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Design and Construction of Mega Wedge Semi-trailer

Real Case Study for the Company NTM

School of Technology and Innovations
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ABSTRACT :

This thesis was carried out on behalf of Oy Närpes Trä och Metall at their trailer construction department. The aim was to plan and design a customized semi-trailer with SolidWorks and to carry out a production follow-up during its manufacture. The unique feature of this semi-trailer is its tilted floor with a 150 mm lower loading height at the rear compared to the front, which corresponds to a floor slope of approximately θ degrees.

The design work began with a standardized semi-trailer, which was then customized to meet the specific customer's wishes regarding dimensions and equipment. During the design phase, it was ensured that the semi-trailer complies with all the company's requirements, as well as various laws and directives, so that the semi-trailer is approved for operation on both national and international roads.

Literature reviews and case studies were utilized both before and after the design process to become familiar with the subject and draw lessons from similar previous projects. To ensure the quality of the new design and optimize production efficiency, the Design for X principle was applied during the design process. SolidWorks Simulation, based on the finite element method was used to ensure the strength of the design. Action research was used to observe and identify quality deficiencies, as well as other success factors and challenges that arose during the manufacturing process.

The result was a completed semi-trailer ready for delivery to the end customer and gained knowledge and insights on how the developed design can be further optimized for similar projects in the future.

KEYWORDS: Mechanical Engineering, Transportation Engineering, Manufacturing Processes, Semi-trailer, CAD Design, and Production/Quality Follow-up

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ABSTRAKT :

Denna avhandling utfördes på uppdrag av Ab Närpes Trä och Metall vid deras konstruktionsavdelning för trailers. Syftet var att planera och konstruera en kundspecifik påhängsvagn med SolidWorks och sedan genomföra en produktionsuppföljning under tillverkningen. Det unika med denna påhängsvagn är dess lutande golv med en 150 mm lägre lasthöjd baktill jämfört med framtil, vilket motsvarar en golvlutning på cirka [REDACTED] grader.

Konstruktionsarbetet utgicks från en standardiserad NTM påhängsvagn som sedan anpassades efter den specifika kundens önskemål angående dimension och utrustning. Under konstruktionsfasen beaktades även att den kundspecifika påhängsvagnen uppfyller alla de krav som företaget samt olika lagar och direktiv ställer, för att den ska vara godkänt för drift på både nationella och internationella vägar.

Litteraturgranskningar och fallstudier användes både före och efter designprocessen för att bekanta sig med ämnet och dra lärdomar från tidigare liknande projekt. För att säkerställa den nya designens kvalitet och optimera produktionseffektiviteten tillämpades Design for X under designprocessen. För att säkerställa designens hållfasthet användes SolidWorks Simulation, som baserar sig på finita elementmetoden. Aktionsforskning användes för att observera och identifiera kvalitetsbrister samt andra framgångsfaktorer och utmaningar som uppstod under tillverkningsprocessen.

Resultatet blev en färdigtillverkad påhängsvagn redo för leverans till slutkunden samt erhållna kunskaper och insikter om hur den framtagna designen ytterligare kan optimeras för liknande projekt i framtiden.

Nyckelord: Maskinteknik, transportteknik, tillverkningsprocesser, påhängsvagn, CAD-design och produktions-/kvalitetsuppföljning

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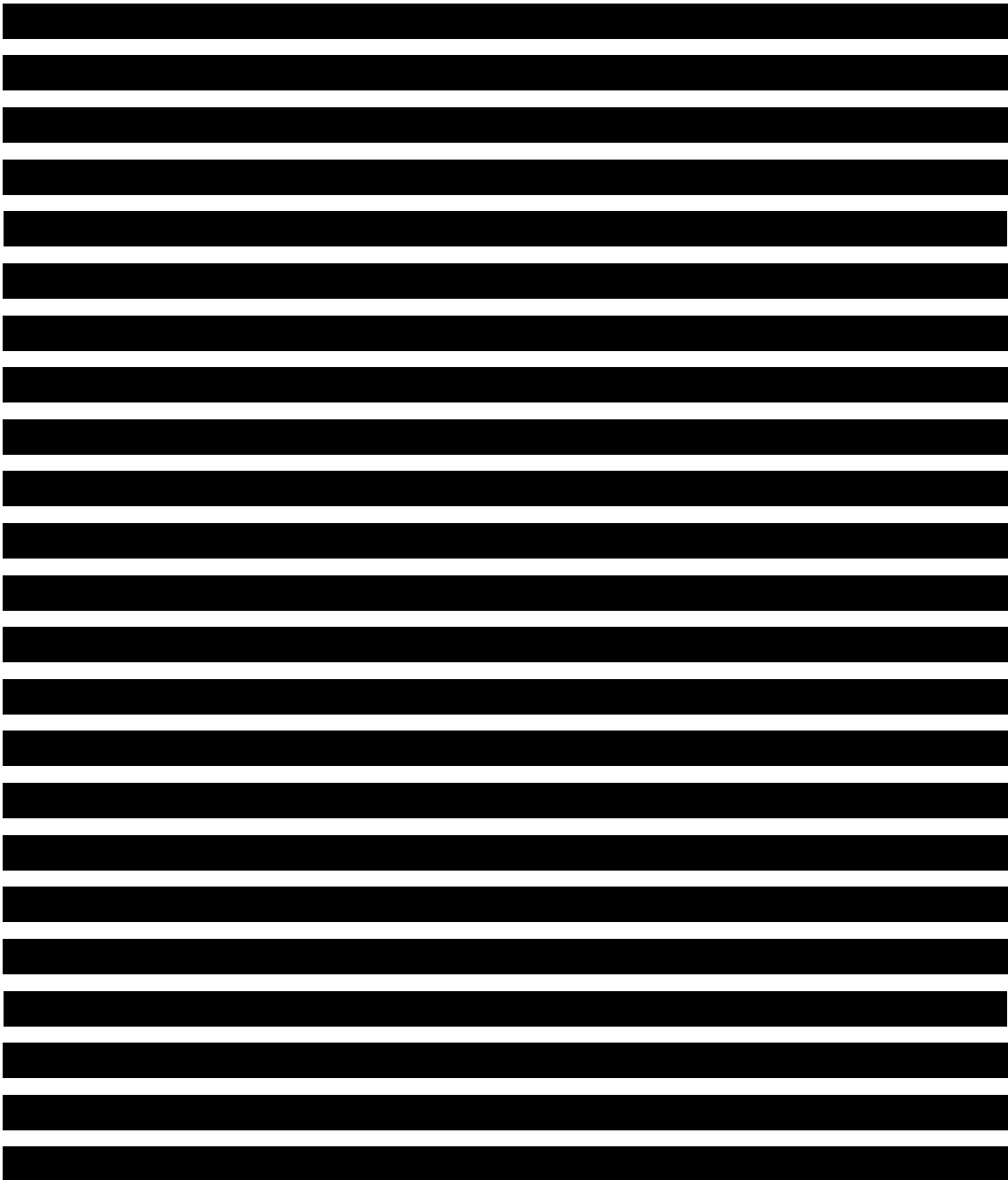
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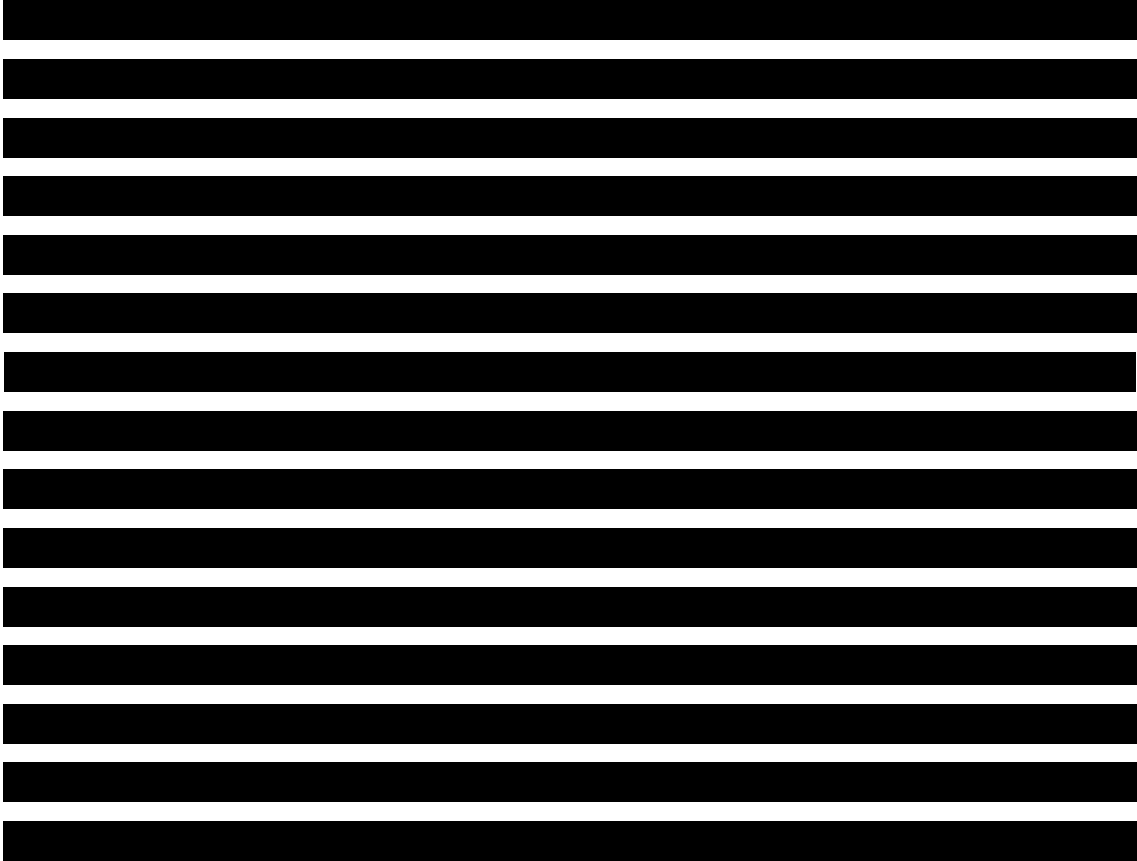


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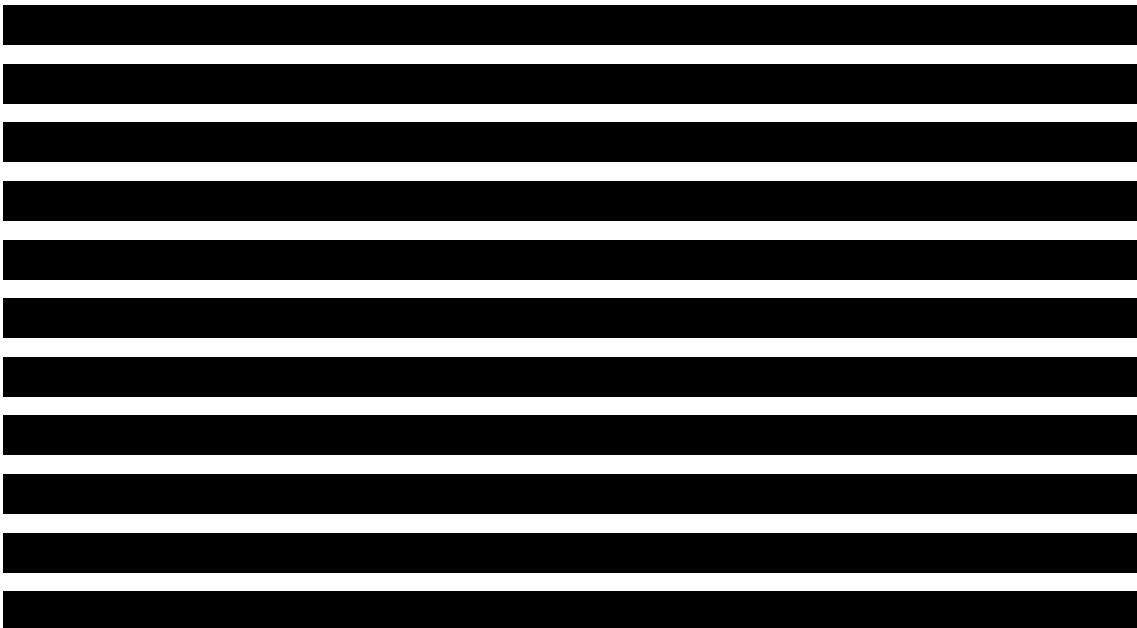
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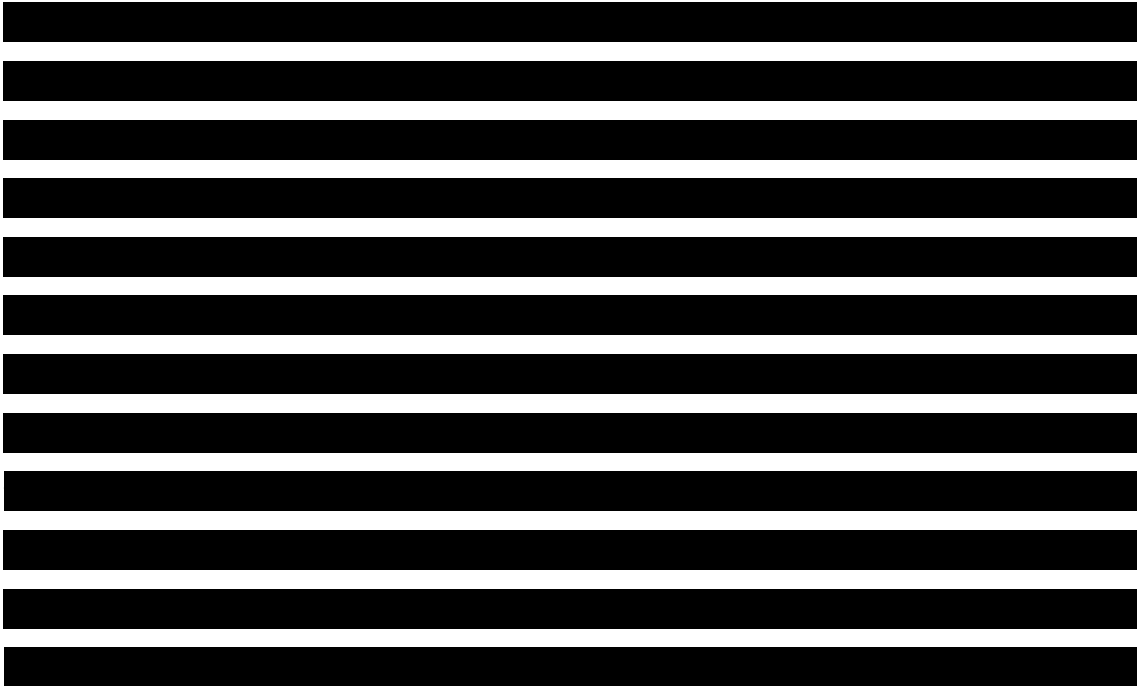
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Abbreviations

BOM Bill of Materials

CAD Computer-Aided Design

CEN European Committee for Standardization

CENELEC European Committee for Electrotechnical Standardization

DfX Design for X

CNC Computer Numerical Control

EC European Commission

EMS European Modular System

EN European Standard

ETSI European Telecommunication Standards Institute

FEA Finite Element Analysis

FEM Finite Element Method

GRP Glass Reinforced Plastic

ISO International Organization for Standardization

MAG Metal Active Gas

MIG Metal Inert Gas

NTM Närpes Trä & Metall

PDM Product Data Management

XPS Extruded Polystyrene Insulation

1. Introduction

This thesis has been conducted for the company NTM, which is an abbreviation of Närpes Trä och Metall. Hereafter, the abbreviation NTM will be used throughout the thesis. This chapter provides the background context for the thesis. It begins with an explanation of the thesis objectives, which includes the company's goals for this research and the unique aspects of the work. This is followed by a review of the academic foundation, which describes the relevant disciplines within academia that underlie the thesis. Subsequently, an overview of the research methodologies used in the thesis is presented. Finally, an outline of the thesis structure is provided, describing the content of each chapter.

1.1. Aim of the Thesis

The company's objective with this thesis is to develop a custom design for a semi-trailer tailored to a specific customer's requirements using CAD design and then oversee and support the production throughout the manufacturing process. The academic aim is to compare and apply relevant theories while documenting the entire process and practical work. What makes this semi-trailer unique is the tilted floor, with a 150 mm lower loading height on the inside of the rear walls compared to the inside of the front wall.

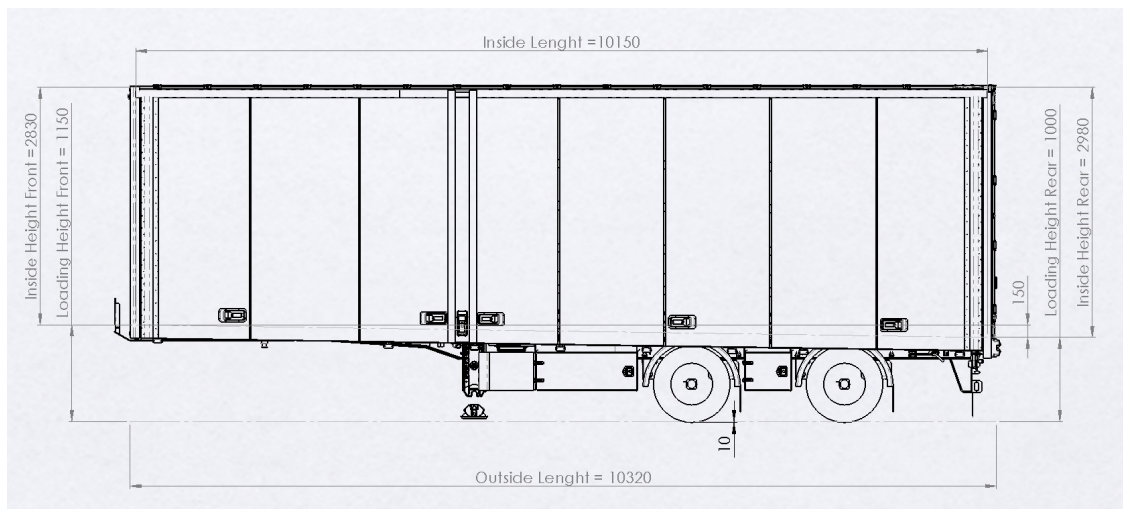


Figure 1. Shows the semi-trailer's specified dimensions regarding the loading height.

In addition, the box body is designed in a wedge-shaped configuration, resulting in the inside height at the rear being 150 mm higher than at the front to maintain the same overall height along the vehicle. This design allows 150 mm higher goods to be loaded at the rear compared to the front. The semi-trailer is also equipped with a rear-opening tarpaulin roof that can be utilized to allow the goods to protrude above the roof, which can be especially useful in special circumstances.

1.2. Academic Background of the Thesis

The background for this thesis is that the company has not previously produced a semi-trailer with a tilted floor of this type for a significant period of time, resulting in a lack of existing knowledge and general experience in this specific field. The academic foundation of this thesis lies at the intersection of three main disciplines:

Mechanical Engineering: The design and engineering aspects of the semi-trailer, including structural integrity, material selection, and mechanical systems, are fundamental to this thesis. Knowledge of mechanical engineering principles, including statics, dynamics, and material science, will be crucial for developing a feasible design solution.

Transportation Engineering: Understanding the requirements and constraints of the transportation industry, including regulations, safety standards, and logistical considerations, are vital. Knowledge of transportation engineering principles will inform decisions regarding the semi-trailer's dimensions, load capacity, and overall functionality.

Manufacturing Processes: In-depth knowledge of manufacturing processes, such as welding, machining, and assembly, is necessary to support the physical manufacturing of the semi-trailer. Considerations regarding cost-effectiveness, production efficiency, and quality control will influence the design decisions and manufacturing strategies.

1.3. Overview of the Research Methodology

The research aspect of the thesis focuses on identifying and addressing the existing gap in knowledge and experience within the company regarding semi-trailers with tilted floors. This involves, among other tasks, conducting literature reviews, collecting relevant data, and using analytical and experimental methods to develop and validate the design concept. Below is an overview of the research methodologies used in this thesis:

Research Philosophy

The research philosophies for this thesis are positivist and objectivism research philosophy:

The *positivist* research philosophy includes:

1. Collecting and familiarizing with the end customer's specific requirements and wishes regarding measurable dimensions such as length, width, height, and equipment.
2. Utilizing SolidWorks to develop and create a detailed design based on the collected information.
3. Conducting necessary strength analyses using SolidWorks Simulation to identify weak points in the design and make necessary adjustments and improvements according to the simulation result to ensure that the design fulfills all the strength requirements.

The *objectivism* research philosophy includes:

1. Verifying the physical feasibility of realizing the end customer's all requirements to ensure that the design is manufacturable.
2. Applying the Design for X methodology to ensure that the developed design meets several important aspects such as quality, cost-effectiveness, manufacturability, usability, performance, and maintainability.
3. Ensuring that all adjustments and improvements made to the design according to the strength results are based on objective results rather than personal perceptions or preferences.

Research Approach

The research approach for this thesis follows a deductive methodology, which means that theory and hypotheses are tested through fact-based observations and experiments.

In this thesis, this approach involves:

- Utilizing SolidWorks to create, develop, and design concepts and drawings according to the end customer's requirements and specifications.
- Considering during the design phase how the developed design might affect assembly time, material usage, end-user experience, and ergonomics for the production department during manufacturing. Additionally, ensuring that the design complies with all relevant regulations and established quality standards in terms of functionality, durability, and safety.
- Conducting necessary strength calculations with SolidWorks Simulation to verify the strength of the structure.
- Conducting observations, interviews, and documentation during manufacturing to gather insights on the practical implementation.
- Collaborate and provide technical support to the production department during manufacturing to address encountered challenges.
- Reflecting on and conducting a final evaluation of the collected data, by analyzing the identified success factors and challenges encountered throughout the entire process. This is to facilitate the refinement and optimization of the design for future similar projects within the company.

Research Strategy

The research strategies for this thesis are:

- *Literature review*: Examining existing research material to understand the theoretical foundations necessary for carrying out the thesis, as well as investigating how NTM and other companies have historically implemented similar design solutions.
- *Case Studies*: Focusing on specific areas and conducting observations, analyses, and documentation during the design and manufacturing process to obtain a deep and detailed area of knowledge.

- *Action Research*: Close collaboration with the production department to identify and address encountered challenges during manufacturing to further optimize the design and its manufacturability.

Choices of Methods

The chosen methods for this thesis are a mixture of quantitative and qualitative methods. The quantitative methods involve making quantitative assessments of the semi-trailer's design, strength, and estimation of the production process before and during the design process. The qualitative methods involve conducting interviews, observations, and documentation of the collected data.

Timeframe

The timeframe for this thesis is cross-sectional, as the research will be conducted over a defined period. This structure is necessary as the company sets a deadline for the completion of the drawings and the strength simulations, as well as a delivery date by which the semi-trailer must be manufactured and ready for delivery.

Data Collection and Analysis

The collection and analysis of data for this thesis involves gathering primary data that is relevant and specifically intended for the research project. This includes conducting case studies to become familiar with similar design solutions, identify previous success factors, and address encountered challenges, as well as literature reviews to understand the theoretical foundations necessary for carrying out this thesis.

1.4. Thesis Outline

This sub-chapter provides an outline of the content of each chapter in this thesis:

This chapter *Introduction* outlines the purpose of the thesis, its academic foundation, and an overview of the chosen research methods.

The chapter *Research Problem Statement and Research Questions* outline the various challenges that have limited and directed the development of this thesis. The chapter ends by formulating the research questions.

The chapter *Theoretical Framework* presents the theoretical foundations that are the basis for carrying out this thesis practically.

The chapter *Methodology* outlines the methods employed to achieve the thesis objectives.

The chapter *Result* presents the final design of the semi-trailer, developed using SolidWorks, the strength calculations performed using the finite element method in SolidWorks Simulation, and the production follow-up conducted for this thesis.

The chapter *Summary of the Research Questions* provides answers to the research questions.

The final chapter, *Discussion* provides a comprehensive conclusion and final discussion.

2. Research Problem Statements and Research Questions

In this chapter, I will outline the most significant research problem statements that must be considered during the design phase of the customized semi-trailer with a floor that should be tilted about ████ degrees so that the loading height will be 150 mm lower at the inside of the rear doors compared to the inside of the front wall.

