kan komma med feedback. Förhoppningsvis har vi gjort enligt ritning. Har kunden gjort det hemma finns det ibland uppgörelsen som skett utan att ha hamnat på ritningen. “Den här ska limmas här”, “det står inte på ritningen”, “det har vi alltid gjort”. Haha. Det ofta mest för kundens skull som de gör en första granskning. Kontrollera sig själva innan de går till kund. Godkännande och sedan kör de på.
E: Ser processen olika ut beroende på hur storskalig serien är?
J: Vår ambition är att alltid lägga sig på högsta nivån, alltid göra arbetsinstruktioner och en dokumenterad instruktion. Ambitionen är där men vi är inte där än.
C: Arbetsinstruktionerna är ofta precis hur de ska vara men innehåller inte de tips och trix man gör under processen som man använder men inte finns med. Man hade gärna velat ha en arbetsinstruktion med sina egna kort för att man visar väldigt mycket där. De ska oftast se lite proffsiga ut men det tappar man väldigt mycket på.
J: Det är en feedback-loop mellan operatören tillbaka till han som skriver instruktionerna, ingenjören. Transparent mot kunden så att man kan visa det här och få den signa, att de har tolkat ritningen rätt. Därav snygg nivå på instruktionerna
C: Nä, då går det kanske inte ha de där 20 korten som finns på ett klipp.
J: Ja det är en kompromiss däremellan. Men de underlaget vill vi ha hela tiden.
C: Så att vem som helst ska kunna bygga den delen sen, mha instruktioner

J: Det är där i branschen vi valt att placera oss. Vi vill ha långa serier just för att det är på den nivån vi funkar bäst. Bara one-offs kan man skippa instruktioner då det är erfarna gubbar. Men det är mer långsiktigt att fylla på med långa jobb och kunna fylla på med lokala anställda. Vi har tränat upp personalen själva och det är långsiktigt mycket bättre. Men då måste man också begränsa sig till vilka jobb man tar. inte ta one-offs.
E: Hur viktigt är det att förstå hela proccesen när man laminerar? Vet man bara vad man själv gör eller har alla insikt i den stora processen?
J: Ganska isolerat just nu. Inga jättefördelar att behöva hänga med hela vägen. Ändstationen, slipning och polering, deras jobb blir mycket lättare beroende på hur det gick i början. Formens skick och hur skarvarna ligger. Det är bättre att lägga 20 min på att polera formen för då sparar de 2 h i slutet. Om de inte pratar med varandra kommer de aldrig inse det.
C: Kommunikation är väldigt viktigt i det vi gör, inom bygget internt. Det har nog de flesta ganska bra koll på. Skärbordet och skärfilerna görs nära varandra. De känner de som sitter och polerar och kommer in och tittar. Vi har ganska bra insikt där inna.
J: Stor fördel. Vi försöker hålla det så här inne. Att samma person som bygger delen, bagar den och sedan tar ut den ur formen. Så man ser hur det blev och hur bagningen påverkade resultatet.
C: Då kan man se i formen, att ja, det berodde nog på det här. Eller också inser man att man själv lagt något galet.
V: Hur verifierar ni att resultatet blev så som ni tänkt det?
C: Koenigsegg har sina mallar på hur det ska se ut. Vad som inte är godkänt och vad som är godkänt.
J: Rent visuellt är det väldigt tydligt specat. Strukturellt är mycket svårare. Vi väger allting för att se så de inte missat något stort eller en riktigt stor maja. Laminattjocklek kan man mäta men där kommer man bara åt i kanterna, det är ett ineffektivt mätsätt. Strukturella delar kan man ultraljudscanning för att upptäcka fel, men långt ifrån allt går vi det med. Sen är specen ofta inte så hårt satt förutom hur lagrena ska ligga och i vilken riktning. Där får vi säkerställa att vi, dels genom uppmärkning i skärbordet numrerar alla bitar, så att vi minimerar risken att fel bit hamnar på fel ställe. Men oavsett vad som händer i autoklaven och hur den ser ut på ställen de inte kommer åt är jättesvårt att kontrollera. Så det är en utmaning i branschen generellt. Framförallt är det det visuella och vikten som vi kollar.
9:50
C: Väger det fel är något som är galet. Vi ser om det har läckt i Autoklaven och då får vi gå igenom bitarna extra noga.
J: Om trycket droppar har vi ett varningssystem så vi försöker snappa upp fel som uppstår.
C: Ibland får man gå in i autoklaven för att åtgärda och dokumentera.
E: Är det era ingenjörer som räknar på de strukturella delarna? Ofta överdimensionerar man för att det är svårt att veta.
J: Våra ingenjörer gör det om vi får uppdraget. Ofta är det i samråd med kundens konstruktörer. Vi föreslår en lösning med hur många lager men kunden har sista ordet. Båten har vi konstruerat och bestämt exakt antal lager.
E: Litar man på beräkningarna eller överdimensionerar man för att man inte litar på att det håller i verkligheten?
J: Vågar inte svara på det. Ganska säker på att man överdimensionerar sen hur mycket beror på vilken del det är såklart. Ibland vill kunde slänga på fler lager för att inte chansa.