2.1. Adaptability and Dimensioning

One of the most challenging aspects of this thesis is to adapt and design the semi-trailer according to all the unique wishes and requirements of the end customer. At the same time, the design should be as manufacturing-friendly and flexible as possible, utilizing standardized components to the greatest extent to minimize the need for designing many new customized components. The new design must comply with the end customer's specified dimensions for length, width, and height, and comply with all relevant guidelines established by EC directives, national regulations, and the company's internal standards.

To facilitate this process, case studies and literature reviews will be conducted to identify and familiarize with the requirements set by EC directives and various regulations. In addition, previous design solutions implemented by NTM and other companies will be studied to gain insight into how similar design solutions and challenges have been addressed previously. The methodology design for X will be applied to optimize the manufacturing process and reduce potential challenges during the manufacturing process. This approach will facilitate the investigation of how the developed design affects manufacturing and assembly times, material usage, end-user experience for the customer, and ergonomics for the production department that will manufacture the semi-trailer.

2.2. The Balance between Strength and Weight

Another significant challenge in the adaptation and design of the semi-trailer is ensuring sufficient strength while keeping the weight of the semi-trailer as low as possible. The design must withstand both static and dynamic loads. Insufficient strength can lead to material fatigue or cracking when the material's yield limit is exceeded. On the other hand, an oversized and heavy structure would mean unnecessary weight. Striving for a low self-weight on the semi-trailer is critical because it allows better utilization of the payload capacity, which enables more cargo to be loaded before reaching the maximum permissible vehicle weight. Another advantage is that the fuel consumption is reduced with a low self-weight. To ensure this, the strength of the design will be analyzed using the SolidWorks Simulation module, which employs the finite element method for precise simulations and analyses. By performing strength analyses, the balance between structural strength and weight is optimized. This process ensures that the semi-trailer follows the safety standards and is robust enough to handle its operational demands.

2.3. Research Questions

1. Customization, Compromises, and Design Challenges during the Design Phase with SolidWorks:
 - *How has the design been tailored to address customer requirements, potential customization needs, production efficiency, regulatory compliance, and quality standards?*
2. Strength Analysis with SolidWorks Simulation:
 - *Which specific area of the structure experiences the highest stress concentrations and the greatest displacement?*
3. Construction-Related Difficulties in Manufacturing:
 - *What construction-related challenges were observed during the manufacturing process and how were these challenges addressed?*
4. Reflection and Final Evaluation of the Collected Data:
 - *How can the design be further refined and optimized based on the final collected data?*

3. Theoretical Framework

This chapter outlines the theoretical foundations that serve as the basis for the practical implementation of this thesis.

The first theoretical foundation I selected was to gain an in-depth understanding of the theory of material strength. The objective of strength theory is to make the best use of the properties of structural materials. From this perspective, there will first be an explanation of what static and dynamic loads are, followed by a description of the different types of mechanical loads. Finally, a description of the fracture mechanisms that must be considered when designing for strength will be described.

The second theoretical foundation I selected was product development and CAD design. From this perspective, there will first be a description of what new and further developments are. After that, there will be a description of CAD design, followed by an explanation of SolidWorks and the modules utilized in SolidWorks to carry out this thesis in practice. Finally, there will be a description of the purpose of the Bill of Materials (BoM) on drawings.

The third theoretical foundation is standardization. From this perspective, there will first be an explanation of what standardization means in practice. This will be followed by an enumeration of the most significant standardization organizations relevant to this thesis. Finally, there will be a description of the concept of standardized components.

The fourth theoretical foundation I selected concerns the requirements of various laws and directives regarding the dimensions and weights of the semi-trailer, necessary for vehicle inspection and its use on both national and international roads within Europe. From this perspective, there will first be a description of what EC-Directives are, followed by a description of the two most important EC-Directives addressed in this thesis.

Subsequently, there will be an explanation of the types of vehicles in the heavy goods vehicle category, followed by a description of the available axle combinations and the most important weight concepts. This will be followed by a description of what a light-insulated semi-trailer is, along with an explanation of how a sandwich element is designed, and which main dimensions are the most essential on a semi-trailer. Finally, there will be an explanation of the concept European Modular System, along with the permissible lengths, widths, and heights within this concept.

The final subchapter provides an overview of the primary manufacturing methods used to physically manufacture the semi-trailer addressed in this thesis. This includes an explanation of the operation and application of a press brake, plasma cutter, machining, MIG/MAG welding, and different surface treatment methods.

3.1. Literature Review

To obtain a solid theoretical foundation for the thesis, a lot of literature reviews were conducted. A literature review is a research method that involves the collection, summarization, and critical evaluation of existing and relevant data within a given or specific field. The literature reviews for this thesis will be conducted as follows:

1. Collect and summarize existing studies on similar vehicle types, focusing on semi-trailers with tilted floors, which NTM and other companies have historically manufactured. The objective of these studies is to examine previous design solutions, manufacturing methods, material selection, quality control measures, and feedback, to identify success factors and challenges.
2. Analyze the collected summarized data to identify possible knowledge gaps and areas where further research is needed.
3. Develop and select appropriate research methods, approaches, and tools to conduct and manage the research, as well as to develop a design that meets customer specifications and requirements, while complying with applicable regulations and technical standards related to functionality, durability, and safety.
4. Compare the conclusion and discussion of the thesis with the result of the literature review to evaluate how well they match with each other. This is to identify potential challenges and to draw conclusions on whether their significance can contribute to the development of knowledge and improvements in the specific field of semi-trailers with tilted floors.

3.2. Strength Theory

Since the semi-trailer will be constructed from several different materials such as steel, stainless steel, aluminum, and fiberglass it is important to establish a theoretical basis regarding strength theory to understand how different materials and structures behave under various loads. The purpose of strength theory is to make the best use of the properties of structural materials. Utilizing the properties of the materials ensures that all safety requirements against breakage or harmful deformation, as well as functional and geometric requirements, are met.

Strength theory is a technological discipline that examines the relationship between mechanical forces and deformable bodies. (Johannesson, Persson, & Pettersson, 2013) In this subchapter, I will outline the most important fundamental concepts applied to strength dimensioning from a design engineer perspective. First, there will be a description of what static and dynamic loads are. After that comes a description of the types of mechanical loads there are, followed by an explanation of various fracture mechanisms and their causes. Finally, there will be a description of the finite element method and its applications.

3.2.1. Static and Dynamic Loads

Static loads are constant loads that are applied without any further change in direction or magnitude over time. It can be said that static loads are mass forces acting on a system at rest. (Dattakumar & Ganeshan, 2017) Examples of static loads can be the self-weight of the semi-trailer addressed in this thesis or applied loads, like the payload carried by the semi-trailer.

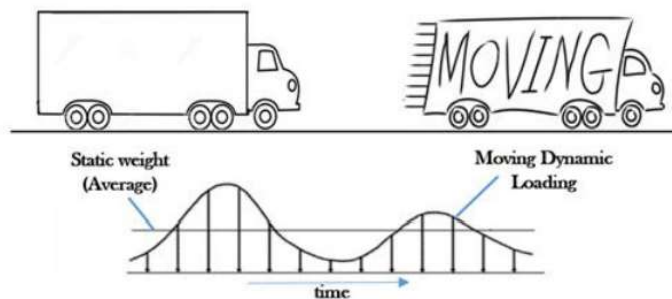


Figure 2. Shows the difference between static and dynamic loads. (Dattakumar & Ganeshan, 2017)

Dynamic loads, unlike static loads, are loads that vary over time. A dynamic load can be either periodic or irregular and its intensity and direction can vary over time. An adapted technique is required to analyze dynamic loads effectively. When analyzing dynamic loads, consideration must be given to different factors, like resonant frequencies, damping, and other dynamic load variations that the structure will be exposed to over a significant period. (Dattakumar & Ganeshan, 2017) Examples of dynamic loads can be the wind resistance to which the semi-trailer is exposed, vibrations from the engine, or other loads the semi-trailer is exposed to while driving in traffic.

3.2.2. Types of Mechanical Loads

During the design process and structural strength analysis, it is important to understand the different types of mechanical loads to ensure that the developed design can withstand all the forces and stresses it will be subjected to in different situations. Below is an explanation of different types of mechanical loads:

Tension Loads

Tension loads are either forces applied in one direction or two forces acting in opposite directions. An example can be when you are applying a load to the center of a beam, which causes it to bend downward at the exposed area. Another example can be when you are pulling at both ends of a rubber band from which the rubber band is stretched out and becomes longer due to the forces in the opposite direction. (Shigley, Mischeke, & Budynas, 2004)

Compression Loads

Compression loads are when applied forces squeeze a material together, in the opposite direction as tension load. An example can be when you are compressing a spring, which then returns to its original position once the applied pressure is released. (Shigley, Mischeke, & Budynas, 2004)

Bending Loads

Bending loads are when applied forces cause a material to bend in one direction. These loads can lead to stress concentration in the exposed areas of the material that are subjected to both tension and compression. (Shigley, Mischeke, & Budynas, 2004)

Torsion Loads

Torsion loads are when applied forces cause a material to rotate around its longitudinal axis. An example of a torsional load can be when you are turning a screw with a wrench. (Shigley, Mischeke, & Budynas, 2004)

Shear Loads

Shear loads are when two forces with opposite directions are applied parallel to each other, causing the exposed areas of the material to be sheared relatively apart from each other. An example of shear loading is when you cut into a piece of paper with scissors. (Shigley, Mischeke, & Budynas, 2004)

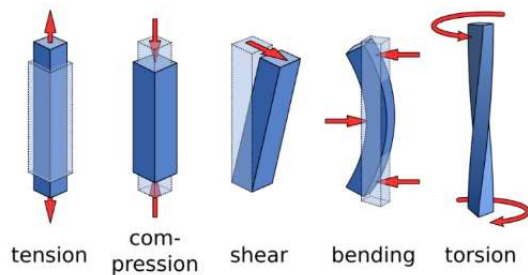


Figure 3. Shows different types of mechanical loads. (Bartleby, 2024)

3.2.3. Fracture Mechanism

Since the semi-trailer will be exposed to different types of loads under different conditions, it is crucial to understand potential fracture mechanisms that can arise throughout its operational lifetime. The fracture mechanism deals with different processes that contribute to the breaking or cracking of a material at different loads to which it will be exposed during its operational lifetime. It is essential in design processes to understand different fracture mechanisms that can occur for different materials and to prevent breakages that can in the worst case result in a serious accident. In the case of a specific given design, it is important to choose the right materials and manufacturing methods to prevent the occurrence of fracture mechanisms (Hodford, 2009). Below is an explanation of the most common fracture mechanisms:

Brittle Fracture

Brittle fractures are when a material rapidly breaks without any visible deformation being noticed before. A brittle fracture occurs if there are loads on the material that are higher than the critical fracture stress of the material. The appearance of brittle fracture often leads to the formation of cracks from the exposed area, which then spreads through the material. The appearance of brittle fracture is more common on materials with low plastic properties such as ceramics or certain types of steel. (Hodford, 2009)

Ductile Fracture

Ductile fractures are when a material starts to deform before it finally breaks. Ductile fractures occur unsteadily at loads lower than the yield limit of the specific material. Ductile fracture is more common on materials with significant plastic properties where the material is stretched into a noticeable deformation before it finally breaks. Metals such as steel and aluminum are examples of materials with plastic properties. (Hodford, 2009) (Krupp, 2007)

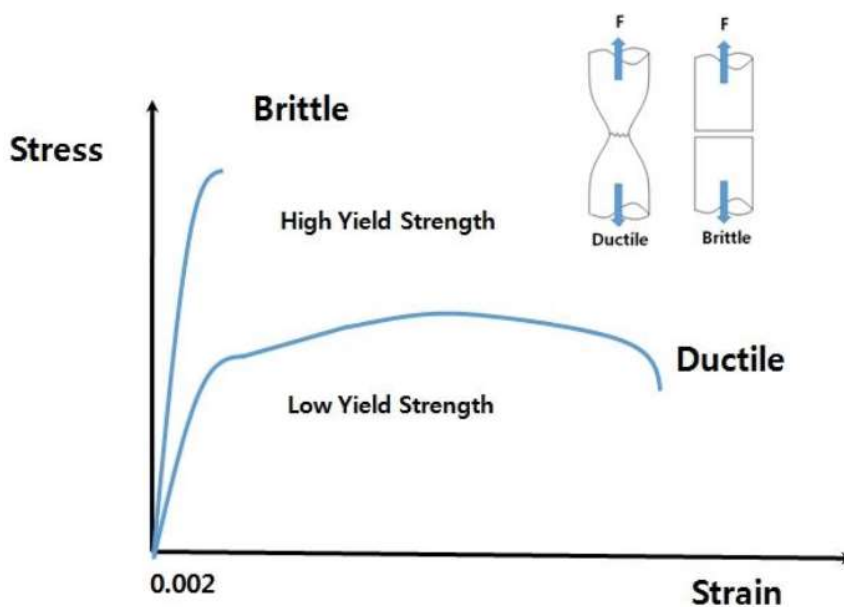


Figure 4. Shows the difference between brittle and ductile fractures. (Woo, 2017)

Fatigue

Fatigue fractures occur in materials subjected to repeated loads due to varying conditions or cyclic stresses. These repeated loads can lead to the formation of microscopic cracks, which gradually spread through the material until a fracture occurs. Fractures like this are more common for metallic materials, and they can also occur under loads that are below the maximum strength of a particular material. (Hodford, 2009) (Krupp, 2007)

Fracture Toughness

Fracture toughness occurs if there are cracks or other microstructural defects on the material that decrease its fracture resistance. This can result in cracks or other microstructural defects starting to rapidly spread through the material and cause a potential fracture even at low loads that would not normally cause a fracture. (Hodford, 2009) (Krupp, 2007)

Corrosion Fracture

Corrosion fracture occurs due to chemical reactions contributed by the surrounding environment. In case of corrosion fracture, the material begins to gradually break down, which degrades its structure and properties until it finally breaks. Corrosion fractures can even occur at loads lower than the material should have been able to withstand. (Fontana, 1987) (Krupp, 2007)



Image 1. Shows what a steel structure can look like when it has broken due to rust formation. (Wikipedia, 2023)

3.3. New Development and Further Development

Since the practical implementation of this thesis focuses on developing a customized design for a semi-trailer tailored to the specific needs of a customer, it is essential to understand the various types of product development there are. Industrial product development projects can be divided into two main categories: new development and further development.

In new development, you develop something completely new that no one before has experienced. Thus, this development method is characterized by high creativity and contribution of new, previously unknown solutions, uncertainty, and risk-taking. An example can be the development of new technologies which later will be included as part of a product concept. (Johannesson, Persson, & Pettersson, 2013)

The second major category in industrial product development is further development. In this category, the company develops their products which they have extensive experience with. This category is the dominant development method in industrial product development projects. This method of development is usually based on improved previously known product concepts such as an existing NTM product in this case. The changes made during further development take place at the subsystem level, this means that previous design solutions are improved to either meet new criteria or to be able to introduce new technology, for example, created during new development. (Johannesson, Persson, & Pettersson, 2013)

3.4. CAD Design

Since the practical implementation of this thesis focuses on developing a customized design for a semi-trailer based on the needs of a specific customer using CAD design, it is essential first to establish a theoretical basis for how CAD design can be utilized effectively. CAD design is the process of creating digital representations of physical objects or systems with the help of computer programs. The CAD program SolidWorks was used to make the digital representation of the semi-trailer addressed in this thesis. This section will first provide an enterprise overview of SolidWorks, followed by a detailed description of its approach and the structure and functionality of its different modules.

3.4.1. SolidWorks

The actual design work and finite element analysis for this thesis will be performed by using SolidWorks. SolidWorks is a two- and three-dimensional CAD program owned by the company Dassault Systemès. CAD is an abbreviation that stands for Computer-Aided Design. The purpose of CAD programs is to create technical drawings digitally.



Figure 5. Shows the SolidWorks logo. (1000LOGOS, 2024)

The CAD program SolidWorks functions as a coordination system with an origin point in which different axes and planes are used. SolidWorks was founded in December 1993 by Jon Hirschstick and the first release of SolidWorks was released in 1995. SolidWorks was then the first CAD program to use 3D modeling and this changed the approach for engineers to bring their ideas to life. SolidWorks was bought in 1997 by the French company Dassault Systemès. (Scan2CAD, 2023)

3.4.2. The SolidWorks Approach

The operational approach in SolidWorks is divided into several distinct modules. The modules used for this thesis are SolidWorks Parts, SolidWorks Assembly, SolidWorks Drawings, and SolidWorks Simulation.

3.4.2.1. SolidWorks Part Module

First, the SolidWorks Part module is used to create the geometry of individual parts utilizing various tools and functions. This process involves that you first create different basic shapes, and sketches in 2D, which can be anything from drawn lines and curves to cylinders and cubes. The model is then built up in 3D by using a feature-based modeling approach that adds various features to the geometry. This can be anything from extrusion and cutting to mirroring and pattern features.

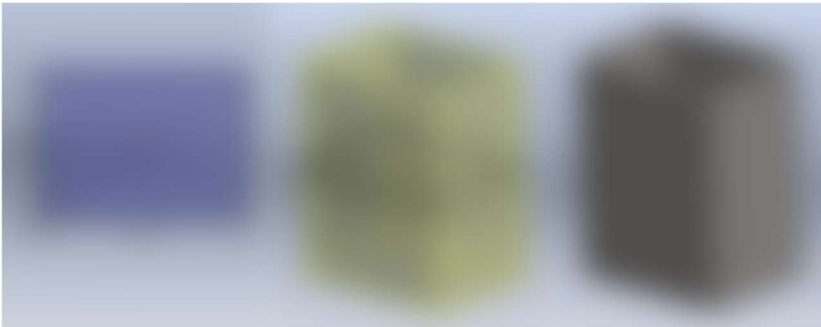


Figure 6. Shows what it looks like when you extrude a drawn-up sketch.

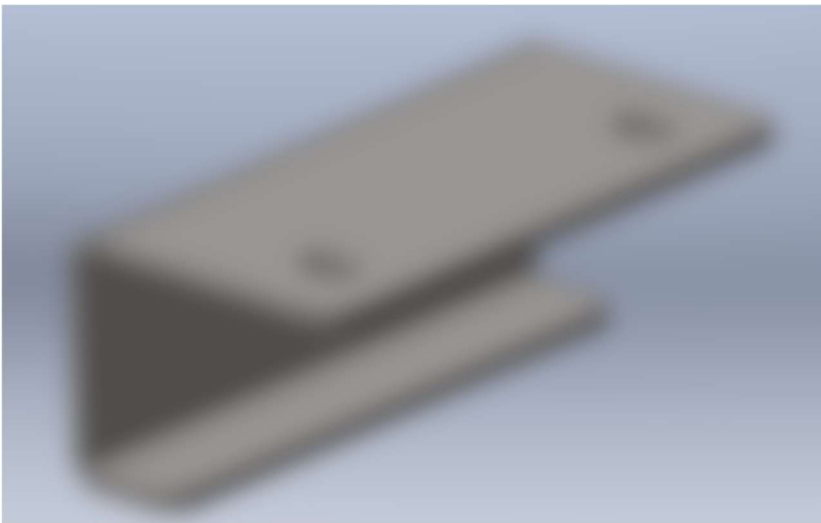


Figure 7. Shows a bent sheet metal part that has been created using the SolidWorks part module.

You can also choose between different materials in the module that you want the created geometry for the design to have. By choosing materials, it is possible to identify the properties and behavior of different materials in the developed design. Properties such as weight, density, and other thermal properties can also be specified in this module.

(Official SOLIDWORKS Community)

3.4.2.2. SolidWorks Assembly Module

The SolidWorks Assembly module is used to create and manage collections of multiple components and elements. The procedure involves importing selected components and elements that you want to place and connect to the assembly. The SolidWorks Assembly module includes tools that allow you to move, rotate, adjust, and lock the position of each component to fit together according to your requirements and preferences.

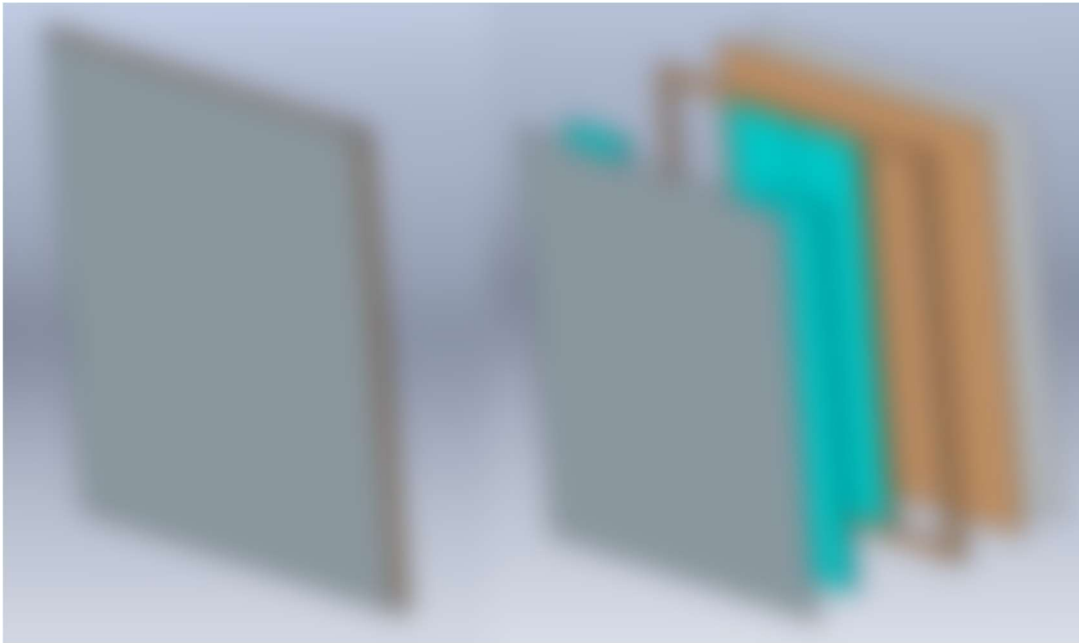


Figure 8. Shows the front wall of the semi-trailer addressed in this thesis, which has been assembled using the SolidWorks Assembly module.

It is also possible in the module to create movable connections and other realistic movements between the imported parts. You can also create subassemblies in the module to make it easier to manage and organize large collections of components and elements by categorizing and treating multiple components or elements as a single unit, which results that you have fewer components and elements to keep track of in large assemblies. (Official SOLIDWORKS Community)

3.4.2.3. SolidWorks Drawing Module

The SolidWorks Drawing module is used to create detailed 2D drawings of the created 3D models in the Part and Assembly modules. It is possible to create different default views in the drawing module such as front view, side view, top view, or other views automatically from the selected 3D model. Then, to clearly describe the dimensions and requirements of the design, different dimensions and tolerances can be added to the drawing. All this is added to be able to visualize the 3D model in different 2D views with specified dimensions and tolerances so that the reader of the drawing can get a holistic view of the design and be able to manufacture it physically by reading the drawing.



Figure 9. Shows a drawing of a centre beam used in the frame of the semi-trailer addressed in this thesis.

In the module, it is also possible to add various tables of content to the drawing such as Bill of Material, welding information as well as annotations to provide additional information. It is also possible to manage revision history, i.e. it is possible to track and manage different changes and updates that have been made to the drawing over time. (Official SOLIDWORKS Community)

3.4.2.4. SolidWorks Simulation

SolidWorks Simulation is an add-on module in SolidWorks based on the finite element method. The simulation module contains various tools that can be used to simulate the following:

- **Simulation of static loads:** This allows you to simulate static load analyses such as how a part or assembly reacts to applied forces such as pressure, torque, and other static loads to assess which areas of the developed design are deformed or exposed to high-stress concentrations.
- **Simulation of dynamic loads:** This allows you to simulate dynamic load analyses such as how a part or assembly reacts to vibration, shock, and other dynamic loads to assess the dynamic stability of the developed design.
- **Thermal Analysis Simulation:** This allows you to simulate heat transfers, temperature changes, and other thermal loads on a developed design to analyze and assess the thermal behavior.
- **Simulation of computerized fluid dynamics:** This allows you to simulate how liquids or gases move and behave within designs with close systems to analyze, understand, and optimize the flow patterns and pressure of the system.
- **Drop test Simulation:** This allows you to simulate how a design behaves when it is exposed to a fall or when something falls on it. This allows you to assess what forces are generated by the fall or how the object being exposed is deformed.

The purpose of SolidWorks Simulation is to perform in-depth analyses to improve developed designs and ensure that they are sufficiently reliable and that they achieve their intended performance. (SolidWorks education)

3.4.2.5. SolidWorks PDM

To find different parts, assemblies, drawings, and simulations quickly and easily, NTM uses a database program called SolidWorks PDM. PDM stands for Product Data Management. PDM assumes that each user has their own personal account with a username and password that gives different rights over what the users have the right to do with different files.