Inte lika lätt att beräkna som metalldelar. Det är inte bara vi som inte fattat utan alla andra kämpar med detta.
E: Det är en svår del i processen?
J: Ja tillsut står en ingenjörs initialer på ritningarna och hen ska då stå för det och då tar man oftast i.
C: Vi gjorde skidor ett tag och då testskruvade vi dem så att vi visste att vi fick samma resultat på alla och kontrollera att de inte flexade olika. Så att det speglar vad de har tänkt sig och deras krav.

GUIDELINES

V: En del i projektet är att vi ska komma med beskrivningar för Fibersim och hur nya personer lätt ska kunna använda programmet. Så att någon ska kunna ta manualerna och sedan förstå hur man ska kunna använda programmet. Hur är en bra manual? Vad ska finnas i den för att man lätt ska kunna förstå? Använder ni er av några manualer i allmänhet kring hur man går tillväga?
J: Vi håller på med en generell instruktion, Aston Harald Guidelines, för alla moment, en övergripande. Den är inte helt utrullad men tanken är att beskriva de generella stegen. Utöver det har vi två nivåer av instruktioner: en kundspecifik och en produktspecifik. Så om kunden säger att det alltid ska skickas i en plastpåse, skrivs det in i kundspecifik. Om något avviker från huvudinstruktionerna per produkt så finns arbetsinstruktionerna, som vi har för alla. De tre nivåerna har vi på instruktioner för det operativa. Sen har vi instruktioner för hur man klickar runt i våra affärssystem: men mest skärmdumpar och kladdar. Det försöker vi hålla uppdaterat och se till att operatörerna signar att de tagit del av det och att inte Cissi gör ett jobb till en kund om hon inte kan den kundspecifika instruktionen. Förklara gärna vad Fibersim är.
E: *förklarar Fibersim*... simulerar hur väl mattorna draperas över formen. Men vi har insett att det är bra att förstå hur materialet beter sig så vi tror att större förståelse behövs. Snitt…
J: skarv?
E: Ja. Flat patterns - skärfiler
J: Då låter det som att vi efter det får ut skärfiler
C: Man kan jobba bort väldigt många väck som inte syns sen. Kan programmet räkna på det med?
E: Man kan välja vilja fibermattor och de har ju olika strukturella.
V: Man kan sätta olika toleranser på det. Man kanske vet att man kan arbeta med ett gult området. Då kan man säga: mellan de här kan de va gult men när det blir rött måste vi hantera det.
J: Vad gör man då? Är det snitt och grejer?
E: Ibland bättre att ha två delar än att ha ett snitt. Vi har precis börjat men vi kommer kanske märka att programmet kan göra mer. Räknar också på data som vikt etc…
C: Då kan man även se hur mönsterpassningen blir i en skarv?
V: Ja. Man kan även säga att de ska överlappa och se hur det blir
E: Det kan ju va bra att själv förstå hur man ska överlappa, beskära. Man vill hitta ett sätt att drapera som har stor design flexibilitet. Det ska resultera i en Plybook och visa hur de olika flat patterns blir.
J: Hur börjar man ? Vad är första steget om jag har en 3D-modell från en kund?