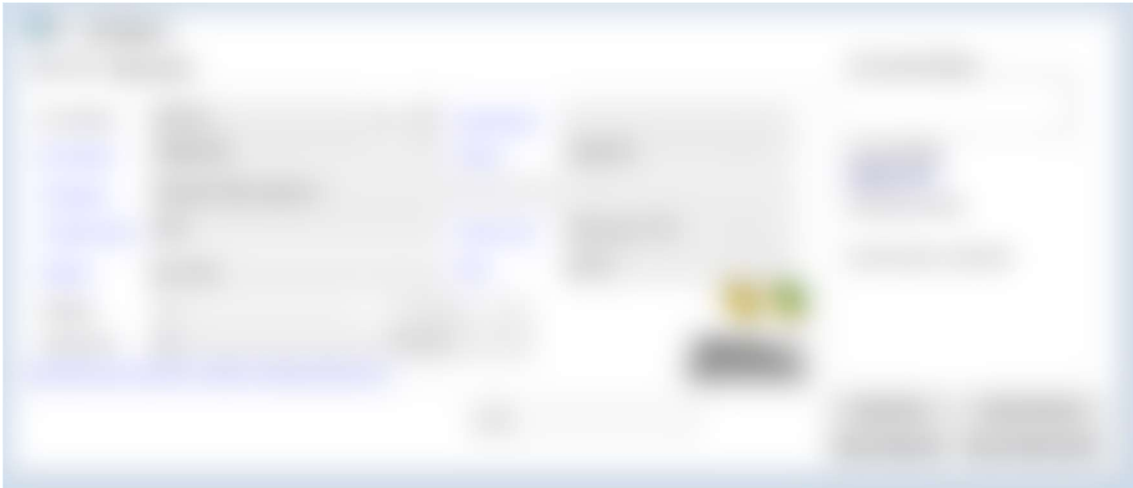


Figure 10. Shows what a data card looks like in SolidWorks PDM for a specific product at NTM.

Each file in the PDM system has its own data card, in which the most essential information is filled in, such as part name, dimension, and material selection. When you save a file in PDM, it automatically receives its own article number and a drawing number a so-called D-number, which also becomes the name of the file. When searching for a file, you can easily find it by searching through the information on the data card. When you are clicking on a file a thumbnail of the object is shown in a window that you can review before you open the file. To make a change to a file, it should first be checked out. While the file is checked out, no other user can open the file and revise it. When the file is checked in after the revision, it is saved as a new revision. (NTN-Internal Document)

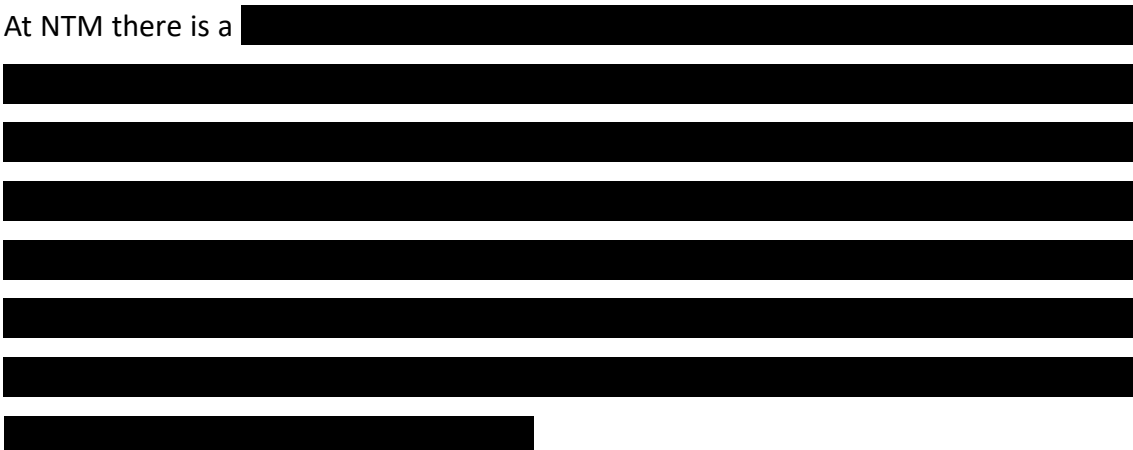
3.5. BOM Part Lists on Drawings

When creating each drawing, a BOM part list is created, specifying the components required to manufacture the semi-trailer. This list is crucial to ensure that all necessary parts are identified and available during the manufacturing process. BOM is an abbreviation that stands for Bill of Materials. BOM is a part list created by the engineer or designer on the drawing that lists all the components and materials that are required to manufacture or assemble a product. The BOM part list includes product information such as product- or material description, dimensions, article number, and needed quantity. The purpose of managing components and materials from BOM part lists is to optimize the production process by minimizing excess inventory and waste, as well as improving delivery times and product quality. By carefully planning and following the BOM part lists, companies can streamline their component and material handling and therefore achieve more cost-effective and resource-efficient manufacturing. (Ullman, 2018). Below is a description that explains how NTM handles the BOM part list for their production process.



Figure 11. Shows a BOM (Bill of Materials) part list for an assembly drawing at NTM.

At NTM there is a



[REDACTED]
[REDACTED]
[REDACTED]
[REDACTED]
[REDACTED] Through this process, efficient and smooth management of material flow from purchase to production is ensured. (NTN-Internal Document)

3.6. Standards

Knowledge of standards is a critical aspect of product development. Standards ensure that the developed products are safe, reliable, and acceptable to the market, while also contributing to efficient production. Standards are general agreements on solutions to common problems in all areas. A standard can apply to most products used in our everyday life, ranging from the simplest screws or nails to more complex products such as data communication, industry, healthcare, and the environment. Standardization means developing a product to get the best solution for its general use. (SIS, Svenska Institutet för standarder, u.d.) Below is a description of two standards organizations ISO standard and EN standard, which both play an important role in supporting innovation and growth in their respective fields and ensuring that technology and products meet high standards of safety, quality, and performance.

1. **ISO-standard** is an international standard that develops global standards in all areas except telecommunication and electricity. ISO is an abbreviation of the International Organization for Standardization. (Taavola, 2021)
2. **EN-standard** is a European standard developed by the organizations CEN, CENELEC, and ETSI. CEN is an abbreviation of the European Committee for Standardization, and they develop European standards for manufacturing, testing, and approval. CENELEC stands for European Committee for Electrotechnical Standardization, and they develop standards in electrical engineering and other related fields. ETSI stands for European Telecommunication Standards Institute, and they develop standards in telecommunications and information technology. (Taavola, 2021)

3.6.1. Standardized Components

The purpose of having standardized components is to cut down on unnecessary and costly variants of semi-finished products, purchased components, and raw materials. The objective of this standardization is to be able to offer customers a large quantity of final products based on a limited number of raw materials and purchase components. In component standardization, it is common for a component to be interchangeable, i.e. the component is adapted to be used for several different designs and end products.

A summary of the benefits of this standardization is described in the following points:

- Unnecessary design work is avoided if a useful component already exists.
- Planning and management become easier when fewer components are available.
- Better use of warehouse space, production equipment, and tools.
- Purchase of components is improved, as a greater number of the same components are bought instead of many different components.
- Each specific component is given a wider range of use, and they can be better exploited where they are needed for existing product mixes.

However, the disadvantages are that the standardization limits the design of the component and that it limits better design solutions for certain products and customers. (Olhager, 2013)

3.7. What is an EC Directive

When designing a customized semi-trailer, many EC directives must be followed to be able to inspect the vehicle and perform it on both national and international roads. An EC directive means that the European Union sets out the objectives to be achieved by the Member States, but it is up to the manufacturer to decide how to do so. Motor vehicles and trailers fall into four different categories. These categories are L, M, N, and O. The categories addressed in this thesis are N and O. The semi-trailer will belong to category O, and the tractor unit that pulls the trailer belongs to category N. Below are the two main EC directives that will be addressed in this thesis: (EUR-Lex, 2022)


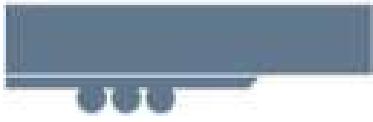
EC Directive 2007/46/EC compiles the administrative provisions and general technical requirements for the approval of certain types of vehicles and their associated peripherals. This directive applies to both individual and type-approval processes for vehicles and their peripherals designed and manufactured for use on the road within Europa. (Official Journal of the European Union, 2007)



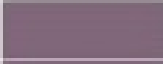


EC Directive 96/53/EC specifies the maximum permitted dimensions and weights for certain vehicles in both national and international traffic. The objective of this directive is to remove barriers that may adversely affect the competitive conditions for transport between Member States, since the difference in the laws of Member States regarding dimensions and weights may result in vehicles being prohibited from driving in certain countries. (Official Journal of the European Union, 2019)

3.8. Definition of Different Vehicle and Trailer Types

Although this thesis focuses on a 2-axled semi-trailer, it is crucial to understand other types of vehicles within the category of heavy goods vehicles, as well as various axle combinations and weight concepts. This subchapter provides an overview of various vehicle and trailer types across different vehicle combinations, presented in tabular format.

Table 1. Shows all available vehicles and trailers that can be used to connect different types of vehicle combinations. (Fröjd, Pettersson, Larsson, & Cider, 2017)


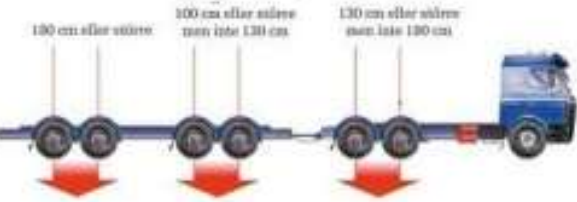

<p style="text-align: center;">Tractor Unit</p> 	<p>Tractor units do not have their own cargo compartment, but they are instead equipped with a turntable which is used for pulling semi-trailers and link semi-trailers.</p>
<p style="text-align: center;">Semi-trailer</p> 	<p>A semi-trailer is a trailer that has axles at the rear and a coupling pin at the front. Either a tractor unit or a truck with a coupled dolly can be used to pull a semi-trailer.</p>

<p style="text-align: center;">Link Semi-trailer</p> 	<p>A link semi-trailer or link is a semi-trailer equipped with a turntable at the rear that allows an additional semi-trailer to be attached. A link semi-trailer is often equipped with a sliding bogie that allows the bogie to be pushed under the load carrier when no additional semi-trailer is attached.</p>
<p style="text-align: center;">Truck</p> 	<p>A truck is a pulling vehicle with its own cargo compartment. A truck can be used to pull a trailer or a dolly with an attached semi-trailer.</p>
<p style="text-align: center;">Box Body</p> 	<p>A box body is the cargo compartment itself that is put on the truck or trailer.</p>
<p style="text-align: center;">Dolly</p> 	<p>A dolly is a vehicle that is equipped with a drawbar at the front and a turntable over the axles. A dolly can be attached to a truck and is used to pull a semi-trailer or a link semi-trailer. When a dolly is attached to a semi-trailer, it functions functionally as a trailer.</p>
<p style="text-align: center;">Trailer</p> 	<p>A trailer has axles at the front and rear. The front axles sit on a separate front chassis which is attached to the main upper chassis with a steering turntable. This allows the front carriage to steer and accompanies the turning of the drawbar.</p>

3.8.1. Different Axle Combinations

The axle combination of a vehicle acts as an undercarriage on wheels that distributes the vehicle's load across multiple axles and reduces the total axle pressure for each axle. By having multiple axles, for example, a vehicle can have a greater load weight while staying within permissible axle pressure. An axle combination can be either single, 2-axle bogie or 3-axle bogie type. A 3-axle bogie is also called a triple bogie. The type of axle combination depends partly on the number of axles and partly on the spacing between the axles. (Transportstyrelsen, 2024)

Table 2. Shows three different axle combinations. (Transportstyrelsen, 2024)

 <p>A truck and a trailer with single axles.</p>
 <p>A truck and trailer with a 2-axle bogie.</p>
 <p>A truck and trailer with a 3-axle bogie.</p>

If the mutual distance between two axles of a vehicle is less than two meters, the axle combination is called a bogie. On a vehicle with three axles where the distance between the first and third axles is less than 5,0 meters, the axle combination is called triple bogie or triple axles. If a vehicle has only one axle or if the mutual distance between two axles is greater than 2,0 meters, the axle combination is referred to as a single axle or axle only. (Transportstyrelsen, 2024)

3.8.2. Definitions of Different Weight Concepts

Service Weight

Service Weight is the total weight of the vehicle in normal, fully operational conditions without cargo. Normal, fully operational conditions mean the weight of the following factors:

- the heaviest peripherals and associated tools belonging to the vehicle,
- fuel, lubrication oils, and water, and
- the weight of the driver. (Transportstyrelsen, 2024)

Gross Weight

Gross weight is the total static mass that all axles of the vehicle transfer to the ground at a specific time. (Transportstyrelsen, 2024)

Total Weight

Total Weight is the total mass transferred to the ground when the vehicle is maximally loaded and coupled to the pulling vehicle. The total weight is calculated by adding the following factors:

- service weight,
- weight of the largest quantity of goods for which the vehicle is manufactured for, and
- the estimated weight of the largest number of passengers for which the vehicle is manufactured for. (Transportstyrelsen, 2024)

Technical Permissible Maximum Total Mass

The technical permissible maximum total mass is the maximum permissible mass based on the design and performance according to the manufacturer's specifications. (Official Journal of the European Union , 2019)

Axle Pressure Load

Axle pressure describes the maximum weight a vehicle or trailer can carry at each axle. (Official Journal of the European Union , 2019)

3.9. Light-insulated Semi-trailer

The box body of the semi-trailer addressed in this thesis is classified as a light-insulated unit. A light-insulated semi-trailer is a vehicle used to transport cargo that is sensitive to changes in temperature or other external factors affecting heat transfer. For a semi-trailer to be classified as a light-insulated unit, some insulation is required to minimize heat transfer, protect the goods from temperature changes, and maintain a stable temperature inside the box body. It is usually the semi-trailer's box body such as the roof, walls, openable side and rear doors, and sometimes the floors that are constructed with an insulating material.



Image 2. Shows a light-insulated semi-trailer manufactured by NTM.

An effective sealing system around doors and hatches is required on light-insulated units that prevent unwanted air and moisture from entering the box body. It is common for light-insulated units to be equipped with a refrigeration or heating unit to regulate and maintain a constant temperature inside the box body that is appropriate for the specific type of goods being transported. It is also common to have a ventilation system installed to ensure that good air circulation is obtained as well as to prevent humidity and mold formation. (NTN-Internal Document)

3.9.1. Sandwich Element

The insulated box body of the semi-trailer is constructed according to a structure called a sandwich element. It is called a “sandwich-element” because the structure is reminiscent of a sandwich with different layers of material joined together to create a strong and insulated structure. The structure usually consists of an outer and an inner glass-reinforced plastic sheet that serves as a protective cover for the insulation material in the middle. These plastic sheets are joined to the insulation material in the middle using an adhesive binder. (NTN-Internal Document) (Groover, 2021)

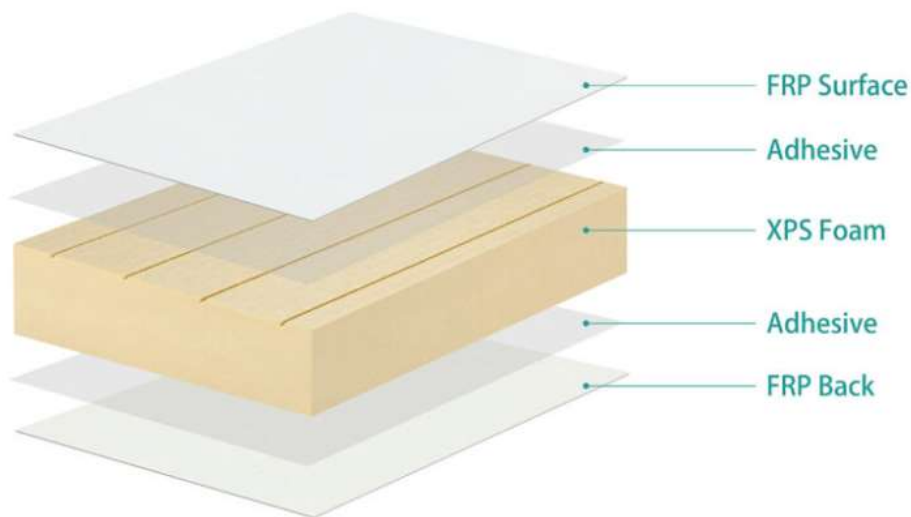


Figure 12. Shows how a sandwich element is structured. (Topolo, 2024)

The material for the insulation is XPS foam, which stands for Extruded Polystyrene Insulation. The XPS foam in the middle forms the core of the sandwich element to provide thermal insulation and regulate the temperature inside the box body. (NTN-Internal Document)



Figure 13. Shows how the sandwich element is structured for the front wall of the semi-trailer addressed in this thesis.

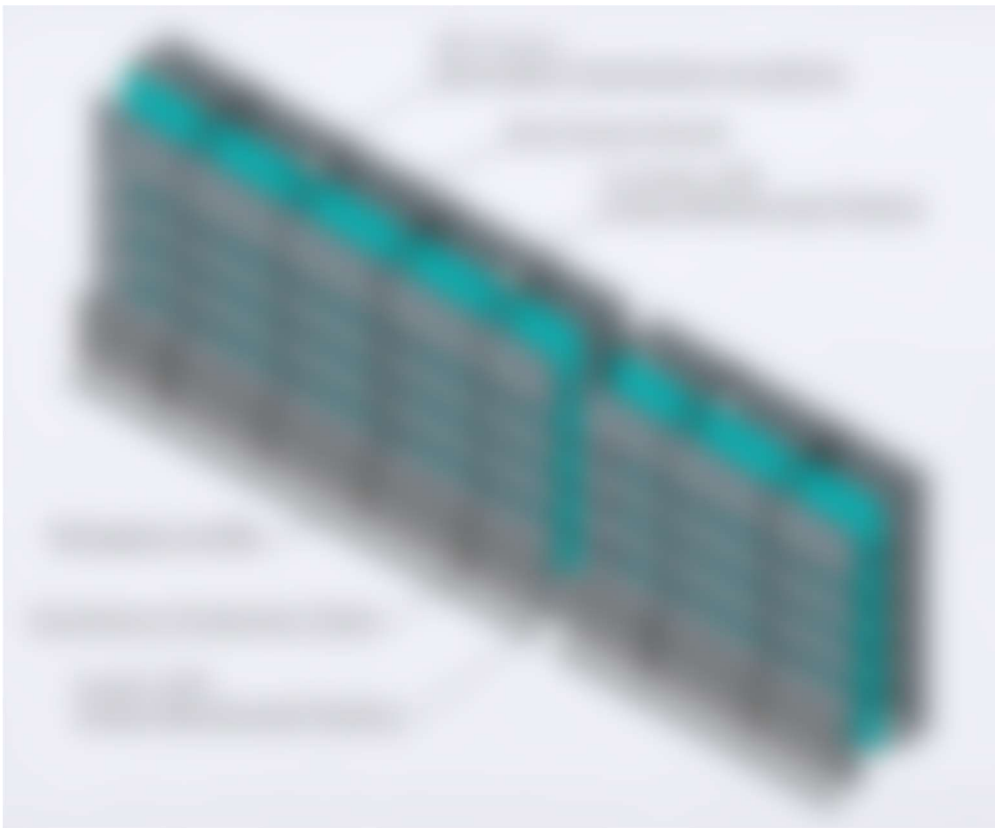


Figure 14. Shows how the sandwich element is structured for the side doors.

3.10. Main Dimensions of the Semi-Trailer

When designing a semi-trailer to meet the needs and requirements of a specific customer, the desired main dimensions must comply with the approved dimensions set by different regulations, directives, and the company. This subchapter presents the main dimensions of the semi-trailer addressed in this thesis.

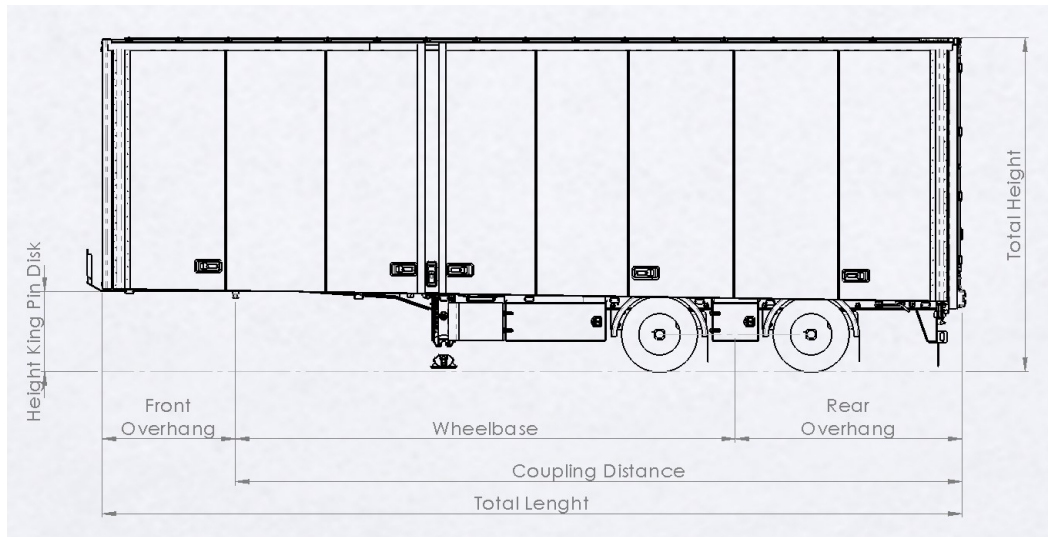


Figure 15. Shows the main dimensions of the semi-trailer seen from the outside.

Front Overhang

The front overhang is the distance from the front end of the vehicle to its coupling pin, known as the King Pin. This measurement is used to determine how far the vehicle extends forward from the coupling pin. Stability and steering response are improved with a longer front overhang, but there is an increased risk that the front of the vehicle will touch the pulling vehicle when cornering or on steep slopes. (NTN-Internal Document)

Rear Overhang

The rear overhang is on a two-axle semi-trailer the distance from the rear end of the vehicle to the middle point between the two rear axles. This measurement is used to know how far the vehicle extends rearward from the middle between the two rear axles. With a shorter rear overhang, maneuverability is improved when cornering and reversing, but the stability of the vehicle deteriorates when it is heavily loaded, and there is less space available for loading and unloading. (NTN-Internal Document)

Wheelbase

The wheelbase of a two-axled semi-trailer is the distance from the coupling pin at the front to the middle point between the two rear axles. This measurement is used to assess the total length of the vehicle, together with the front and rear overhang. This measurement can vary depending on the vehicle's design, the weight and distribution of the load, and the regulations applicable in the area where the vehicle will be operated. (NTN-Internal Document)

Coupling Distance

The coupling distance on a semi-trailer is the distance from the coupling pin at the front to the rear end of the vehicle. This measurement is used to determine the total length of the vehicle train when the semi-trailer is attached to a tractor unit, a tractor unit with a link semi-trailer, or a truck with an attached dolly. This measurement can vary, like the wheelbase distance, depending on the vehicle's design, the weight and distribution of the load, and the regulations applicable in the area where the vehicle will be operated. (NTN-Internal Document) According to the European Modular System concept, this distance must not exceed 12 meters. (Transportstyrelsen, 2024)

Total Length

The total length of a semi-trailer is the distance from the front edge to the rear edge of the vehicle. The total length is calculated as the sum of the front overhang, rear overhang, and wheelbase, or the sum of the front overhang and coupling distance of the semi-trailer. (NTN-Internal Document) In the context of 25,25-meter-long vehicle trains according to the European Modular System concept, the total length of a semi-trailer must not exceed 13,6 meters. This limitation is due to the requirement that the coupling distance must not exceed 12 meters and the radius from the coupling pin to the front edge of the vehicle must not exceed 204 centimeters. (Transportstyrelsen, 2024)

Total Height

Total height is the vertical distance from the ground to the highest point of the semi-trailer. It is common for semi-trailers to specify the total height at both the rear and the front in case there are variations. This measurement is also used to determine how much the semi-trailer will tilt depending on the height of the turntable when it is coupled with a tractor unit, link semi-trailer, or a dolly. (NTN-Internal Document) According to the European Modular System concept, the total height must not exceed 4,5 meters. This limit cannot be exceeded even if the vehicle is unloaded, and the axles are lifted to their highest position. (Official Journal of the European Union , 2019)

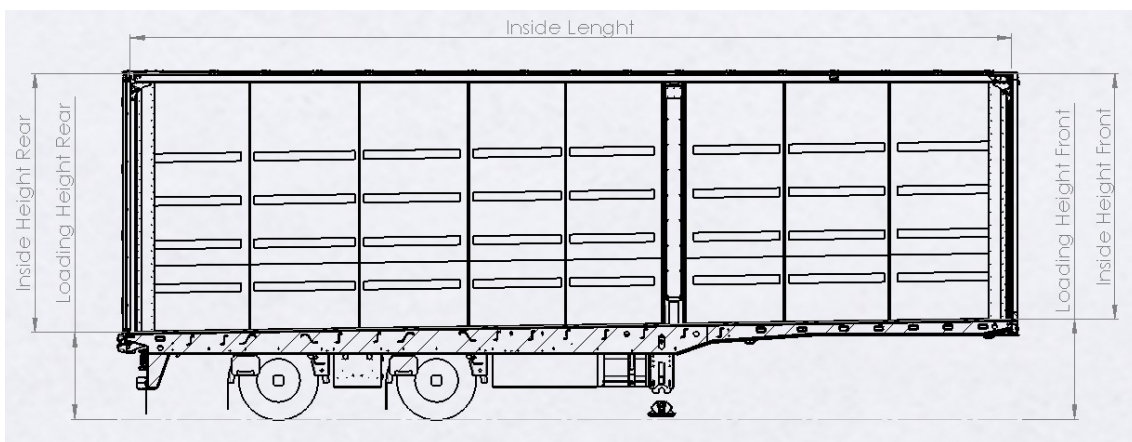


Figure 16. Shows the main dimensions of the semi-trailer seen from the inside.