V: Net boundary och extended boundary. Dela upp i zoner eller säga att allt ska draperas. Gör koordinatsystem som bestämmer utgångspunkt och riktning. Resultatet påverkas av var du placerar din rosette. Man måste veta vart man ska börja laminera
E: Sen väljs lager och riktning och man kan sen spegla lagren. Om man ska använda detta programmet behövs först guidelines för hur man gör. Sen är frågan hur mycket man ska förstå själv. Det är inte självförklarande. Frågan e hur mycket ingenjörerna behöver veta själva. Hur vet ni hur ni ska börja? Finns instruktioner för t.ex. var draperingen ska börja?
C: Nej, oftast gör vi de första mallarna själva på den biten vi ska göra, eller någon annans mallar. Man provar sig fram, börjar på kanten och ser så att den passar. Det går inte lägga bara platt eftersom den går upp och ner. Då får man skriva att de ska va ca. 2 cm överlapp. Börjar man i en annan ända är det kört. Så det är bara prova sig fram och efter det görs mallarna efter det sätt som jag valt.
J: Gissningsvis behöver man prova sig fram även i datormiljön men med Cissis erfarenhet behöver man färre tester än en grön ingenjör. Men testerna går mycket fortare i programmet, tacksamt.
C: Här behövs en helt ny bit för att testa igen eftersom fibrerna dras isär fel. Oftast görs mallarna i ett annat material än vad som ska användas sen från ritningen, två till fem t.ex.
E: Så ni testar er inte fram med de dyrare mattorn. Blir det mycket spill i denna prövningen?
C: Ja det blir mycket spill till skillnad från skärmaskinen.
J: Då får vi hellre finjustera när vi har en första test-skärfil i rätt material och sedan får vi finjustera lite grann.
C: Mallarna som skickas fram och tillbaka håller bättre om de görs i ett styvare material. Från början gjordes mallarna i plast men det är lättare om de sitter fast. Är det bara en platt mall kan man ha mall i plast eller papper.
J: Det låter som ett verktyg som i rätt händer skulle kunna vara väldigt väldigt värdefullt.
C: Det tycker jag med.
E: Catias komposit-design-arbetsbänk är inte tacksam att jobba med.
J: Är det ett stand-alone verktyg eller tillägg?
V: Tillägg. Catia-filen länkas.
26:30
E: Skärfilerna. Får ni de från kund eller har ni efter det manuella tagit fram att det är så de blir?
J: Arbetet idag är att de kommer fram till att såhär vill vi ha bitarna. Så försöker vi digitalisera de manuellt genom att ta bilder eller scanna och det har varit ett tidskrävande arbete. Det tar den här kameran hand om som skapar en skalenlig bild och alla linjer blir raka. Det kommer snabba upp det väldigt mycket. Vi får då ut 2d-CAD-filer. Ett nesting-program pusslar in bitarna på minsta möjliga yta för att slippa spillet. Det tjongas sen in i skärbordet. Alltså en mellanlösning… För med Fibersim från början hade vi manuellt inte behövt göra skärfiler och sedan behöva digitalisera dem utan vi hade fått ut mer eller mindre perfekta skärfiler från början. Men i vår värld kommer vi alltid ha kunder som kommer med en grunka utan ritningar så kameran behövs ändå. Men en kombination med en kamera och ett sånt verktyg hade skärfilerna varit en no-brainer, oavsett vad som kommer till oss.
C: Då hade vi kanske till och med klarat av första lagret ibland, som vi inte gör idag. Idag kör vi många första lager för hand som ska mönsterpassas exakt.
J: Där är det ofta materialkvaliteten. Leverantören till materialet specar att det får va en viss skillnad över materialets bredd på 2,5 cm.

C: Menar du millimeter? Det får inte ens va 1 mm då är det åt skogen!
J: Tråden får va 2,5 cm off men den kan utmed vägen ändå kan va dålig. Därför får vi manuellt stå med rullen och hitta en plats där fibrerna är visuellt bra, oavsett hur fibrerna går. Därför måste leverantörerna steppa upp sin nivå.
C: Det är ett ganska stort steg.
J: Ja det känns som att det kommer aldrig gå. Vi kastar en rulle direkt som är mer än 2,5 cm.
Tystnad……
E: Vilka steg i processen fungerar bra idag?
C: När skärfilerna är färdiga och de skärs ut och vi har kommit på ett system för var de ligger. Kunna hämta en färdig påse i frysen där allt material till rätt del finns. Det syns då i datan om delen finns.
J: När vi plöjt igenom stegen i vårt tänka process så blir det ganska strömlinjeformat måste jag säga. Skärbordet ska skära ut veckobehov för varje rulle så att de inte behöver ställas om varje dag. Det syns då direkt i datorn om rätt skärkit finns i kylen. Men vägen dit är olika krokig beroende på komplexitet och i vilket skick underlaget är och formarna är. Det är många variabler.
E: Hur mycket tror ni att man behöver förstå teoretiskt och i praktik?
C: Ganska mycket egentligen. Du måste känna materialet du gör i händerna och förstå att det krävs en liten ryckning och att plast släpper bättre om den legat i frysen. Har plasten släpps finns det ingen anledning att lägga den biten för att fibrerna kan ha dragit sig. Det måste man uppleva och inte läsa av av data.
E: Det är väl det, världens bästa material på pappret…
J: ...sen kom den jävla verkligheten.
C: Rullarna är inte perfekta och fibrerna går inte så i verkligheten. Hur gärna du än vill det hade det underlättat otroligt. I datan gör de ju det och i kundernas specar är det datorgjort, ideal värld.

TEORI VS PRAKTIK

J: Ska man vikta det teoretisk eller det praktiska om vad som är tyngst, om vi pratar om det fysiska arbetet att drapera eller laminera, så är det den praktiska erfarenheten som väger tyngre. Sen behöver en teoretiker komma fram till vilka lager vi ska ha, de grovhuggna riktlinjerna. Men sen vänder behovet över till det praktiska,
C: Det behövs nog ett bra samarbete där emellan. Du klarar dig inte utan det praktiska arbetet överhuvudtaget.
J: Inte om man i förväg ska göra detta jobbet, det känns svårt. Det är nog även svårt att hitta en individ som klarar båda delarna, man måste nog hitta team som kompletterar varandra på ett bra sätt.
C: Finns säkert vissa enkla grejer man kan göra utan att ha sett en kolfiberbit, om du bara kan mycket i teorin. Men inte de svårare grejerna när det går upp och ner, fram och tillbaka och man ska lära sig var snitten ska vara. Så det behöver nog ett samarbete
E: Ska bli spännande vad vi kommer fram till. Det generellt svåra med kolfiber är att förutspå från papper till verkligheten, kommer det här hålla?
J: Inte mitt och Cissis område men det är så jag upplever det, att det är en stor utmaning till skillnad från traditionella plast och metall-konstruktioner. Det är så många fler variabler att det börjar bli komplicerat. Det finns säkert jättemycket hjälp att få i till exempel Fibersim antar