Loading Height

Loading height is the vertical distance from the ground to the floor of the cargo compartment. This measurement can vary depending on the type of load and the need to provide sufficient space to secure the load as well as to facilitate loading and unloading. On the semi-trailer addressed in this thesis, the loading height should be tilted so that the loading height is 150 mm lower at the inside of the rear doors compared to the inside of the front wall. The purpose of this design is to make better use of the loading height inside the box body and be able to load higher goods at the rear.

Inside Height

Inside height is the vertical distance from the floor to the roof within the box body. On the semi-trailer addressed in this thesis, the loading height is tilted so that it is 150 mm lower at the inside of the rear doors compared to the inside of the front wall. Consequently, the inside height is 150 mm higher at the rear to obtain a uniform overall height along the vehicle. This design allows higher cargo to be loaded at the rear. (NTN-Internal Document)

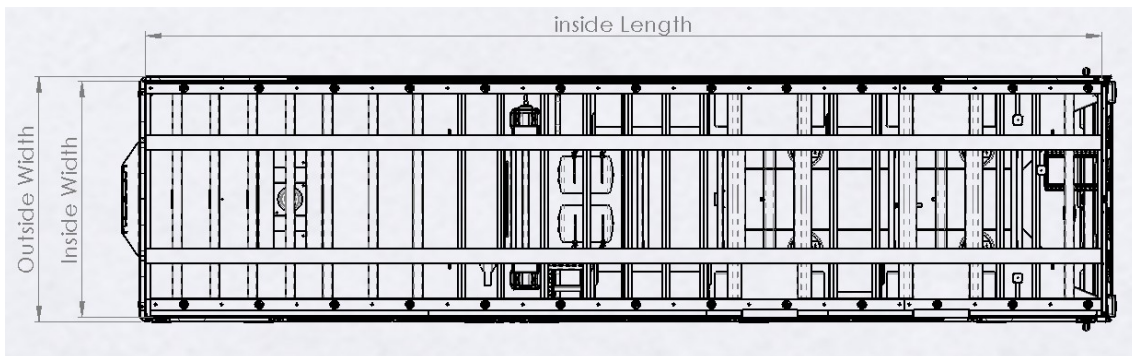


Figure 17. Shows the main dimensions of the semi-trailer seen from above.

Inside Length

The inside length is the horizontal distance from the inside of the front wall to the inside of the rear doors within the box body. This measurement is crucial for determining the maximum length of cargo that can be loaded. (NTN-Internal Document)

Inside Width

The inside width is the horizontal distance between the right wall and the side doors within the box body. This measurement is crucial for determining the maximum width of cargo that can be loaded. (NTN-Internal Document)

Outside Width

The outside width is the horizontal distance between the two outer sides of the semi-trailer. This measurement is crucial for determining how much space the vehicle takes up on the road. (NTN-Internal Document)

3.11. The European Modular System

The European Modular System or EMS is a vehicle design and manufacturing concept for heavy goods transport vehicles. The modular system is based on configuring vehicles so that they can be combined in different ways, creating various types of vehicle trains for different purposes. The key objective of EMS is to make goods transport more efficient by allowing longer and heavier vehicle trains so that fewer vehicles are required to transport the same amount of goods over long distances. Sustainability is also improved as fewer vehicles are required to transport the same amounts of goods, resulting in reduced fuel consumption and greenhouse gas emissions. The introduction of standardized dimensions for modular vehicle trains within Europe simplifies border crossings, which in turn promotes trade and increases competitiveness across national borders. (Transportstyrelsen, 2024) (Official Journal of the European Union, 2019) In practice, three different types of vehicle trains can be coupled together. These vehicle combinations are as follows:

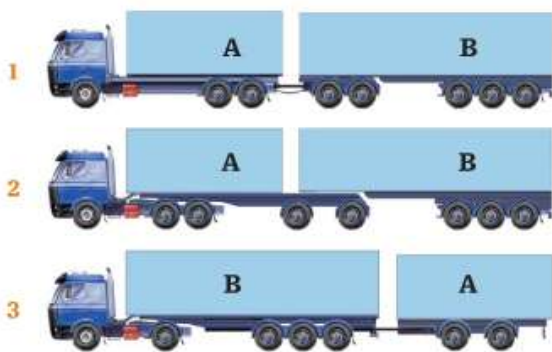


Figure 18. Shows the three different vehicle train combinations that can be coupled in practice. (Transportstyrelsen, 2024)

1. A truck coupled with a dolly and a semi-trailer or trailer only.
2. A tractor unit coupled with a link semi-trailer and a semi-trailer.
3. A tractor unit coupled with a link semi-trailer and a center-axle trailer.

For it to be legal to operate a vehicle train at a maximum speed of 80 km/h, ABS brakes are required on all axles of the vehicle train, and it must be possible to turn with a full steering lock on the axle of the pulling vehicle without any of the coupled trailers touch each other. Unless all these above requirements are met, the maximum allowed speed is 40 km/h. (Transportstyrelsen, 2024)

3.11.1. Permissible Lengths, Widths, and Heights for different Modular Systems within Europe for 25,25-meter-long Vehicle Trains

Within the European Modular System, a modular vehicle train may be up to 25,25 m long. The provision provides for the possibility of coupling certain types of vehicles and trailers so that the total length of the vehicle train is not more than 25,25 m. This presupposes that the vehicles being coupled do not deviate from the common EU rules laid down in Directive 96/53/EC. However, the distance between the frontmost loading space of the front vehicle and the rearmost loading space of the rear vehicle must not exceed 22,9 m on a vehicle train. The width must not exceed 2,6 m. This also applies to other attachments that are tangible and removable, such as containers and swap bodies. (Transportstyrelsen, 2024)

The radius from the coupling pin to the front edge of the semi-trailer shall not be greater than 204 cm and the distance from the coupling pin to the rear end shall not exceed 12,0 m. This gives the longest permissible vehicle length for a semi-trailer to be 13.6 m. (Transportstyrelsen, 2024)

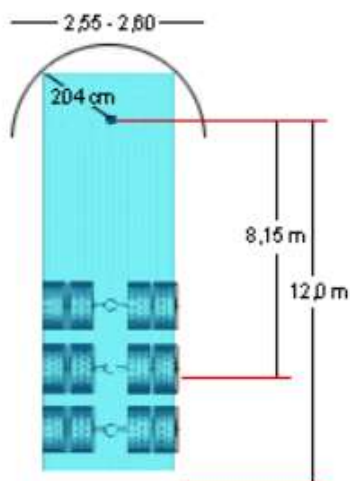


Figure 19. Shows the permissible lengths for a semi-trailer. (Transportstyrelsen, 2024)

The turning requirement for a vehicle train is that it must be able to turn within a circle where the outer radius is less than 12,5 m, and the inner radius is less than 2,0 m. This is considered to be fulfilled if the distance a in the Figure below is not more than 22.5 m and the distance b is not more than 8.15 m. For the vehicle that pulls the semi-trailer, the turning requirement is 12.5 m for the outer radius and 5.3 m for the inner radius. (Transportstyrelsen, 2024)



Figure 20. The turning requirement is considered fulfilled if the distance a is not more than 22,5 m and the distance b is not more than 8,15 m. (Transportstyrelsen, 2024)

The distance between the pulling vehicle and the trailer is measured from the last axle of the pulling vehicle to the first axle of the coupled trailer. The minimum distance between the last axle of the front vehicle and the first axle of the trailer depends on the type of vehicle it is. (Transportstyrelsen, 2024)



Figure 21. Shows how the distance between the last axle of the tractor unit and the first axle of the semi-trailer is measured. (Transportstyrelsen, 2024)

3.11.2. 34,5-meter-long Vehicle Trains

Following a change in traffic regulations in autumn 2023, 34,5 m long vehicle trains will be allowed on a designated road network. For a vehicle train between 25,25 and 34,5 m to be allowed to operate on a designated road network that allows these lengths, there are certain technical requirements that the vehicle train must fulfill. Today, there are only two vehicle combinations approved under these requirements and all vehicle trains longer than 25,25 m must have a warning sign at the front and at the rear that shows that it is a long vehicle. It is the transport administration or the municipalities that authorize roads on which a vehicle train between 25,25 and 34,5 m can be performed on. (Transportstyrelsen, 2024)

3.12. Manufacturing Methods

In this subchapter, I will describe the primary manufacturing methods used in the production of the semi-trailer addressed in this thesis. The semi-trailer's frame is mainly constructed from plasma laser-cut sheet metals, bent with a press brake to the desired shape. Machining processes such as turning, milling, and drilling are also used to manufacture some parts. After all the necessary parts have been manufactured, the frame is assembled using MIG/MAG welding. Since the semi-trailer is constructed of several different materials like steel, stainless steel, aluminum, and fiberglass, several surface treatment methods are used to protect all these materials from corrosion.

The following subchapter explains the application of different manufacturing methods, including press braking, plasma cutting, MIG/MAG welding, various surface-treatment methods, and machining techniques such as turning, milling, and drilling.

3.12.1. Plasma Cutting

In plasma cutting, an electric arc is used between a non-fusible tungsten electrode and the workpiece. The electrode is connected to the negative pole and the material being cut is therefore electrically conductive. The electrode is encased in a nozzle through which plasma gas is directed. The nozzle is cooled with water to prevent overheating. When the machine is operational, a low-power pilot arc lights up between the nozzle and the electrode. (Lepola & Makkonen, 2004)

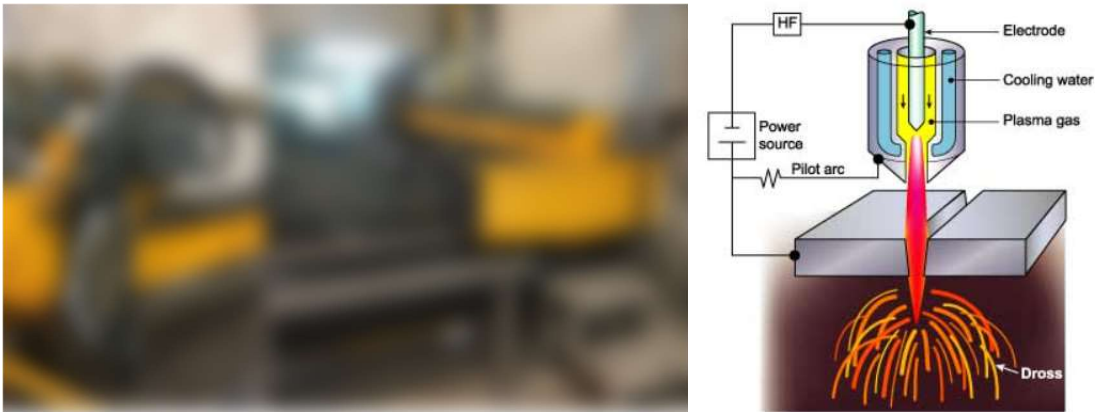


Figure 22. Shows the plasma cutter at NTM on the left and the plasma arc cutting process on the right. (TWI, 2024)

As the cutting head comes towards the workpiece during cutting, the power is increased, and the arc automatically starts cutting the workpiece into the desired shape. The molten material created during the cut is blown away by the powerful plasma gas. The temperature in a plasma arc can reach up to 30 000 °C depending on the type of gas you use and other factors. Plasma cutting can be performed on most metallic materials and sheet metal thicknesses from less than 1 mm up to 100 mm. (Kalpankjian & Schmid, 2024) (Lepola & Makkonen, 2004)

3.12.2. Press Brake

A press brake is a tool used to bend sheets. During use, the sheet is placed on the sub-tool called the die. The die essentially consists of two crests. Once the sheet is in place, the upper tool called the punch is pressed down in a vertical direction using a foot pedal against the die, whereupon a crease occurs, and the placed sheet starts to bend from the crease. The angle of bending is determined by how much the punch is pressed down into the die, but it is also influenced by other factors such as sheet thickness and the distance between the crown of the pad. (INLEARN, 2024)

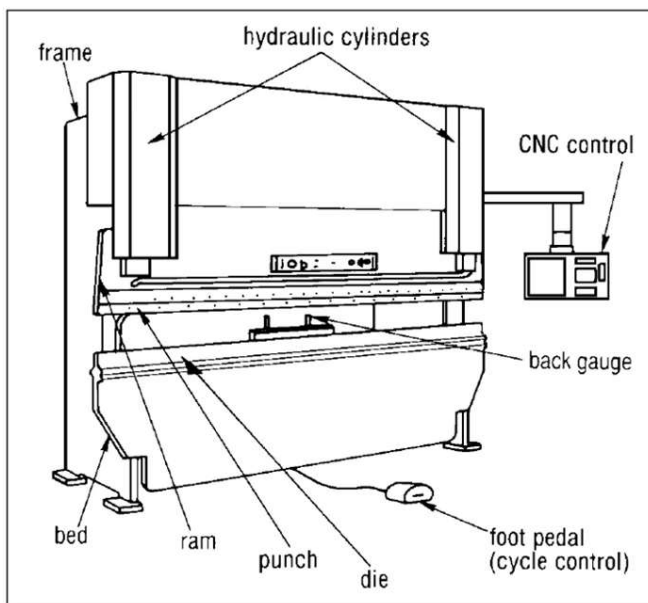


Figure 23. Shows the components of a typical CNC hydraulic press brake. (INLEARN, 2024)

Today, most press brakes are CNC-controlled. CNC is an abbreviation that stands for Computer Numerical Control. In a CNC-controlled press brake, the machine operators create a bending program in which the desired profile is buttoned in, at the right angle and length. This means that the machine is automatically set to the correct height and depth position and the sheet only needs to be pushed into place during bending, and the machine does the rest. (INLEARN, 2024) (Lepola & Makkonen, 2004)

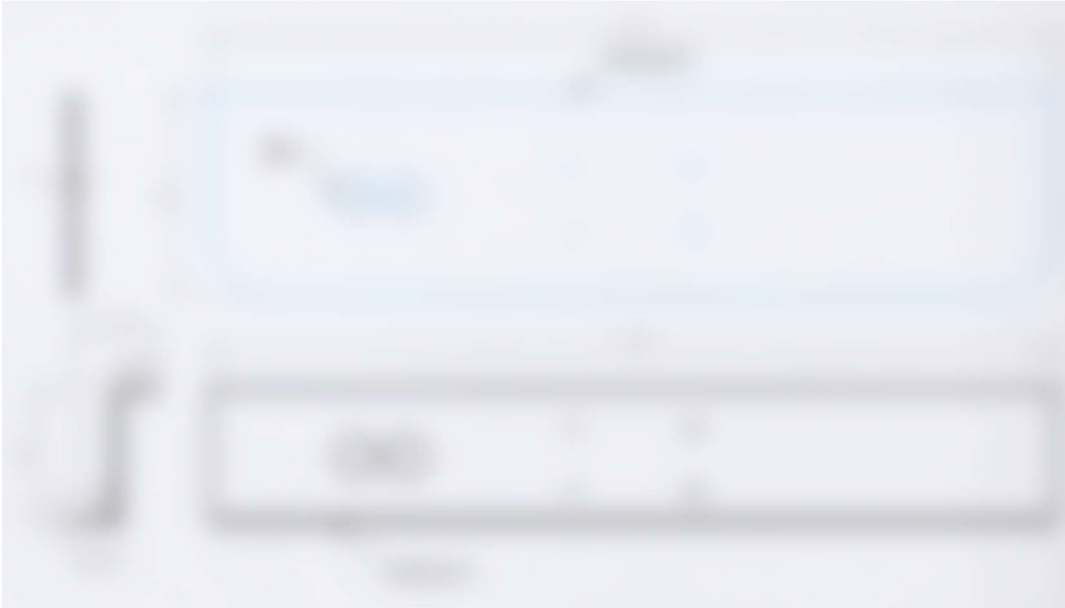


Figure 24. The drawing shows a cutting template used for cutting out the sheet metal with the plasma cutter, along with bending instructions showing how the sheet metal should be bent.

3.12.3. MIG/MAG Welding

The frame of the semi-trailer addressed in this thesis is primarily constructed from various steel components, including stainless steel, which are welded together using MIG/MAG welding. MIG/MAG welding is an arc welding method in which an electric arc is generated, forming a weld joint between a negatively grounded workpiece and a positive electrode, which is a continuously fed welding wire. The equipment used in MIG/MAG welding includes a power source, a supply mechanism for the welding wire, a welding gun, and a gas cylinder. MIG/MAG welding offers several advantages, such as high welding speed, the ability to weld in various positions, and the method's relative ease of learning. (Lepola & Makkonen, 2004)

MIG/MAG welding is a flexible method suitable for welding most materials, including steel, stainless steel, aluminum, and various alloys. The welding wire serves as a supply of welding material during welding. There are several types of welding wires available, that can be used depending on the material being welded and the specific requirements of the weld, like solid wire, tube wire, or flux wire. (Lepola & Makkonen, 2004)

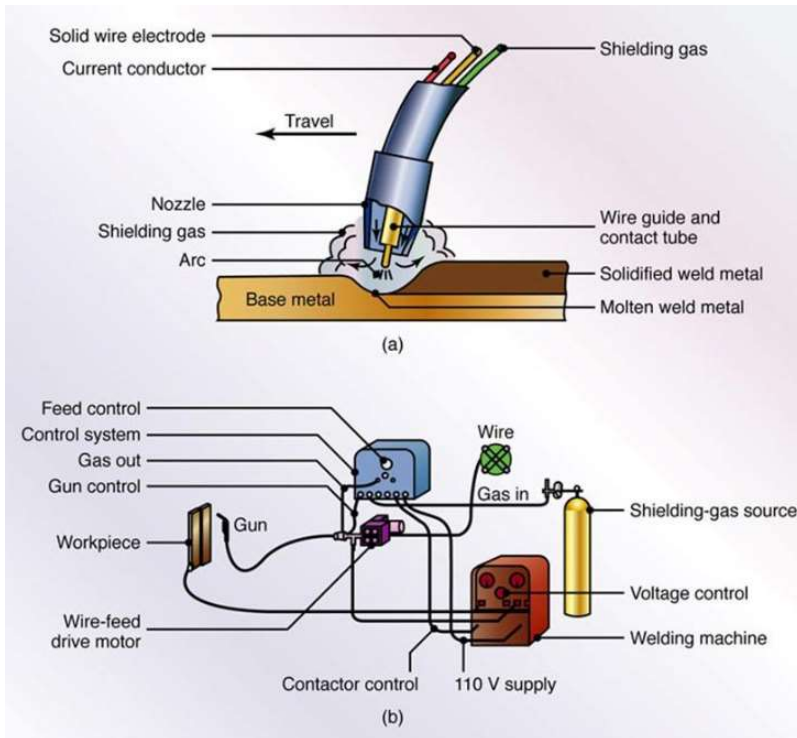


Figure 25. Shows the equipment used for MIG/MAG welding. (Kovinc, 2024)

MIG stands for Metal Inert Gas and MAG stands for Metal Active Gas. The difference between these two is that in MIG welding, an inert gas, usually argon or helium, is used to create a protective atmosphere that prevents oxidation and impurities from reaching the welding arc. In contrast, in MAG welding an active gas is used, such as a mixture of argon and carbon dioxide, which reacts with the weld metal to stabilize the welding arc during welding. (Lepola & Makkonen, 2004)

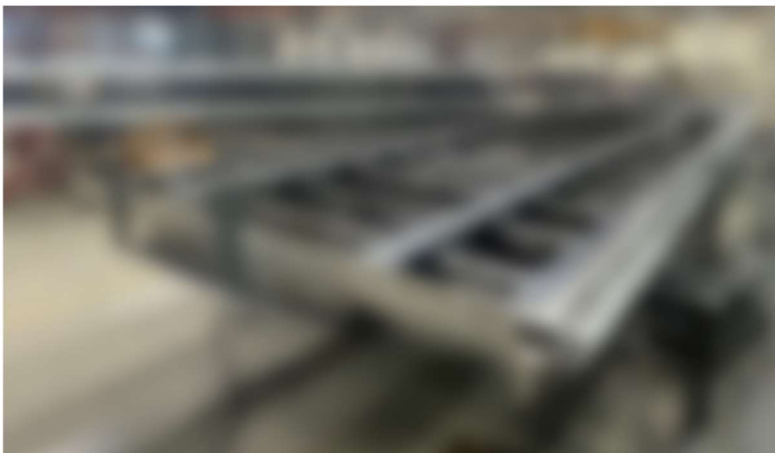


Image 3. Shows the frame of the semi-trailer addressed in this thesis during the welding process.

3.12.4. Surface Treatments

The semi-trailer addressed in this thesis is constructed from various materials, including steel, stainless steel, aluminum, and fiberglass. Below is an overview of the most common surface treatment methods for these materials.

Painting

Painting is a surface treatment method primarily used on steel and aluminum to protect these materials from corrosion. This method can also be used on fiberglass to protect it from UV radiation and other external influences. The method involves first pretreating the material with a primer to improve the adhesion of the surface paint and further improve the corrosion protection. After the primer has been applied, the surface paint is applied to provide an aesthetic appearance and offer additional protection against corrosion. (Mannari & Chintankumar, 2015) (Lepola & Makkonen, 2004)

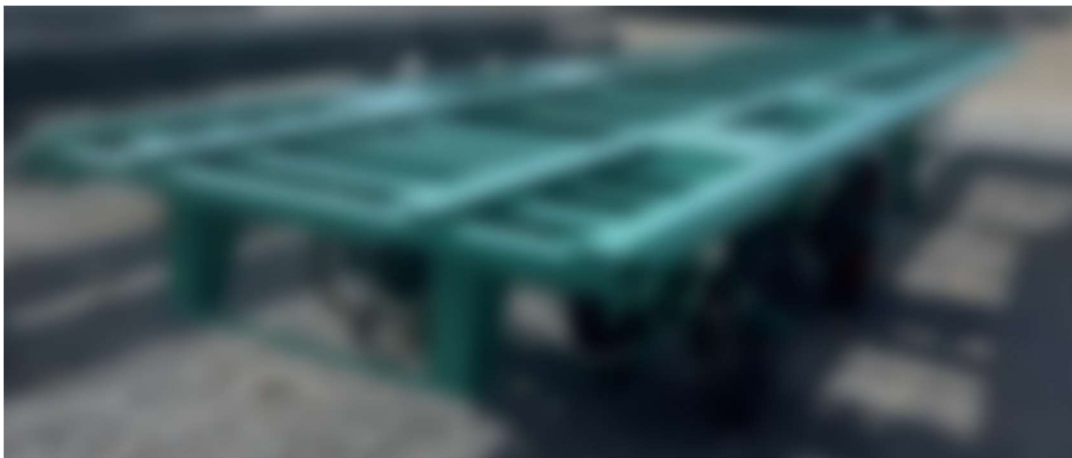


Image 4. Shows the frame of the semi-trailer after it has been painted.