jag för har man bara alla egenskaper för alla materiallager borde det gå att räkna ut ganska väl tycker jag. Sen är det ju olika tryck i autoklaven, ytterligare en variabel.
C: Ja och det finns så många olika sorter och varianter av en sort. En två-åttio matta kan ha olika bäst- och sämsta-grejer. Ibland behövs glu-film för att ens kunna fästa. Finns ett överlapp måste du slipa.. man måste ha allt med sig.
E: Vad tror ni krävs för att bilindustrin ska kunna använda kolfiber i storskaliga produktioner?
J: Storskaligt funkar inte handläggning av mattor utan pressar av något slag som replikerar en människas sätt att laminera, vilket inte blir samma sak, men kan ändå funka om det ändå är en dörrsida som ska lackas. Det är en annan värld än vad vi jobbar med. Sen vet jag inte om ni på ert exjobb behöver klura ut på detaljnivå var mattan behöver börja läggas. Hittills har vi ingen kund som gett det till oss. Vi får grovhuggna laminatbanor, långt ifrån färdigt, som en wish-list, “vi vill att de här lagrena ska hamna här”. Och så får vi klura ut allt möjligt och vad det innebär.
C: “Vi vill ha en hel bit här” Jaha, det hade vi önskat att vi kunde.
J: För gemene man-konstruktören i befintliga industribolag, är ju detta ett ovanligt stort kliv att försöka även reda ut detta. Det överlämnar man ofta till leverantören, oss. Det löser vi ju uppenbarligen, oavsett verktyg eller inte. Sen tycker jag det här är jätteintressant att ha sådana verktyg och göra så mycket som möjligt i den virtuella digitala världen innan man börjar använda dyrt material och arbetstimmar. **Där finns hur mycket som helst att tjäna!**
E: Tack för att vi har fått vara här och testa på!
J: Kul! Hör av er om ni undrar något mer eller vill komma ut igen!

Visar de laminatplaner AH får
Väldigt basic laminatplaner, inte alls detaljstyrt.

C

Transcription Interview 2

Date: Friday 27/4
Name: Siddharth Kumaraswamy
Company: Volvo cars

E: Are they going to buy Fibersim now, is that like a decision made?
S: Fibersim is my tool of choice. Do you understand the workflow of composite? Do you have a good idea?
V/E: Yeah
S: If you design a part, do you know how development of a certain component works? In a full car program. Because at the end you have to fit this in to the program.
E: Maybe you can describe this briefly
S: Normally you have something like a concept work. The concept guys sit here. They decide how your supway, where you sidemembers/sill. You get a design on look. They normally will start with a very basic layout of the output and then they will go into first diction. This is where they start CADing stuff and most often in car companies you will see that they will use materials that they know with a specific thickness bla bla bla and its always steel. So basically, the old guys they do it very well because they been doing it for so long. So here is where you do the first CAE-loop. So, in the concept you take a lot of carry over parts. Carry over means a lot of parts from earlier platforms, to reduce cost, because each of this mould cost tens of millions of crowns. You have the first CAE-loop, then you go back, then you say “ok, I need these redesign changes”. Then this loop happens 6-8 weeks and then its finally goes on to “Beredningsmöte”.
Do you know what a beredningsmöte is? That's where you sit down with the cross-functional team. Here you have a cross-functional team sitting together looking all aspects, can you assemble this, is our equipment ok, is our process ok, is out tolerance fine. Normally you have another loop “from here to here”, so the concept goes back and forth, it’s a lot of jumping around. Then you package it fully and send it to specific CEA teams.
For body construction/mechanics, you have three CEA teams that work with you. CEA durability, safety, NVH (noise vibration harshness, how you feel in the car). They really, this I´ve never work with but these I’ve work with (durability, safety?). They just come in the last minute and they tell you “Ohh, this doesn’t work”. So, right now keep this away, but these are the two CAE which are more extensity working with the design team in the early stages of the process.
But if you look at where Fibersim fit in here, or you Fibersim tools are add-ons, or let’s not say Fibersim let’s say composite design extension. Where they fit in here, right in between these two. Because when you´re doing concept design you need certain analysis, like drapeability, packaging space (you have these darts that you cut in CFRP-plies), so packaging study. All this happens here. Fibersim is doing that here. Then it’s still part of this loop, but then you have this (how it will work in the future, when you implemented my…).
Let’s say Escenda comes out with a competes in fibersim, the way Volvo will work (or the way my team will work), we will use Fibersim there first only here. Over here fibersim will be in exile, it won’t do much. Because here, from the first group of CAE back at some working concept and then you sit down together with everyone and discus “Does this work?”. But this is more like an assembly, because Volvo doesn’t make parts, Volvo makes cars, suppliers makes parts. In this loop, you will send data to the suppliers. You will have to send a package of information to the supplier, that is where fibersim is well. So, these two is where Fibersim is working. The most important is the same information goes to the CEA as well.

So, if you´re building a composite part, the standard Volvo workflow (that doesn't exist now, that will exist in one month) that's how it will look. So this is what we´re implementing today. We´re bringing this workflow in and the thing is, over here you have something called Teamcenter, you know what that is?
V: Heard of it.
S: It's a PDM/PLM-tool. 06:24 Designers work in CATIA, everyone works in different tools but then you need a common place where you can go and see the car (in full assembly). Because nobody works with the entire car, everyone works on small systems. The place where it all comes together is Teamcenter. You can find every single document of the car, technical regulations, productions documents, everything in Teamcenter. Fibersim also has to communicate with Teamcenter and that's very nice for Fibersim because Teamcenter is also made by Siemens.
So this is the process that you will have to tend to with Fibersim. That's the important part. This looping, there is a lot of intermediate steps, but this is how we work.
And over there those things produce official attribute reports and it goes back to the design-loop and then that loop is 6-8 weeks. Now we can start with the interview, haha.

E: So what's your role in this development process?
S: What's my role… that's a hard question, I'm all over the place. I'm what you call a SA (property responsible), I'm responsible for the properties of the car. Like stiffness, crash, certain properties of the body, make sure it works. I'm the costumer for every engineer. They have to build a product that reach my requirements. If it meets my requirements it automatically reaches the safety etc.
I also work with method development, how we should build the car. Look at the different results from CAE and see if they are feasible.

V: Which steps in this process would you say works well?
S: "Pointing at whiteboard" The CAE part is sorted out. The information from the concept guys has to be good. Fibersim does automated ply books and flat patterns. The CAE has some requirements. Fibersim has a link between a design tool and a CAE tool. That is what you´re paying for.
We save models in CATIA as CATParts and then we import the geometry. For steel we get a thickness but not for composite, we need a ply book. We do that now, but Fibersim automates that.
FIbersim has two main requirements, Ply book generation and draping analysis. It needs to export .h5 as well. That is the file the CAE guys need, it contains everything you have. Without that Fibersim is worthless. Its important because Volvo calculates everything.
E: So, it's the concept part that´s bad right now?
S: Yeah, its bad. We make a lot of mistakes. Designing parts that can't be manufactured. They are not used to the material they can't see it. The information going from the concept to the manufacturing is also messed up. Its human work and humans suck. It cost Volvo time and time is money. The overlaps in composite design can't be tracked right now, that's where Fibersim is needed. Otherwise will make mistakes.
The Polestar car is a full CFRP car and a low scale production. I've worked in an origination with Fibersim and now in one without Fibersim and the different are just night and day. You need a tool to catch the mistakes.

E: Which step can be more efficient?

S: The Design step and the communication step. Make sure we don't make bad quality part. The documentation should be made automatically. Fibersim is needed.

E: Can you verify reality in Fibersim?
S: Yes, Fibersim just require the right input. The sheer lock angle is the most important thing for good results.

V: Is there any tools in Fibersim that aren't useful?
S: I know what I use and nothing more than I use. Don't know anything extra. It´s doing what I want it to do.
V: We are creating guidelines for Escenda and wanted to know what we shouldn't focus on
E: and what we should focus on.
S: Focus on Draping analysis and Ply book generation. If you focus on that you´re spot on. Information flow, ply book and .h5-file.

E: Is there any risk by using Fibersim?
S: Not any risks, but its difficult finding the competence. There are the scientist and the people in manufacturing, but not the guys in between. You need the experience!
E: How do you get there?
S: Like you guys did. Go to a manufacture and see how carbon fibre works and then work with it digitally. You need to have a overall understanding. Maybe a two week hands-on experience. It's hard to just write everything in words, I'm not even there yet.
Maybe write about the deformations modes in a fabric. Inter-ply slip, Intra-ply slip, ply-to-tool slip, consolidation and shrinkage.

E: We´ve talked to Lars and he said that the things needed for the CAE is a h5-file, a mid-surface with machine features. 28:00
Just need a surface, the tooling surface is fine to work with.