Powder Coating

Powder coating is another surface treatment process used on steel or aluminum to protect them from corrosion. The method involves applying dry powder to the material's surface, which is then melted by heating in an oven to form a durable coating surface. (Mannari & Chintankumar, 2015)

Galvanizing

Galvanizing is a surface treatment method primarily used on steel to protect it from corrosion. This method involves applying a zinc coating to the material, either by dipping it in a hot zinc bath or by utilizing electrode galvanizing, which is an electrochemical process where a zinc anode is used to transfer zinc atoms to the material, forming a protective zinc coating on the surface of the material. (Mannari & Chintankumar, 2015) (Lepola & Makkonen, 2004)

Passivation

Passivation is a chemical treatment method used to protect stainless steel against corrosion. This method is based on dipping stainless steel in an acid-based solution for a specified period, which causes a protective oxide coating to form on the material's surface that protects it from corrosion. (Mannari & Chintankumar, 2015)

Brushing or Sanding

Another method used to protect stainless steel from corrosion is to brush or sand the surface of the material. This technique aims to create a smooth, matte finish on the material's surface by removing scratches and irregularities that could contribute to potential corrosion over time. (Mannari & Chintankumar, 2015)

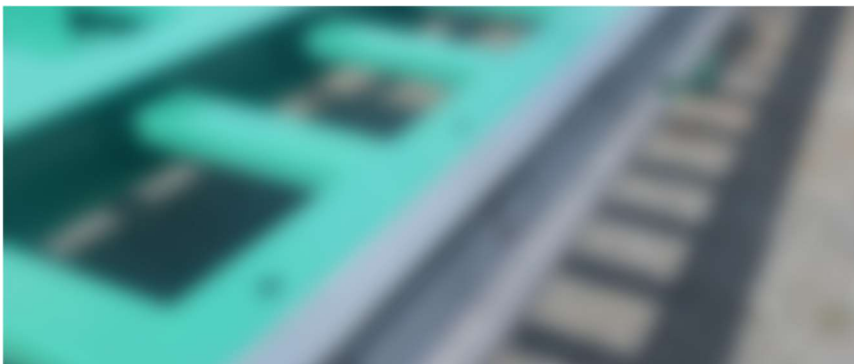


Image 5. Shows the stainless-steel edge profile that later will be sanded with sandpaper to get a smooth and fine surface.

3.12.5. Machining

Machining is the process of shaping a workpiece to the desired shape, dimension, and surface finish through material removal. (Ansaharju & Maaranen, 2020) The most common machining methods are turning, milling, and drilling, where:

Turning

Turning is a process in which a shaft, bolt, or other cylindrical and conical workpieces are clamped into a rotating chuck. A cutting tool is then applied and fed along the length of the workpiece to remove material and shape it to the desired diameter, length, or surface finish. (Ansaharju & Maaranen, 2020)

Milling

Milling is a process used to create flat surfaces, transverse and longitudinal grooves, pockets, holes, and threads of the desired shape on a workpiece. In milling, a rotary cutting tool is used to remove material from the workpiece, which is securely clamped in a clamping device. (Walker & Dixon, 2014) (Ansaharju & Maaranen, 2020)

Drilling

Drilling is a process in which a rotary cutting tool, known as a drill, is used to create holes of different diameters and depths in a workpiece. (Ansaharju & Maaranen, 2020)

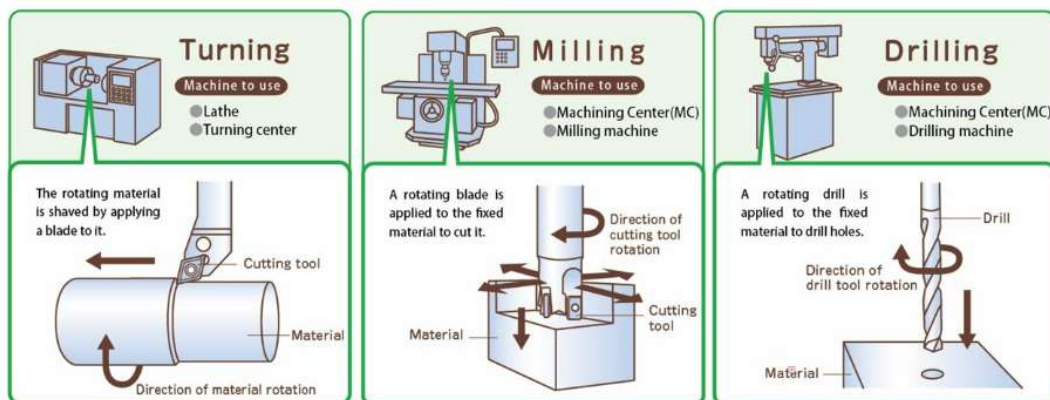


Figure 26. Shows the process of turning, milling, and drilling. (Seisanzai Japan, 2022)

4. Methodology

This chapter presents the methods and approaches used to conduct the practical implementation of this thesis.

4.1. Engineers' Main Duties in Customized Products

The primary role of the engineer is to develop technical drawings and product specifications that are necessary for the manufacture of the product, or in this case, the semi-trailer with a tilted floor, during production. The engineer serves as an intermediary between the customer, the salesman, and the production department. These responsibilities include, among others, the following tasks:

1. Create, develop, and design concepts and drawings on the product according to the customer's specifications and requirements. This means that you have the responsibility to create technical drawings and product specifications that the production department uses to manufacture the product.
2. Contribute with technical expertise and knowledge to ensure that it's physically possible to manufacture the product according to the customer's specifications and requirements and to ensure that the developed design complies with all technical standards and regulations.
3. Established assessment to ensure that the developed and final design meets the established quality standards in terms of functionality, durability, and safety.
4. Be involved in identifying and solving challenges that arise during the manufacturing process. This involves supporting production on design issues and revising drawings as necessary to address specific challenges that arise during the manufacturing process.

By efficiently performing all these tasks, the engineer plays a central role in ensuring that the customized product is produced according to the customer's wishes and meets high-quality standards. (NTN-Internal Document)

4.2. Case Studies

To gather information and gain knowledge before the actual design process, I conducted case studies on how NTM and other companies historically implemented comparable design solutions. Case studies are an appropriate research method for further product development when you want to compare different design options, investigate specific areas, or provide detailed descriptions. A case study can be defined as a comprehensive investigation methodology that focuses on a particular area.

The case study approach usually involves a thorough investigation, either individually or in a group, to become familiar with different solutions to the specific situation or identified problems. These solutions are then evaluated to obtain the most detailed and effective solutions. Information obtained from the case study can be applied to understand the underlying causes of the problems and why they arose. (Forskningsstrategier, u.d.) (Priya, 2021).

The case studies for this thesis will be conducted as follows:

1. Investigate previously manufactured cases focusing on semi-trailers with tilted floors, to analyze previous design decisions and manufacturing processes, and to identify encountered challenges and how they were addressed.
2. Implement Design for X principles in the case studies to investigate how factors such as manufacturability, assemblability, maintainability, and durability were considered and integrated into previous design solutions. The objective is to evaluate the impact of these factors on both the functional and non-functional aspects of the semi-trailers, including their performance, appearance, ease of use, and reliability.
3. Conduct analyses and draw conclusions based on the results of the case studies to identify key success factors, challenges, variances, and how they have been addressed.

4.3. Action Research

Action Research is a research method in which both theoretical and practical implementations are combined to address specific situations or problems. The purpose of action research is to engage in research while actively participating in the practical implementation and involving other stakeholders to better understand the gap between theory and practice to improve the specific situation or problem at hand. The concept was first introduced by MIT professor Kurt Lewin in 1944. Action research is also sometimes referred to as Cycle of Action Cycle or Cycle of Inquiry. (George, 2024)

The two most common types of action research are participatory action research and practical action research, where:

1. Participatory action research focuses on the fact that all participants should be involved parties with knowledge that is considered formative for the research process.
2. Practical action research focuses more on how the research process is designed and conducted to solve the specific situation or problem.

Both types of action research are more aimed at improving the abilities and capacities of future practitioners than merely contributing theoretical knowledge. (George, 2024)

The action research for this thesis will be conducted as follows:

1. Formulate a hypothesis regarding the challenges and problems that may arise during the manufacturing process for the developed design. This involves identifying potential obstacles and adapting the design accordingly.
2. Actively participate in the production process by collecting data through observations and interviews with those involved in manufacturing. The objective is to obtain a deeper understanding of the manufacturing process and to leverage their expertise to further optimize both the design and production process.
3. Continuously optimize the design of the semi-trailer and the production process through continuous evaluations and reflections on the collected data, including observations, interviews, and results.

4.4. Generic Product Development Process

Generic Product development is the process of developing an idea into a new product or improving an existing product. Product development refers to different methods and techniques applied to develop products satisfactorily. When a company develops new products, different phases should be processed in turn before manufacturing and market introduction. These phases include planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up. (Ulrich, Eppinger, & Yang, 2020)

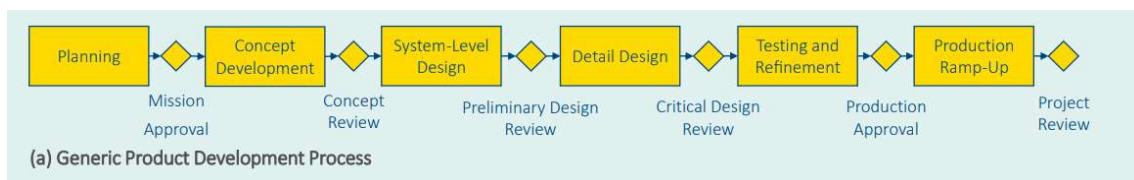


Figure 27. Shows all six phases of a generic product development process. (Ulrich, Eppinger, & Yang, 2020)

4.4.1. Planning

The first phase of the product development process is the planning phase, sometimes referred to as “phase zero” because the actual product development begins in this phase after the project idea has been approved. The primary objective of this phase is to produce the so-called project's mission statement, which should describe the product's objectives along with other critical assumptions and limitations associated with the project. (Ulrich, Eppinger, & Yang, 2020)

4.4.2. Concept Development

The second phase is concept development. In this phase, alternative product concepts are created that describe, among other things, the shape, function, and characteristics of the final product. The primary objective of this phase is to determine which of the developed product concepts should be selected and evaluated for further research, development, and testing. (Ulrich, Eppinger, & Yang, 2020)

4.4.3. System-level Design

The third phase is system-level design. The primary objective of this phase is to produce a geometric layout of the developed product concepts that describe which subsystems and components the developed concepts consist of and how they are intended to be assembled and work together to achieve the desired functionality. (Ulrich, Eppinger, & Yang, 2020)

4.4.4. Detail Design

The fourth phase is detail design. In this phase, the final geometry, material selection as well as tolerances are determined for all specific subsystems and components that the final product will be built from. It is also decided in this phase which existing standard components the final product will be built from. In summary, this phase involves finalizing the design of the product. (Ulrich, Eppinger, & Yang, 2020)

4.4.5. Testing and Refinement

The fifth phase is testing and refinement. This phase involves developing and evaluating detailed conceptual solutions for the proposed product ideas. The objective is to create a basis for evaluating and comparing alternative solutions against similar alternatives. In addition, this phase aims to obtain feedback on the product concept from customers to understand their perception of the idea. (Ulrich, Eppinger, & Yang, 2020)

4.4.6. Production Ramp-up

The sixth phase is production ramp-up. During this phase, there is a gradual transition in which the production team becomes familiar with the manufacturing process of the new product. This transition aims to ensure that the production team has enough time to train staff and that available resources are used as efficiently as possible. It also involves identifying possible challenges or deficiencies that may arise during the manufacture of the developed product. (Ulrich, Eppinger, & Yang, 2020)

4.5. Structural Engineering

The application of principles in structural engineering is critical because the semi-trailer addressed in this thesis must both carry loads and withstand various forces, such as static loads from different weight loads and dynamic loads arising from driving. Structural engineering is a complex discipline that includes the design, analysis, and construction of structures designed to effectively withstand these different types of loads and forces by combining mathematics, physics, and material sciences. This approach ensures that the new design for the semi-trailer is sufficiently safe and durable for a long time and changing conditions. In this thesis, the structural engineering method will be applied to analyze and optimize the strength, load-bearing capacity, and safety of the new structure. By identifying potential weak points in the structure where fractures or deformations may occur, it is ensured that the new structure can withstand the loads and forces it will encounter. In summary, the task of the design engineer in structural engineering is to ensure that the developed design is both aesthetically pleasing and structurally robust. (Chen & El-Metwally, 2011)

4.6. Material Science

Material science involves studies that focus on the properties, structure, and behavior of different materials, as well as how they can be processed and adapted for different uses. Within this thesis, material science is an essential part, since the semi-trailer consists of several materials, like steel, stainless steel, aluminium, and fiberglass. Material science is based on a combination of chemistry, physics, and engineering that is crucial in all engineering fields when it comes to the development of new structures and improvements to existing ones. The material science method will be applied in this thesis to analyze and select suitable materials for the semi-trailer's different components. By exploiting the mechanical properties of the materials, such as strength, ductility, and durability, the functionality, efficiency, and durability of the new structure can be optimized. In summary, by understanding and applying the principles of material science, you can as a design engineer optimize material selection and handling to ensure both functionality and durability. (Kakani & Kakani, 2004) (Ullman, 2018)

4.7. Design for X

The strategy Design for X can be applied to ensure that the developed and final design meets several critical perspectives, such as quality, cost-effectiveness, durability, manufacturability, usability, performance, and maintainability, among others. In design processes, the strategy Design for X is utilized to optimize the performance, quality, reliability, and usability of a product or system, as well as other key characteristics. Design for X is often abbreviated as DfX, where the letter X is replaced by the specific objectives or characteristics relevant to the particular project. Below are the eight primary objectives that were considered during the design phase of the semi-trailer addressed in this thesis. (Ullman, 2018)



Figure 28. Shows the eight primary objectives within Design for X that have been addressed in this thesis. (YouTube, 2022)

Design for Quality: this principle focuses on adapting the quality at each step of the design process to ensure that the semi-trailer addressed in this thesis meets or exceeds all the end customer's wishes and requirements when it comes to functionality and non-functionality such as performance, appearance, ease of use, and reliability. The primary objective of this principle is to identify and eliminate potential quality deficiencies or defects already at the design stage before they reach the manufacturing or use stage. The principle includes the following important aspects:

- Clearly understanding the end customer's specific requirements and expectations, both in terms of functionality and non-functionality such as performance, appearance, ease of use, and reliability.
- Focusing on long-term durability and reliability throughout the design phase.
- Identifying potential risks or critical areas of the design that may affect its quality or reliability.
- Selecting high-quality materials that conform to the specific quality standard. (Ullman, 2018)

Design for Cost: This principle focuses on minimizing manufacturing costs during the design phase by optimizing the design to reduce manufacturing costs and eliminate unnecessary costs for the design. Key aspects of this principle include:

- Simplifying the design by avoiding unnecessary complexities.
- Optimizing material use by minimizing material waste.
- Selecting cost-effective materials.
- Utilizing standardized components and parts wherever possible to reduce purchasing and manufacturing costs. (Ullman, 2018)

Design for Assembly: This principle focuses on designing all the components and details of the semi-trailer to ensure they can be easily assembled during the manufacturing process. The primary objective is to improve the production flow and reduce production costs by reducing the assembly time. (Ullman, 2018)

Design for Sustainability: This principle focuses on the consideration of environmental impact during the design phase, promoting long-term sustainability by minimizing material consumption and exploring opportunities for the reuse of components and materials. It also involves taking social aspects, such as working conditions and human rights, into account throughout the entire production process. (Ullman, 2018)

Design for Manufacture: This principle focuses on designing all parts and components so that the manufacturing process is as smooth and efficient as possible for the production department. (Ullman, 2018)

Design for Maintenance: This principle involves adapting the design of the semi-trailer during each stage of the design process to facilitate its service and maintenance. The objective is to reduce maintenance costs for the product and its components throughout its operational life. This principle also includes that standardized components should be used wherever possible to facilitate and speed up service and maintenance work when a product or some of its components need to be replaced or repaired. (Ullman, 2018)

Design for Testing: This principle focuses on designing the product so that its function and design can be easily tested during different phases of the manufacturing process. The objective is to detect and fix any defects or inaccuracies on the design before it reaches the end customer. (Ullman, 2018)

Design for Reliability: This principle focuses on designing the product to achieve a long service life and high reliability by identifying, analyzing, and reducing the risk of defects or malfunctions that may occur over time during the design phase. (Ullman, 2018)

4.8. Mechanical Simulations

Mechanical simulation is an essential part of design engineering to ensure that the developed design of the semi-trailer addressed in this thesis is sufficiently durable. By applying mechanical simulations to mechanical structures, forces, stresses, deformations, and motions can be effectively studied, providing an accurate analysis of the structure's performance. All this eliminates the need to build physical prototypes, saving both time and money. In this thesis, the method Finite Element Analysis (FEA) and Finite Element Method (FEM) were used, which are based on breaking down complex systems into smaller parts, so-called finite elements. These methods were used to perform the necessary strength simulation on the semi-trailer's frame beams. A more detailed description of these methods is described in the following subchapters. (Johannesson, Persson, & Pettersson, 2013)

4.8.1. Finite Element Method

To ensure that the developed and final design is structurally robust, a strength analysis will be conducted using the finite element method in SolidWorks simulation. The finite element method or FEM as it is also known as is a method used to find, calculate, and solve various strength engineering problems virtually before they arise as problems. Purely mathematically, the finite element method can be described as a numerical technique used to find approximate solutions to a partial differential equation. The underlying mathematical idea of the finite element method is based on the concepts of interpolation and minimization of function, i.e. you seek a zero point to the derivative. (SolidWorks education) (NTN-Internal Document)

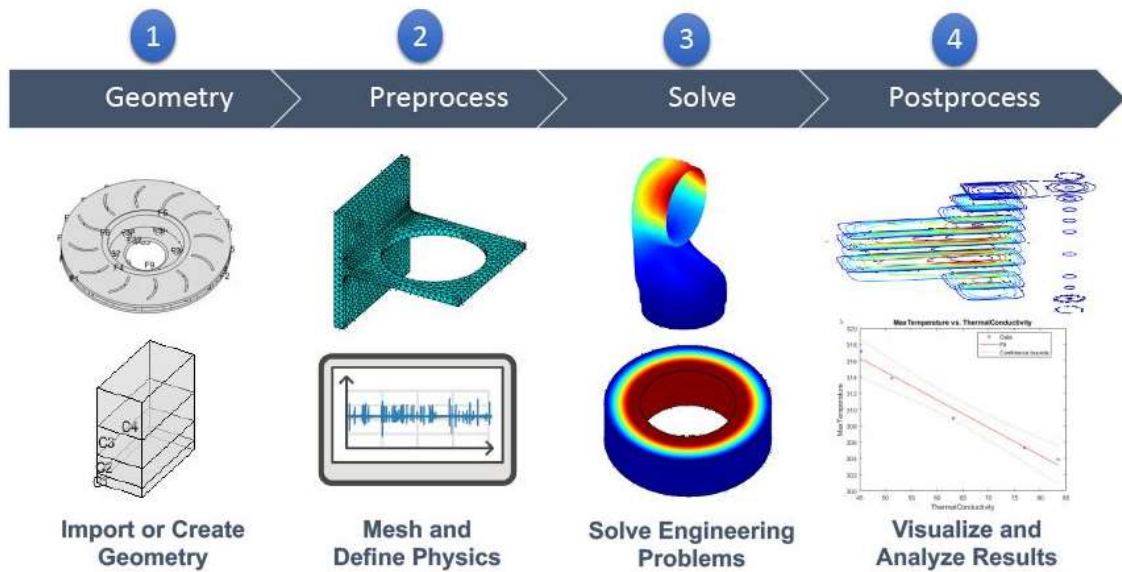


Figure 29. Shows a typical finite element analysis workflow. (MathWorks, u.d.)

The finite element method is based on dividing the real geometry into small parts called finite elements. The distributed elements are connected only in special points, which are called nodes. These nodes are often located at the corners or on the edges of the finite elements. The shapes the distributed elements have are for the most part triangles or quadrangles for 2D and a prism with six sides for 3D. The idea of dividing the real geometry into smaller parts is to be able to describe the behavior of each element in a relatively simple way just by knowing the state of the nodes. (SolidWorks education) (NTN-Internal Document)

4.8.2. Finite Element Analysis

The finite element analysis (FEA) is, unlike the Finite Element Method (FEM), the practical application of FEM used by engineers to perform simulations and analyses of designs. FEA serves as a tool to predict how a design will behave under various conditions, allowing optimization of the design and ensuring its performance and durability. (SolidWorks education) In this thesis, FEA will be conducted on one of the frame beams of the semi-trailer frame using SolidWorks Simulation. The objective of the simulation is to analyze stress concentrations and displacement within the frame beam to ensure its durability and performance under load. (SolidWorks education)

4.9. Production Flowchart

To effectively document and analyze all identified design challenges, as well as to receive development proposals, a flowchart will be created for each activity in the manufacturing process. This flowchart will serve as a structured framework to easily map and sort challenges and development proposals for each specific step in the manufacturing process. By creating a flowchart, each stage of the production process can be analyzed more thoroughly and opportunities for improvement are better identified and implemented. (Engwall, Jerbrant, Karlson, & Storm, 2020).

A flowchart graphically visualizes a sequence of events or activities in a process or system. The purpose of creating flowcharts is to facilitate the analysis and understanding of complex processes by clarifying and visualizing them. A flowchart consists of different lines and symbols that correspond to different parts of the process. A flowchart usually consists of the following symbols:

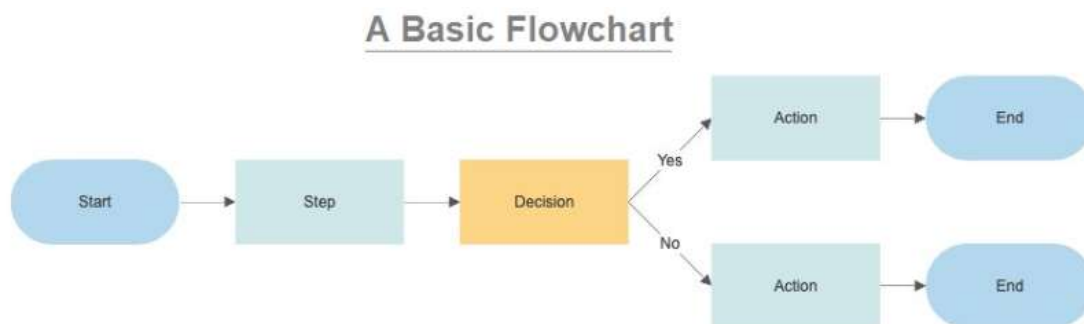


Figure 30. Shows a basic flowchart. (Karan, 2023)

1. The start- and end points are often two oval circles where one circle represents the starting point and the other the endpoint.
2. Process steps or activities are often rectangular boxes that represent a process step or activity, often with a brief description of the process or activity to be performed.
3. Flow arrows are used to connect all process steps or activities and indicate the direction of the flow chart.
4. Connections are used to connect different process steps to the same point and to avoid exaggerating the junction of the flow arrows. (Engwall, Jerbrant, Karlson, & Storm, 2020)

5. Results

This chapter presents the results of the thesis. It begins with a company description, followed by a detailed presentation of the semi-trailer's design developed using SolidWorks. Following this, the result of the strength simulation with SolidWorks Simulation is presented. Finally, the result of the production follow-up is presented.

5.1. Description of the Company

The employer for this thesis was NTM, which manufactures, develops, maintains, and sells transport equipment for heavy goods transport such as trailers and the collection of recyclable materials and waste such as garbage trucks. (NTM, u.d.)

5.1.1. History

Lennart Nordin, together with Sigurd Lärka, founded NTM in 1950. In the beginning, the company had two divisions one for metal products and one for wood products. Production at that time consisted mainly of kitchen cabinets, furniture, car pullers, and heating elements. The first major work that NTM did in terms of transport equipment was to rebuild a Bedford truck into a fire truck for the fire station in Övermark municipality. During the 70s, the factory area grew by 4600 m² as the workshop building was built with two new factory halls.

In 1980, NTM Group became a joint-stock company and in the mid-80s the first welding robot was acquired and shortly thereafter the first CNC lathe. NTM launched a self-supporting frame design for trucks in Finland in 1968. Fiberglass box bodies for trailers made their entrance in 1977 and a few years later box bodies with fully openable sides were launched. The first garbage truck was produced in 1975 and today, after several phases of development, the production of garbage trucks accounts for half of the company's turnover. (NTM, u.d.)