E: We will create this ply book for a Door
S: Nice, doors are a disaster
E: Do you know how long time it would take?
S: Who are you sending it to? You can send it to me. I can tell you how well it works. I will write you a document with what´s right, what´s wrong and how to improve, please send we the ply book as well.
It's not an easy thing to implement, it took 9 years at Volkswagen. But now it can take 3 years.

E: What should the guidelines include?
S: Drapeability, Zone definitions, Zone transitions, Darts, flat patterns, .h5-file/Ply book.

S: Volvos safety analysis is out of this world. They even do moose test. So, it's important to have a good link between CAE and Fibersim.

E: How much do you use CFRP in Cars at Volvo?
S: We use a lot of glass fibre, but carbon fibre will get more common. But 2020 we need to drop the weight of the body. So, in the next two years you will see a lot of growth. 2021, when the next line of cars are introduced we will have a lot more carbon fibre in Volvos cars.

D

Kano Questionnaire

Manual för inlärning

Hej!
Vi heter Emma och Victor och gör just nu exjobb om implementering av kolfiber i bilindustrin. En del av exjobbet är att vi ska skapa en manual/inlärningsverktyg som ska användas av nyanställda på företaget för att lära sig en programvara. Programvaran används för att simulera hur kolfiber beter sig i verkligheten och används i samband med ett CAD-program (ex. CATIA).

Dina svar kommer hjälpa oss definiera vad manualen bör innehålla för att skapa en så bra, effektiv och långvarig inlärning som möjligt.
Tack!

*Obligatorisk

Innehåll

1. **Hur skulle du känna om...** *

Markera endast en oval per rad.

	Vill ha det så	Gillar det	Är neutral	Kan leva med det	Ogillar det
..manualen gav dig översiktlig förståelse kring ämnet?					
..manualen inte gav dig översiktlig förståelse kring ämnet utan bara beskrev programvaran?					
..beskrivningarna blandades med övningar?					
..det inte fanns några övningar?					
..man gick igenom ett verktyg bara en gång?					
..man gick igenom ett verktyg upprepande gånger?					
..innehållet kompletterades med beskrivande bilder t.ex. skärmdumpar					
..innehållet inte kompletterades med beskrivande bilder t.ex. skärmdumpar					

Gränssnitt

2. **Hur skulle du känna om...** *

Markera endast en oval per rad.

	Vill ha det så	Gillar det	Är neutral	Kan leva med det	Ogillar det
..det var ett lättförståeligt gränssnitt?					
..det inte var ett lättförståelig gränssnitt?					
..manualen hade ett proffsigt intryck?					
..manualen inte hade ett proffsigt intryck?					
..det fanns en tydlig struktur t.ex. mha siffror?					
..det inte fanns en tydlig struktur t.ex. mha siffror?					

3. **Har du andra synpunkter på vad som är viktigt/inte viktigt i en manual?** *

E
Design specification

	Design specification - Guidelines		
	M - Must-be O - One-dimensional D - Delighter		
	Demand	**Comment**	**Origin**
M	Written in English	Include wide user group	Escenda
M	File format: PDF	Enable file opening and prevent changes by unfit users	Escenda
M	Describing Fibersim tools	Create knowledge and utility of software	Escenda
M	Escenda logo	Ownership by the company and recognition for employees	Escenda
M	Structure	Consice information, intuitive learning	QFD/interview
M	Table of content	To create wokflow structure and simple overview	QFD/interview
M	Intuitive interface	Ease learning, recognition, comprehensible	User
M	Pictures	Intuitive and easier learning and recognition	QFD
M	Concise information	Not too long	OFD
O	Icons	Recognition to software	Interview
O	Index	Searchability	Interview
D	Examples	Enable practise and reconnect to tool review for long-term knowledge	QFD
D	Professional design	High resolution images and thoughtful color palette	Designers
D	Practical background	Create overall understanding about CFRP	QFD

Figure E.1: Design process for CFRP parts and where Fibersim could be implemented