5.1.2. NTM Today

Today, NTM's product range consists mainly of two different product groups. One is heavy goods transport equipment such as trailers and the other one is collection of recyclable materials and waste such as garbage trucks. NTM Group is today one of the leading Nordic actors in this field. They have been able to achieve this by focusing on product development and quality.

NTM has also today chosen to focus on developing and manufacturing more sustainable and climate-smart products that are energy efficient and emission-free, enabling reuse and recycling. This is because customers today have become more environmentally conscious and the demand for wear and tear products is now one of the predecessors. NTM's parent company is located in Närpes and the company employs approximately 625 people, including about 400 in Närpes. In addition to the parent company in Närpes, the company has subsidiaries in Sweden, Estonia, the United Kingdom, Russia, Poland, and Canada. (NTM, u.d.)

5.2. Presentation of the Designed Semi-Trailer

This subchapter presents the finalized design of the semi-trailer and its most crucial components which were developed using SolidWorks for this thesis, I will begin by presenting the overall design of the semi-trailer, which includes the chassis and box body. Next, I will move on to sub-assemblies and components to highlight the key features and explain what distinguishes this unique design from a standardized NTM semi-trailer.



Figure 31. Shows the design of the semi-trailer viewed obliquely from the front on the left side and obliquely from the rear on the right side.



Figure 32. Shows the design of the semi-trailer from the left and right sides to the left and from the front and rear to the right.

What distinguishes this semi-trailer unique is the tilted floor, which provides a 150 mm lower loading height at the inside of the rear doors compared to the inside of the front wall, In addition, the box body is designed in a wedge shape, resulting in the inside height at the rear being 150mm higher than at the front to maintain the same overall height along the semi-trailer.

This design enables higher loads to be loaded at the rear compared to the front. The semi-trailer is also equipped with an openable tarpaulin roof that can be opened from the rear

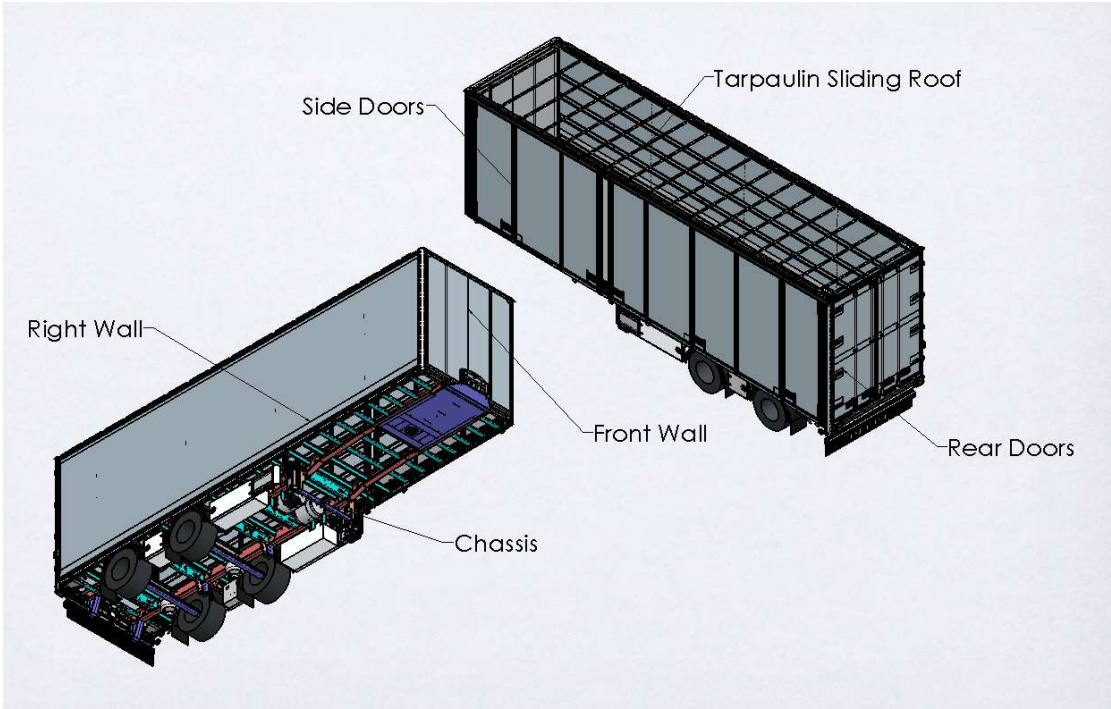


Figure 33. [REDACTED]



Figure 34. [REDACTED]

5.2.1. The Side Doors

The side doors are divided into three sub-assemblies:

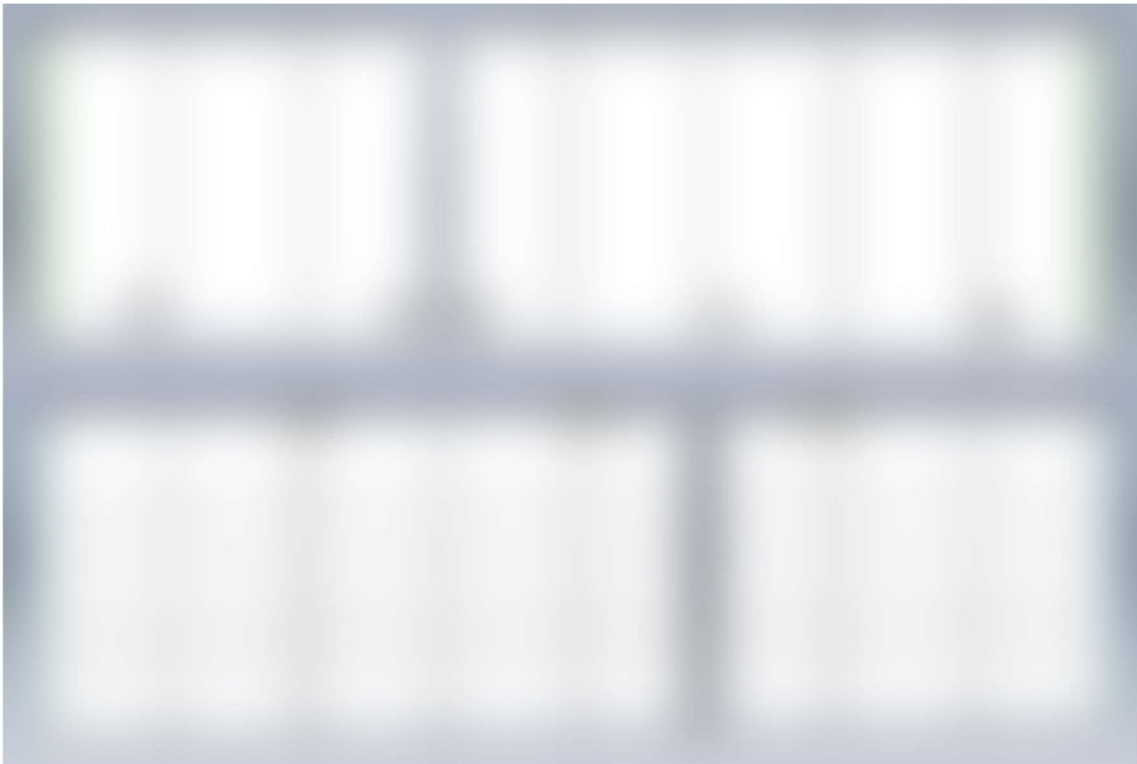
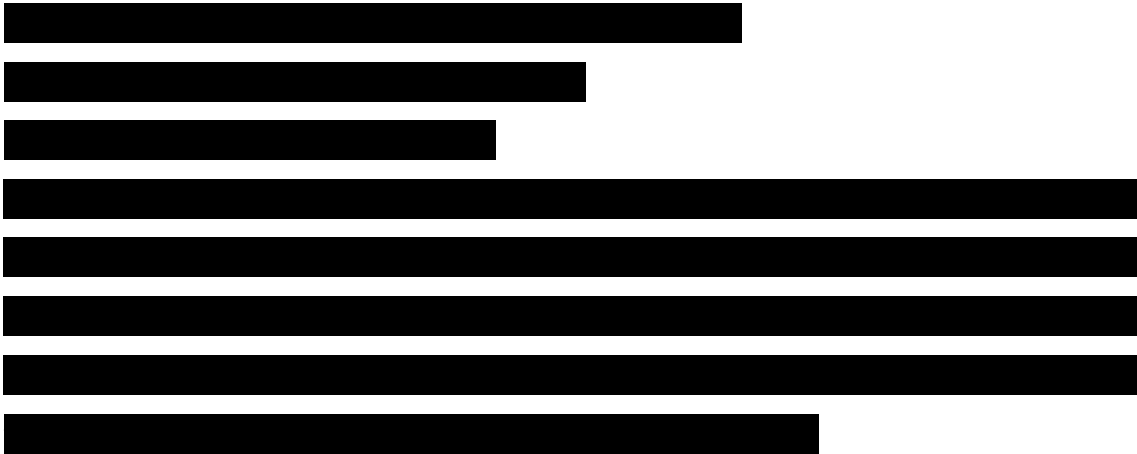


Figure 35. [Redacted text]

5.2.1.2. The Door Frame for each Side Door

To increase the stability, durability, and safety of the side doors, each door is equipped with its own door frame, which serves as a structural foundation. [REDACTED]

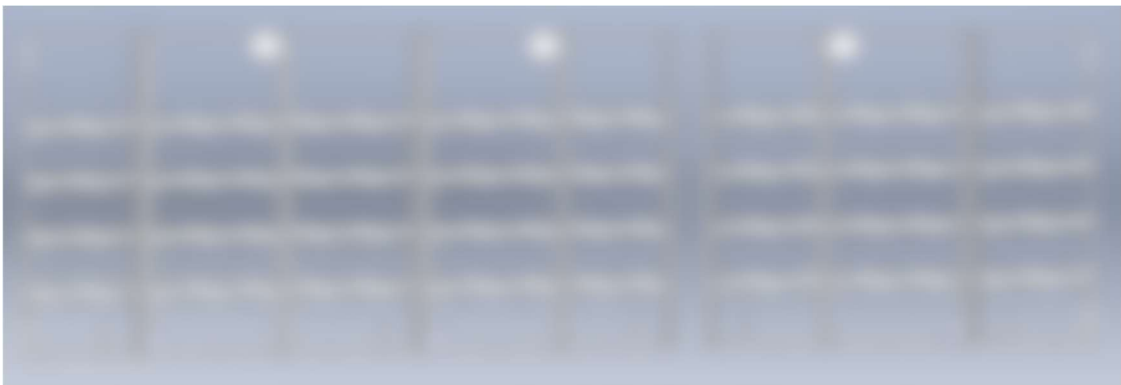


Figure 37. [REDACTED]

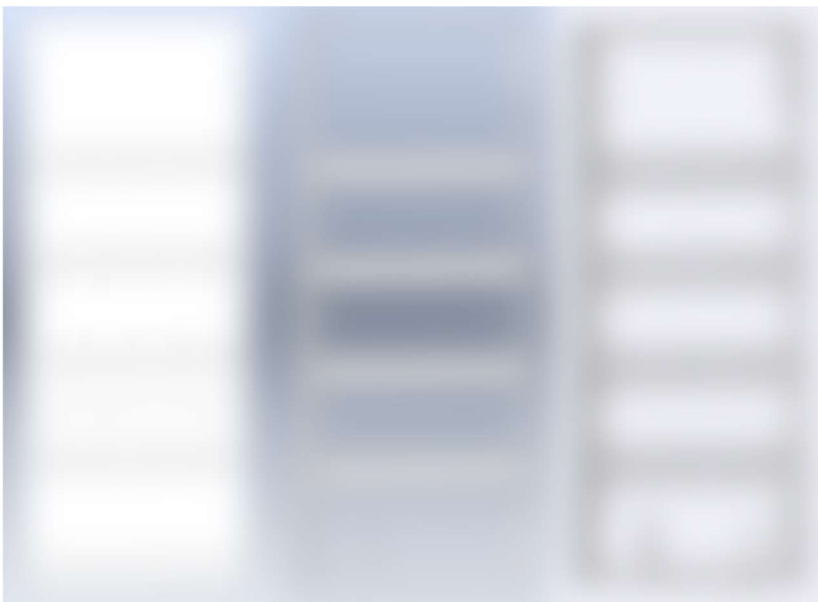


Figure 38. [REDACTED]

5.2.2. Right Wall

The right wall is designed according to the same sandwich element method as the side doors. [REDACTED]

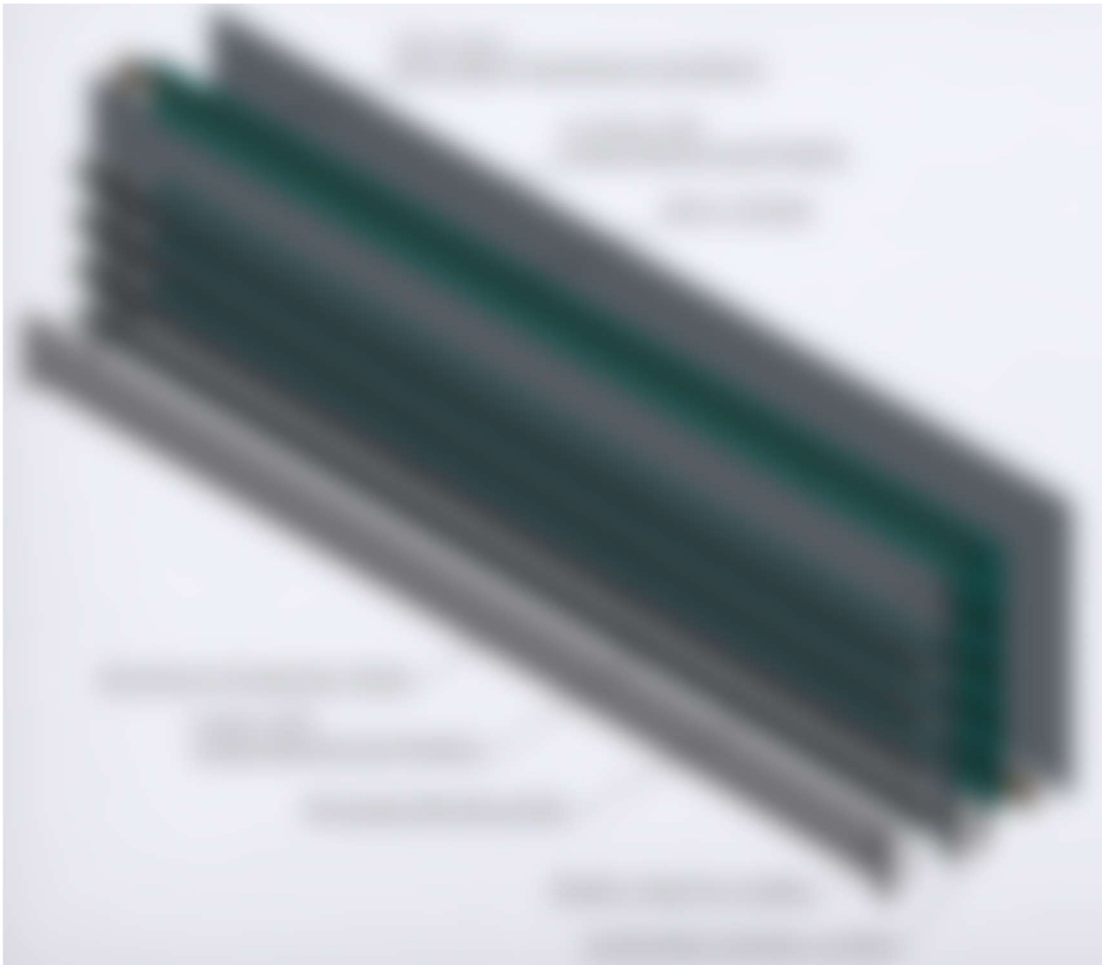


Figure 39. [REDACTED]

5.2.3. Front wall

The front wall is designed according to the same sandwich element method as the side doors and the right wall

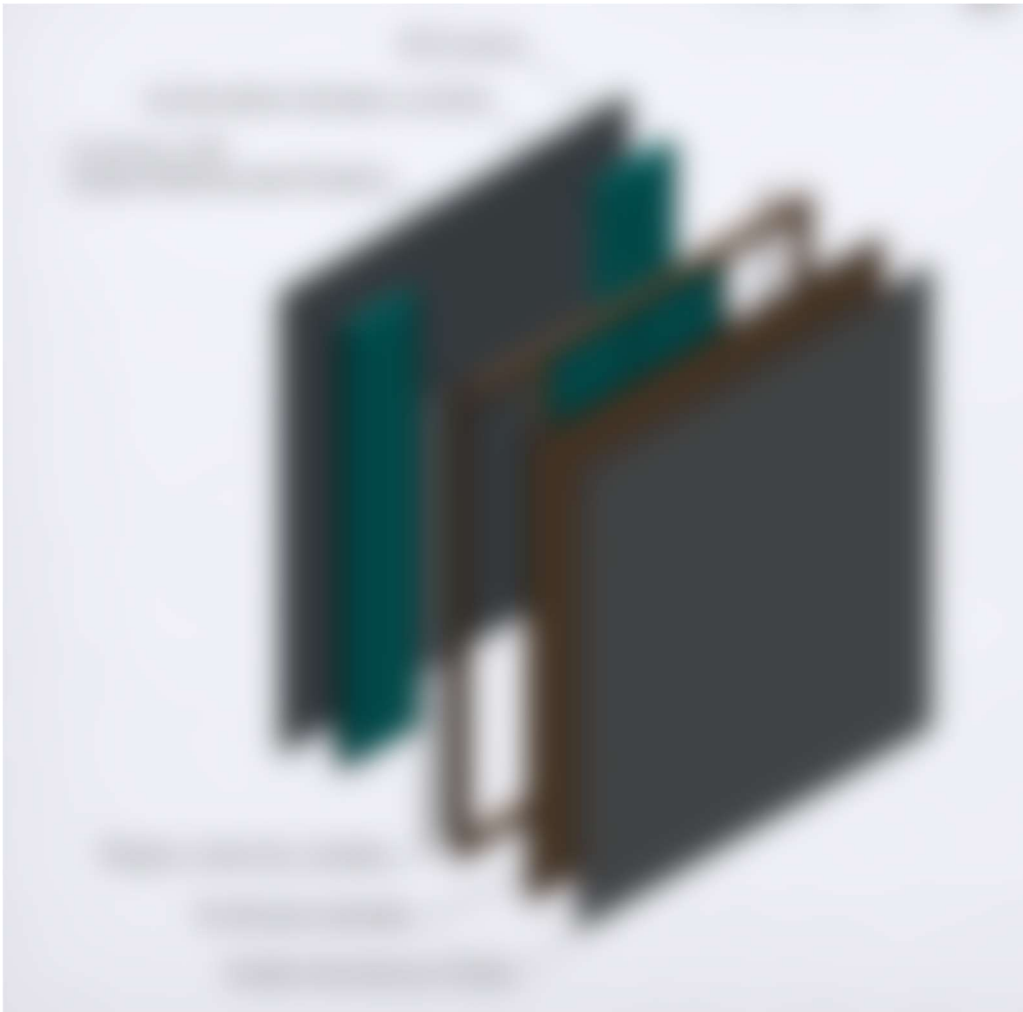


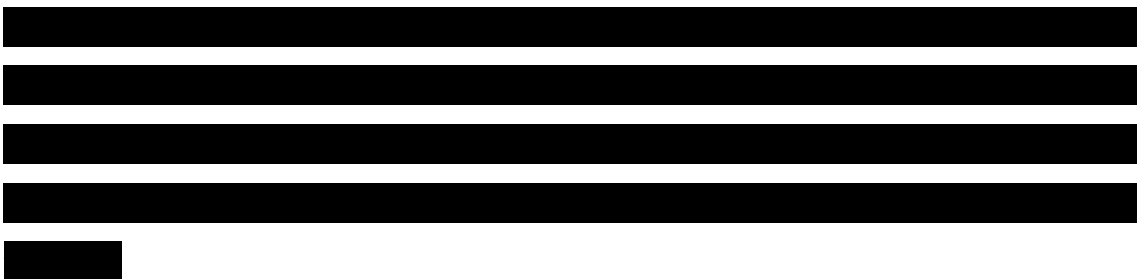
Figure 40.

5.2.4. The Rear Doors

The drawings for the rear doors and its outer door frame is divided into four subassemblies:



Figure 41. [Redacted]



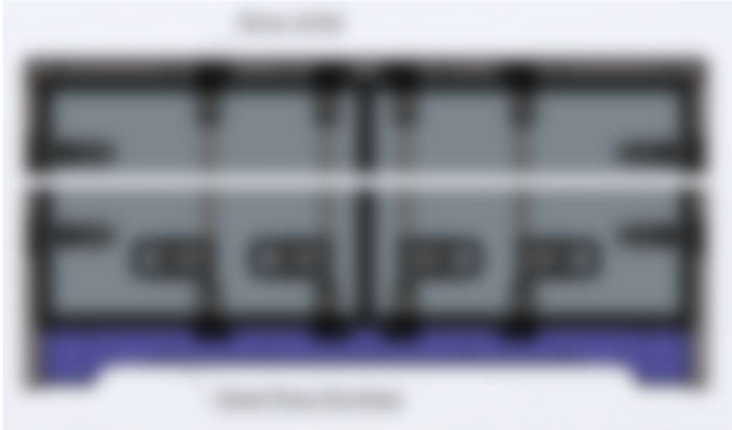


Figure 42. [Redacted]

5.2.5. Tarpaulin Roof

The tarpaulin roof is equipped with grooves, rollers, and hinges used for manual opening or closing. It opens from the rear, and by pulling the toboggan on the tarpaulin roof forward, it opens, while it closes by pulling it backward. [Redacted]

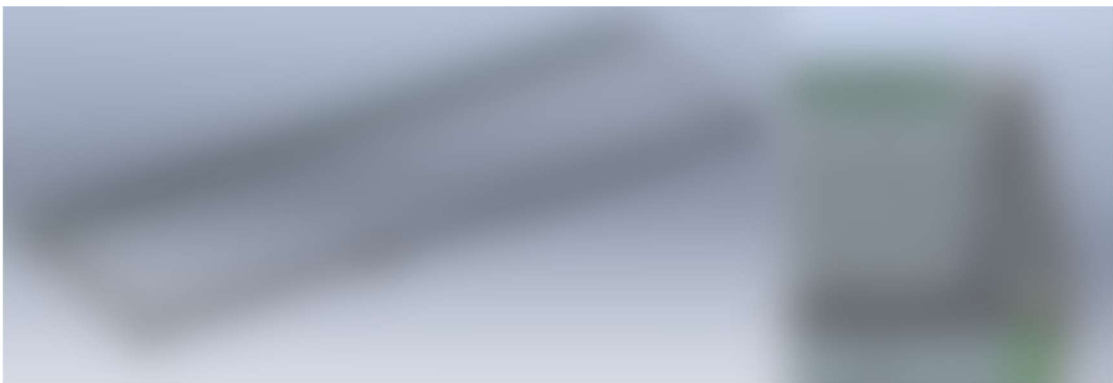


Figure 43. [Redacted]

5.2.6. Chassis

The chassis serves as the frame that supports the load and provides support for the box body. The chassis level includes details such as boxes, underrun protection on the sides and rear, loading legs, a load securing system with associated rails, and electrical and pneumatical components, along with necessary assembled brackets.

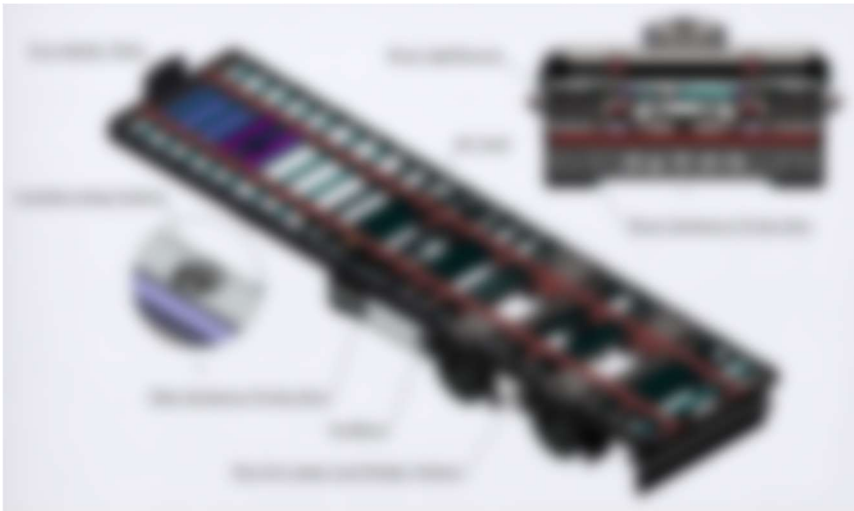


Figure 44. [Redacted]



Figure 45. [Redacted]

5.2.7. Frame

The frame is the fundamental structure of the chassis that supports the load and provides support for components such as wheel axles, suspension systems, the box body, and the coupling pin at the front. [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

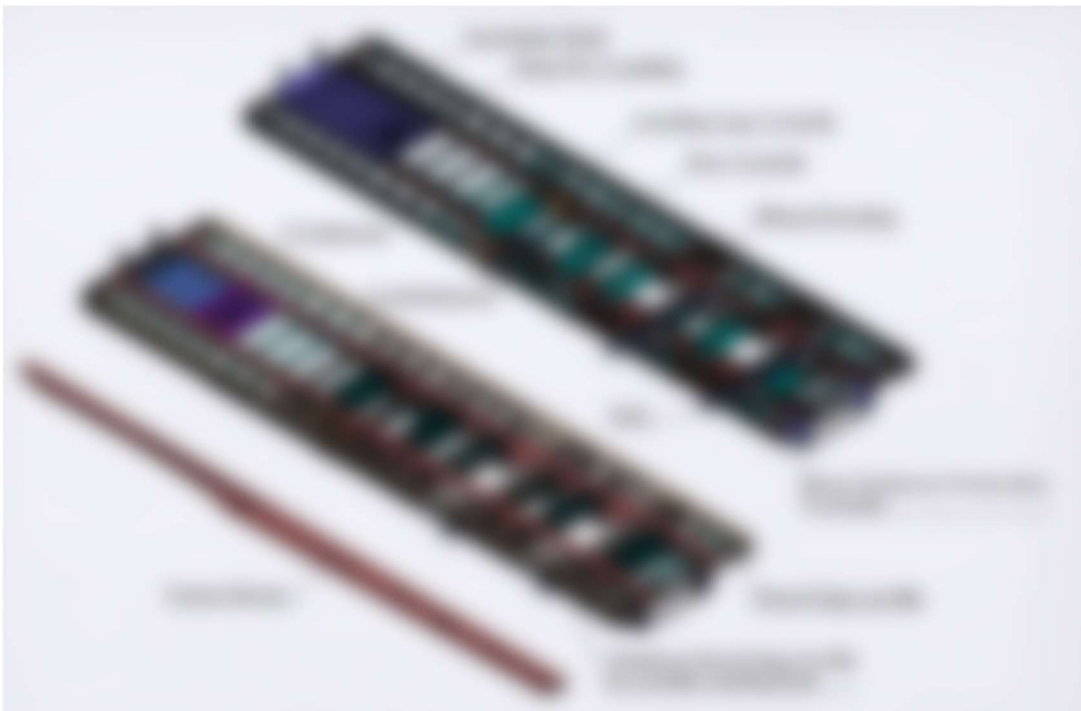


Figure 46. [REDACTED]

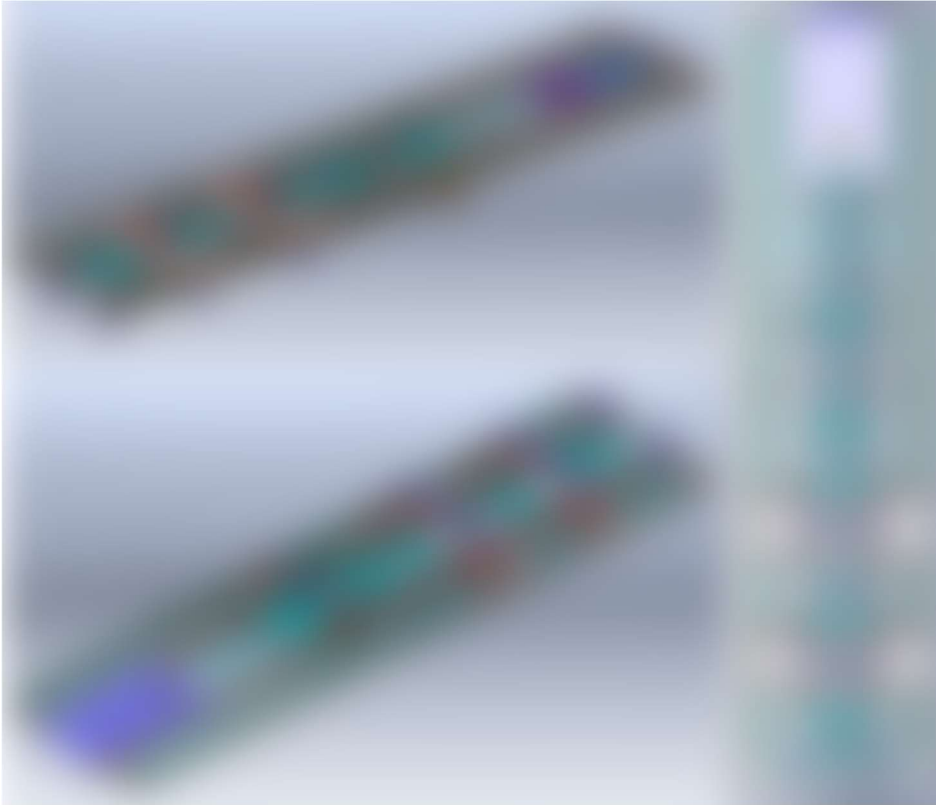


Figure 47. [REDACTED]

5.2.7.1. The Frame Beams

The semi-trailer consists of two parallel-spaced longitudinal frame beams that serve as the foundational frame for the entire structure. These frame beams support different components, including center beams, crossbeams, wheel axles, turntable plate, and other chassis components. [REDACTED]



Figure 48. [REDACTED]

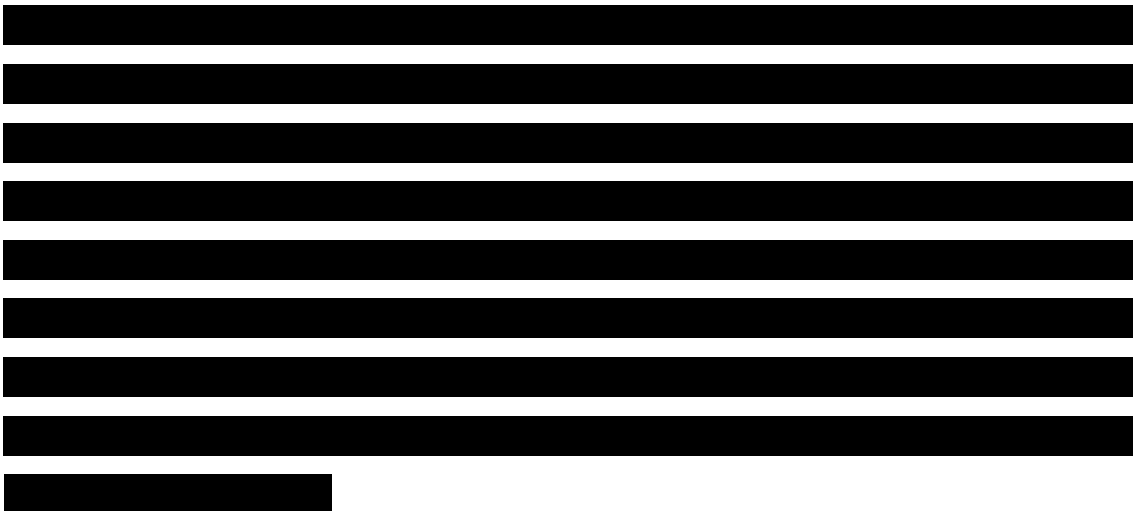


Figure 49. [Redacted]

5.2.7.2. Wheel Housing

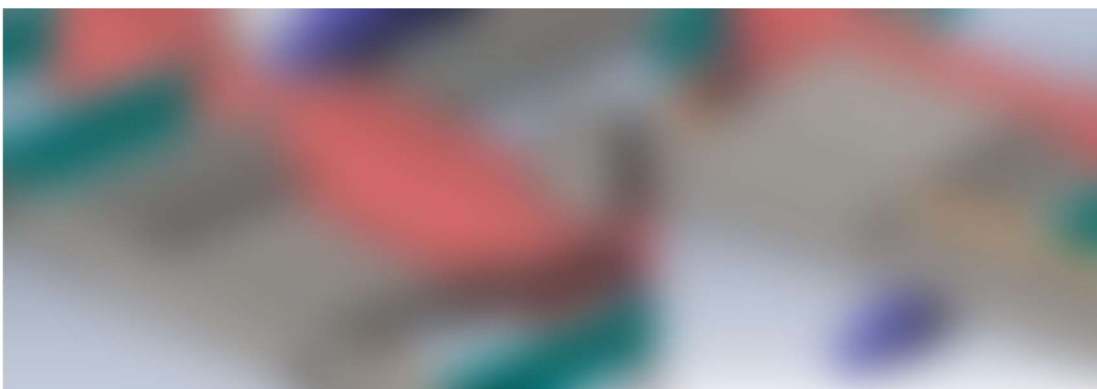
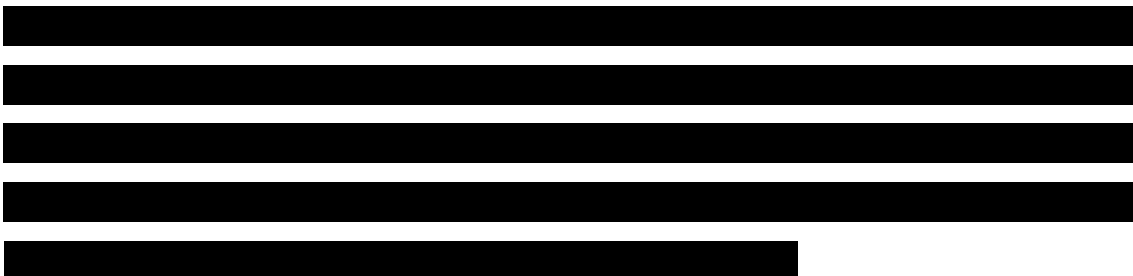


Figure 50. [Redacted]

5.2.7.3. Stainless Steel Edge Profile

The left stainless-steel edge profile provides support for the side doors at the bottom of the semi-trailer's frame. [REDACTED]

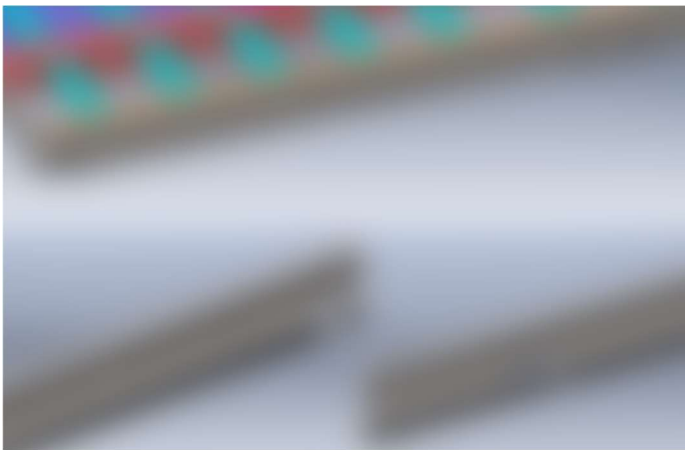


Figure 51. [REDACTED]

5.2.7.4. Coupling Pin and Turntable Plate

The coupling pin also referred to as King Pin, is a cylindrical steel pin positioned vertically at the front underside of the semi-trailer. The coupling pin is used to connect the semi-trailer to the pulling vehicle and to transfer power and control from the pulling vehicle to the semi-trailer.

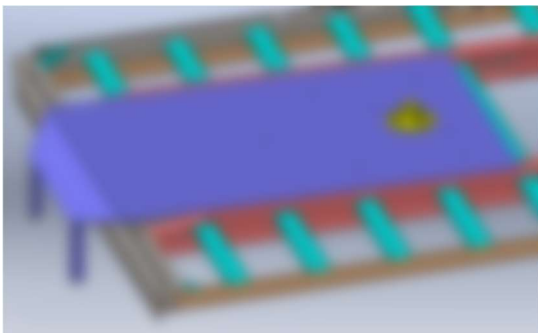


Figure 52. [REDACTED]



Figure 53. [REDACTED]

The turntable plate, also referred to as the fifth wheel plate, is a steel plate assembled under the frame at the front of the coupling pin. The turntable plate serves as a wear-resistant surface, allowing a smooth rotation between the coupling pin and the coupling device of the pulling vehicle. [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

5.2.7.5. Frame Brackets

The frame of the semi-trailer is equipped with customized brackets to facilitate the assembling of different boxes, loading legs, rear and side underrun protection, as well as other electrical and pneumatical components. [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

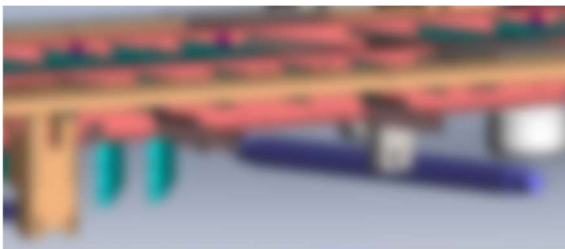


Figure 54. [REDACTED]

5.3. Strength Calculations Using the SolidWorks Simulation Method

This sub-chapter presents the strength calculations performed using the finite element method in SolidWorks Simulation. To simplify the simulation, [REDACTED]

[REDACTED]

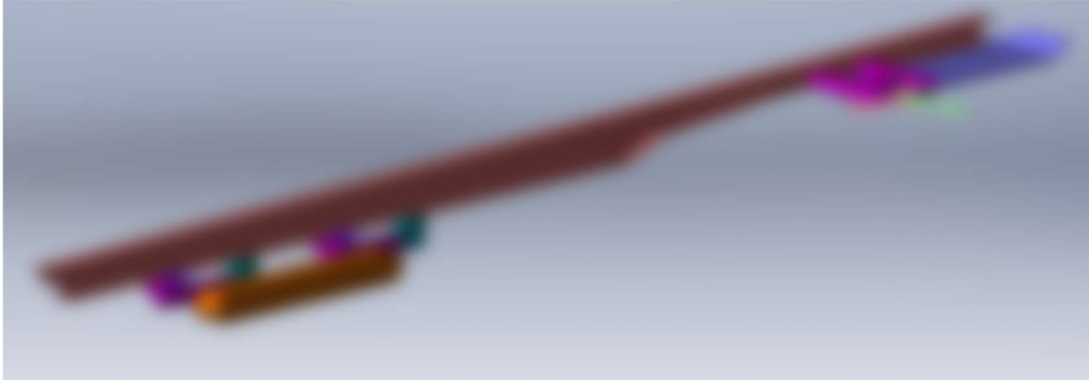


Figure 55. [REDACTED]

Normal forces will support [REDACTED]

[REDACTED]

[REDACTED] The objective of these simulations is to measure displacement and identify areas of high-stress concentrations, referred to as critical areas.

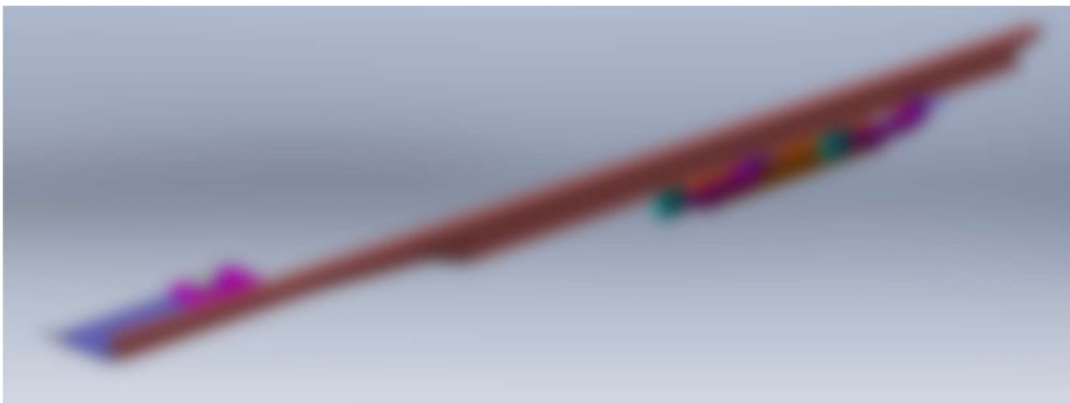


Figure 56. [REDACTED]

5.3.1. Meshing

The simulation began with the meshing process, where the structure's geometry is broken down into smaller parts called finite elements. [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

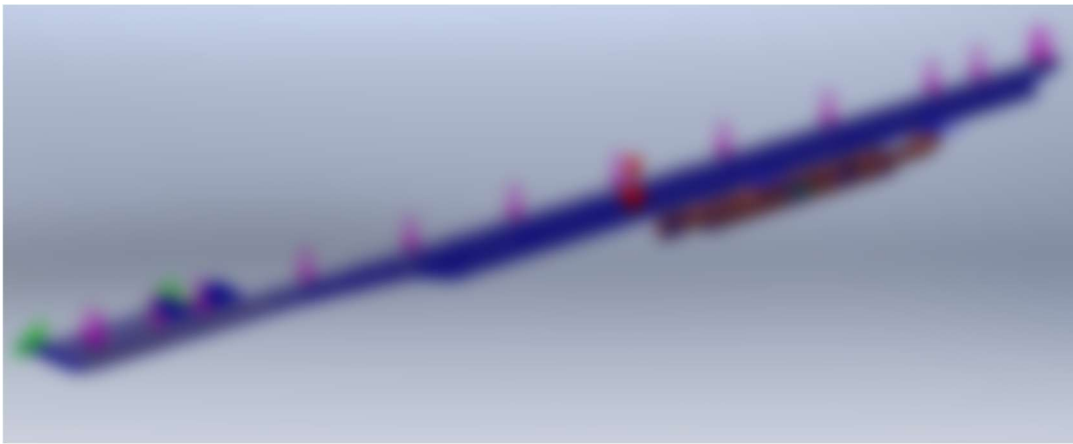


Figure 57. [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

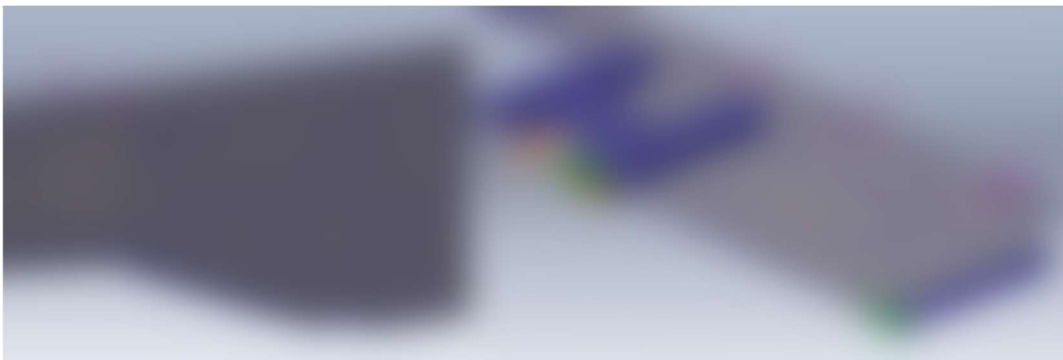


Figure 58. [REDACTED]

5.3.2. Displacement

The result from the displacement, as shown in the Figures below

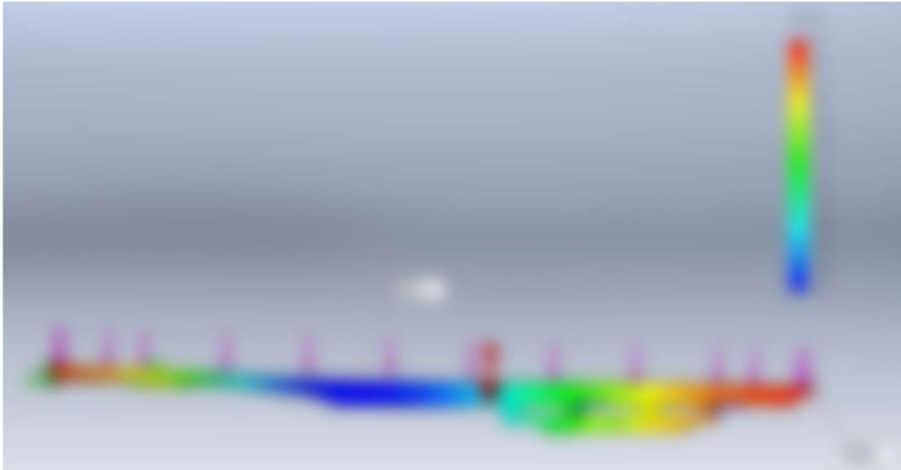


Figure 59.

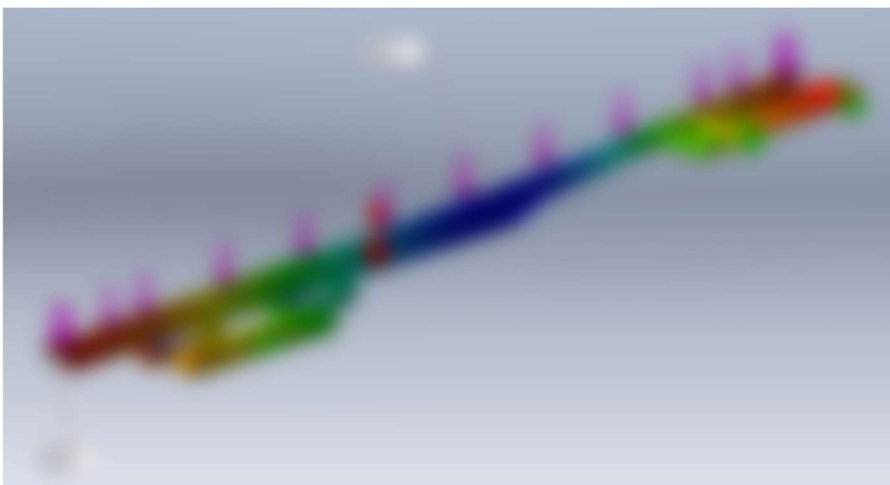


Figure 60.

5.3.3. Stress

The result of the stress calculations shows the exposed areas of the structure that are exposed to high-stress concentrations, referred to as critical areas.

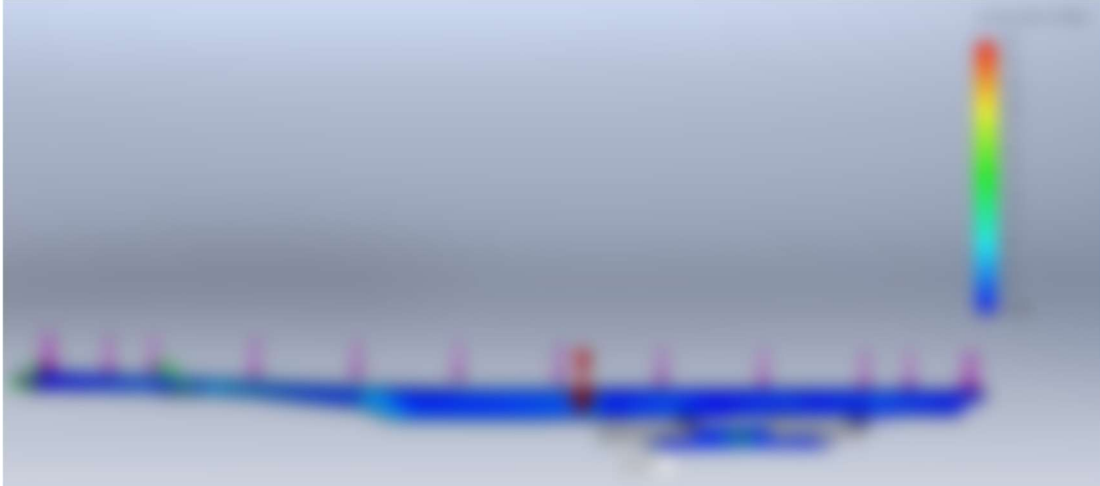


Figure 61. [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

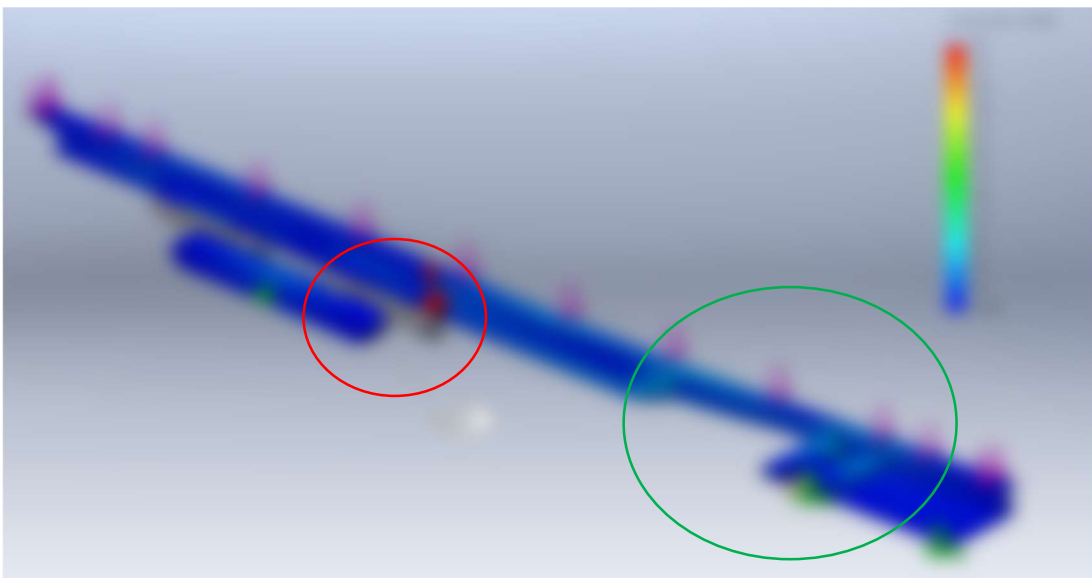


Figure 62. [REDACTED]

5.4. Production Follow-up

This chapter presents the production follow-up conducted for this thesis. It begins by describing the flowchart created to map each activity of the manufacturing process and determine the planned date for each activity. Following this, the results of the production follow-up are presented, including the identified success factors and challenges.

5.4.1. Flowchart to Map the Manufacturing Process

The production follow-up began by creating a flowchart to map each activity in the semi-trailer's manufacturing process. The goal was to carefully track the planned dates for each activity. [REDACTED]

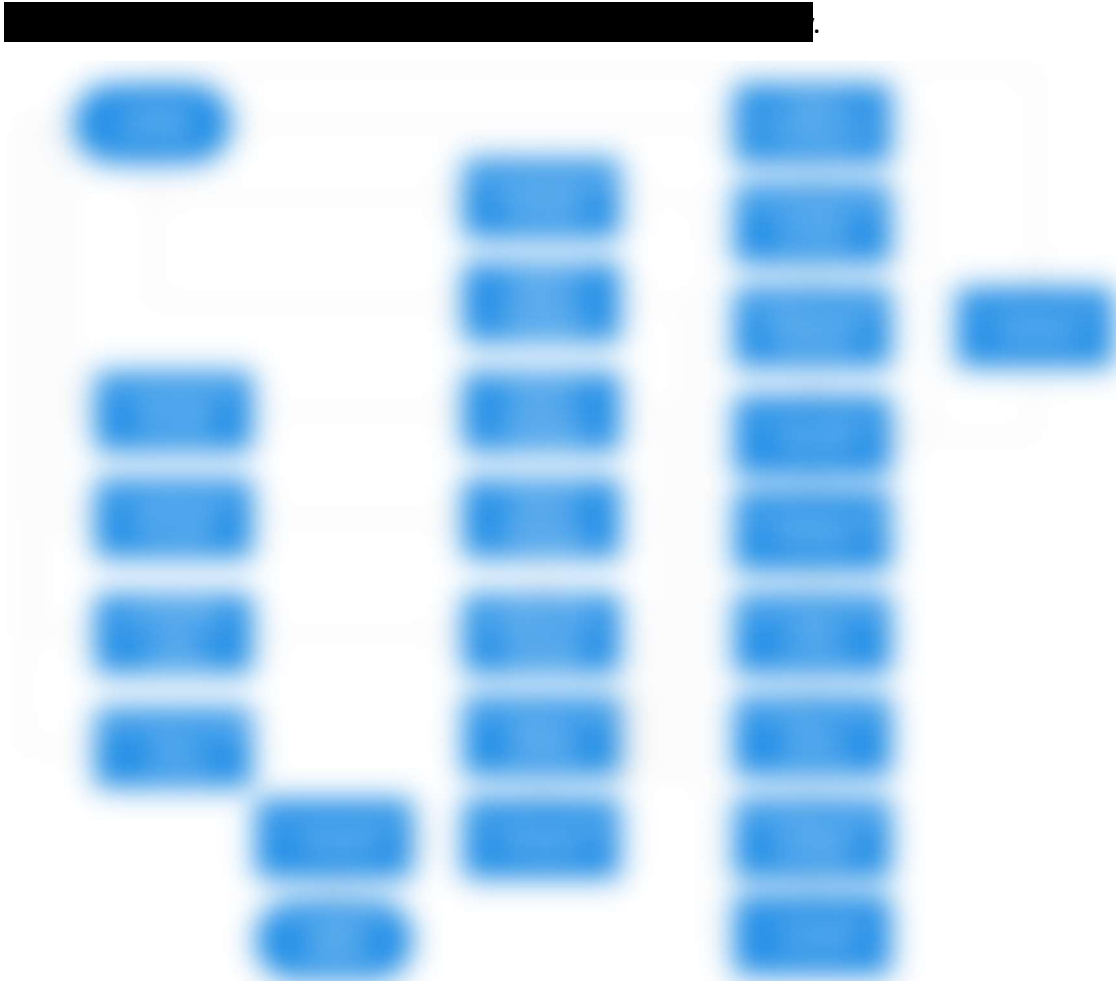


Figure 63. [REDACTED]

5.4.2. Production Follow-up

This subchapter presents the production follow-up conducted during the physical manufacture of the semi-trailer. The production follow-up will be presented according to the sequence outlined in the flowchart shown in Figure 63. To facilitate the procedure and provide a clear and systematic overview of the production process, the production follow-up is divided into five main parts:

1. **Frame Welding:** [REDACTED]
[REDACTED]
2. **Chassis Preparation:** [REDACTED]
[REDACTED]
[REDACTED]
3. **Element Manufacturing:** [REDACTED]
[REDACTED]
4. **Box Body Assembly on the Chassis:** [REDACTED]
[REDACTED]
5. **Final Assembly and Delivery Preparation:** [REDACTED]
[REDACTED]

5.4.3. The Frame Welding

[REDACTED]



Image 6. [REDACTED]

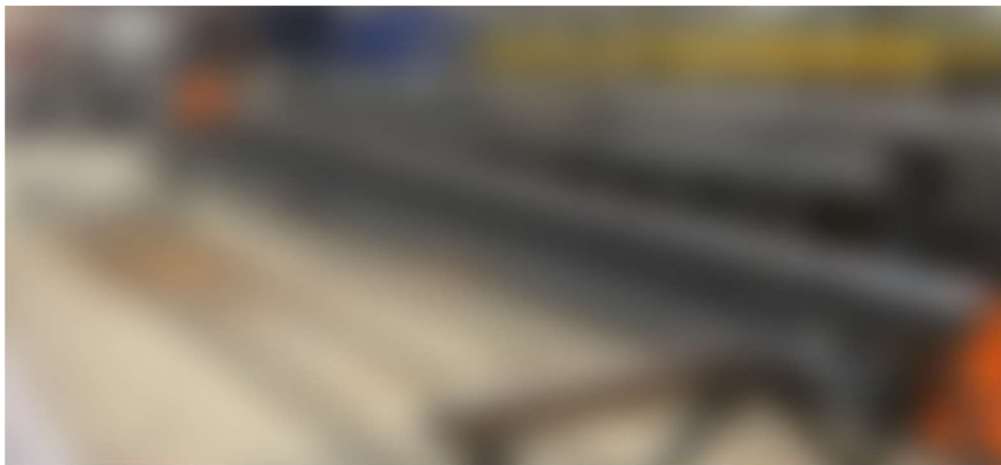


Image 7. [REDACTED]

[REDACTED]

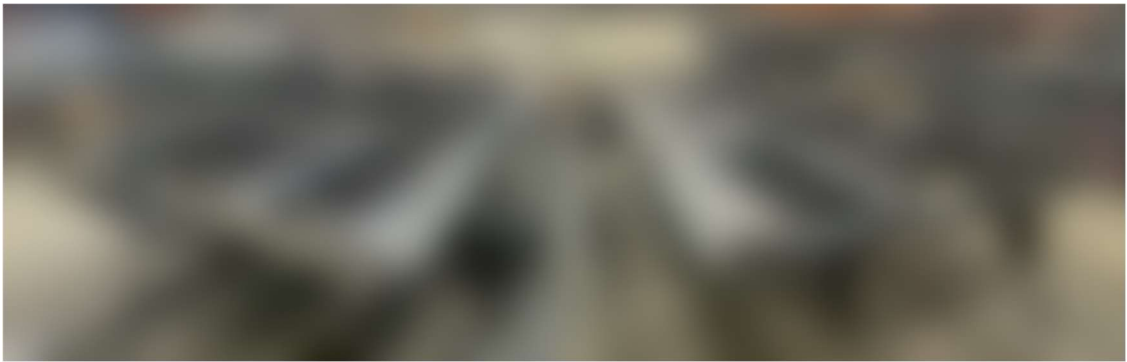


Image 8. [REDACTED]

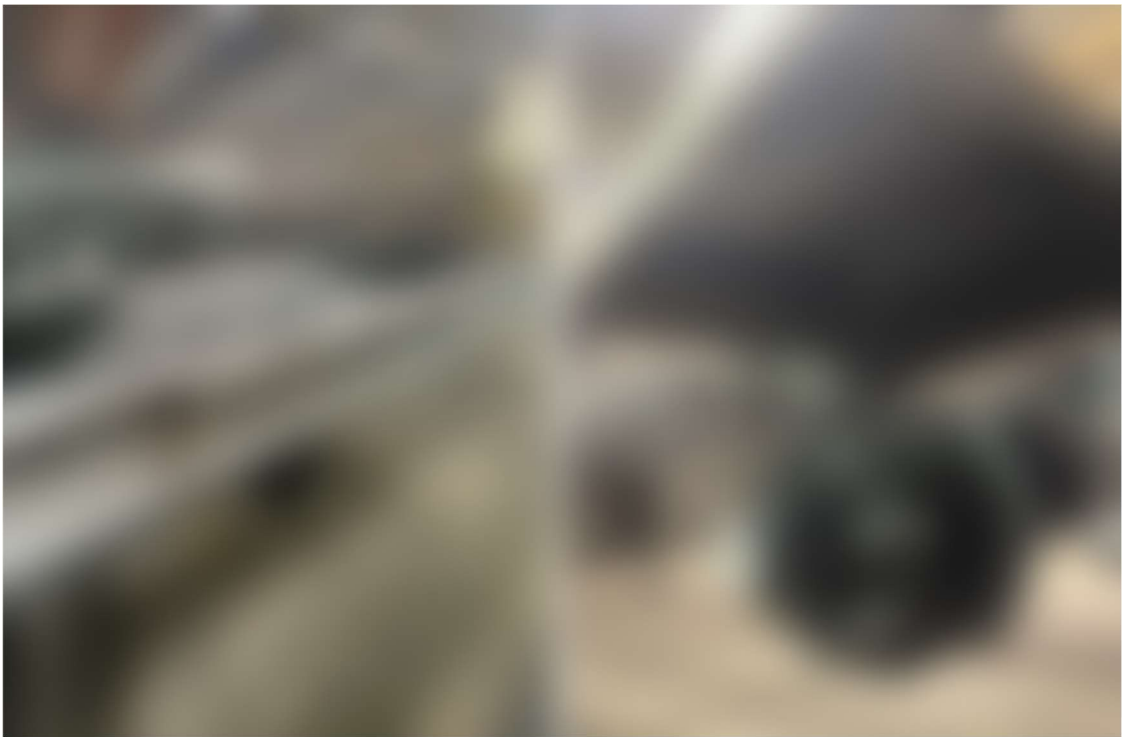


Image 9. [REDACTED]

5.4.3.1. Observed Challenges during Frame Welding

The observed challenges encountered during frame welding are presented below with descriptive pictures:



Figure 64. [Redacted]

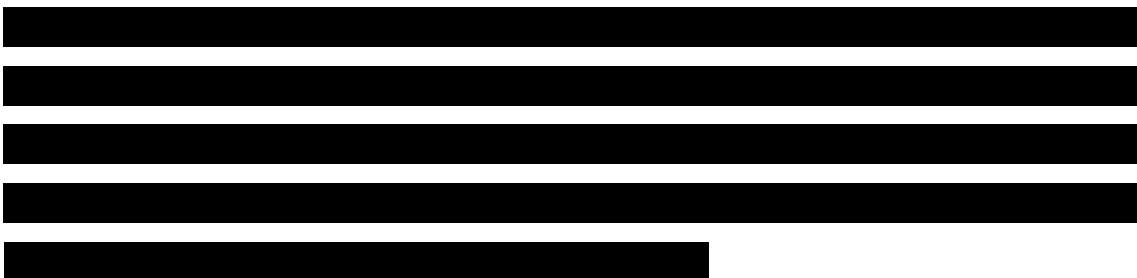
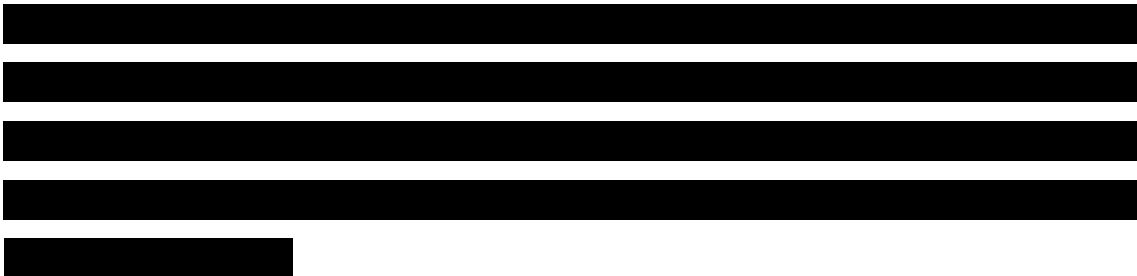




Image 10. [Redacted text]

[Redacted text]

[Redacted text]

5.4.4. The Chassis Preparation

After the frame is fully welded, the chassis is prepared before assembling the box body.

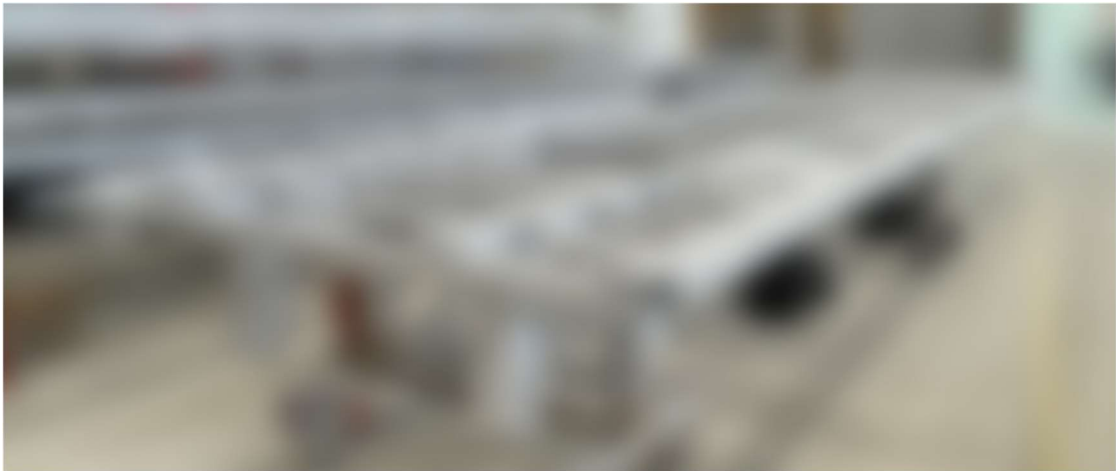


Image 11. [REDACTED]

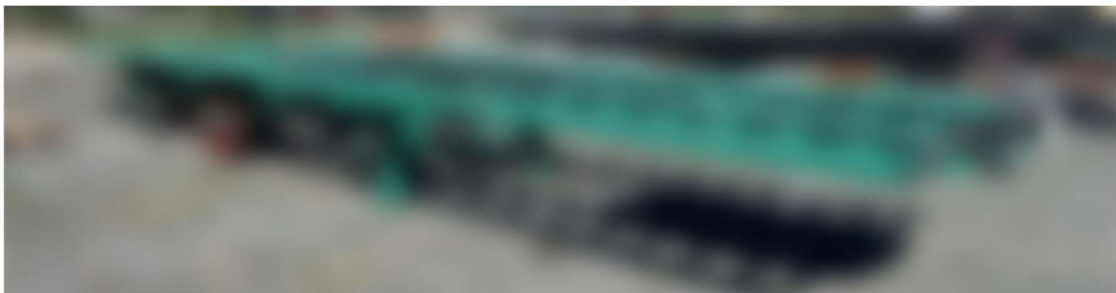


Image 12. [REDACTED].

5.4.4.1. Observed Challenges during Chassis Preparation

The observed challenges encountered during chassis preparation are presented below with descriptive pictures:

[Redacted text block]

[Redacted text block]

[Redacted text block]



Image 13. [Redacted caption text]

5.4.5. The Elements Manufacturing

In element manufacturing, the fiberglass elements of the box body are manufactured, including the front wall, right wall, side doors, and rear doors. [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]



Image 14. [REDACTED]

5.4.5.1. Observed Challenges during Element Manufacturing Process

The observed challenges encountered during the element manufacturing process are presented below with descriptive pictures:

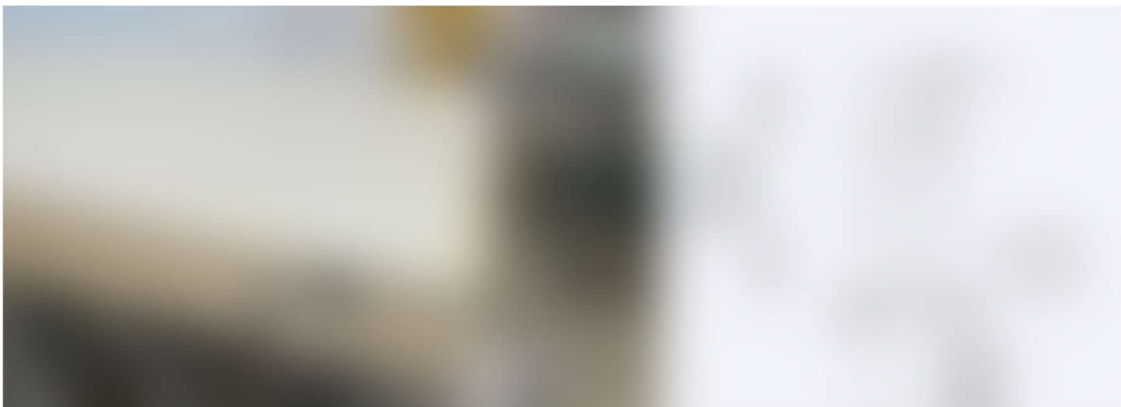
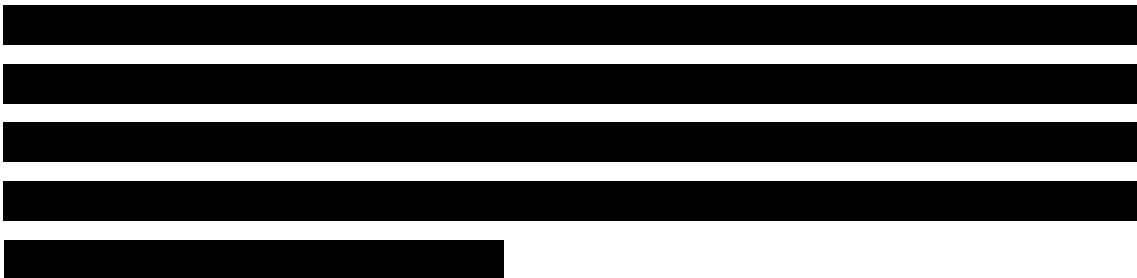
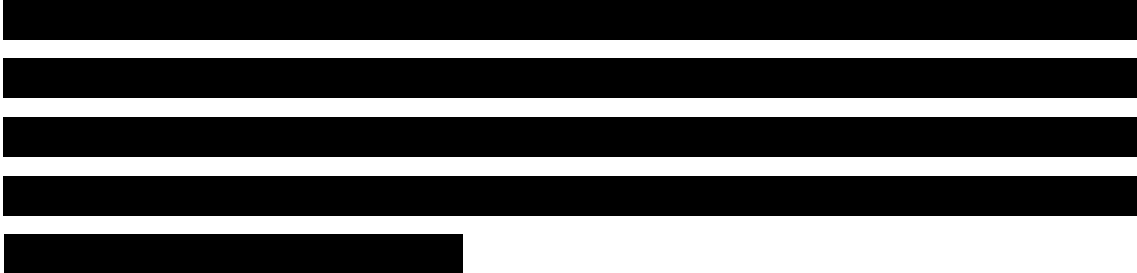


Image 15. [Redacted text]

[REDACTED]

[REDACTED]

[REDACTED]

5.4.6. The Box Body Assembly

When the chassis is fully prepared and all the fiberglass elements have been manufactured, the box body is assembled. [REDACTED]

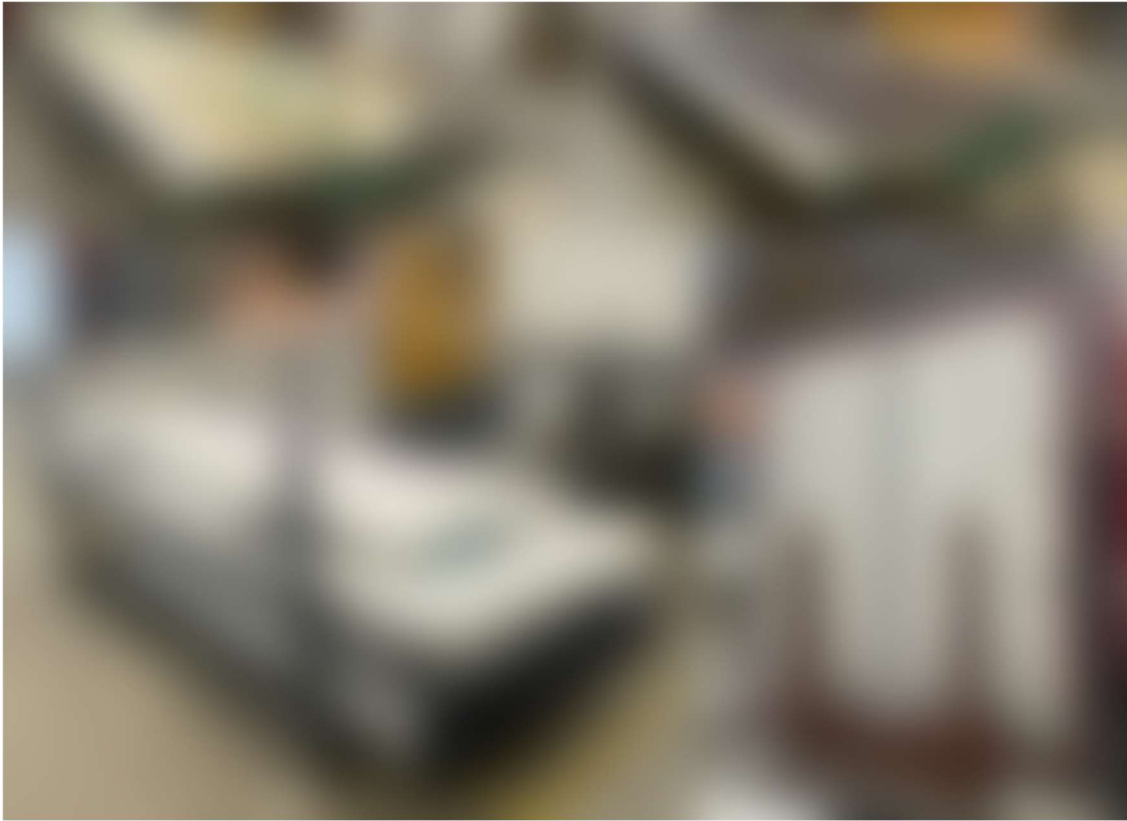


Image 16. [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

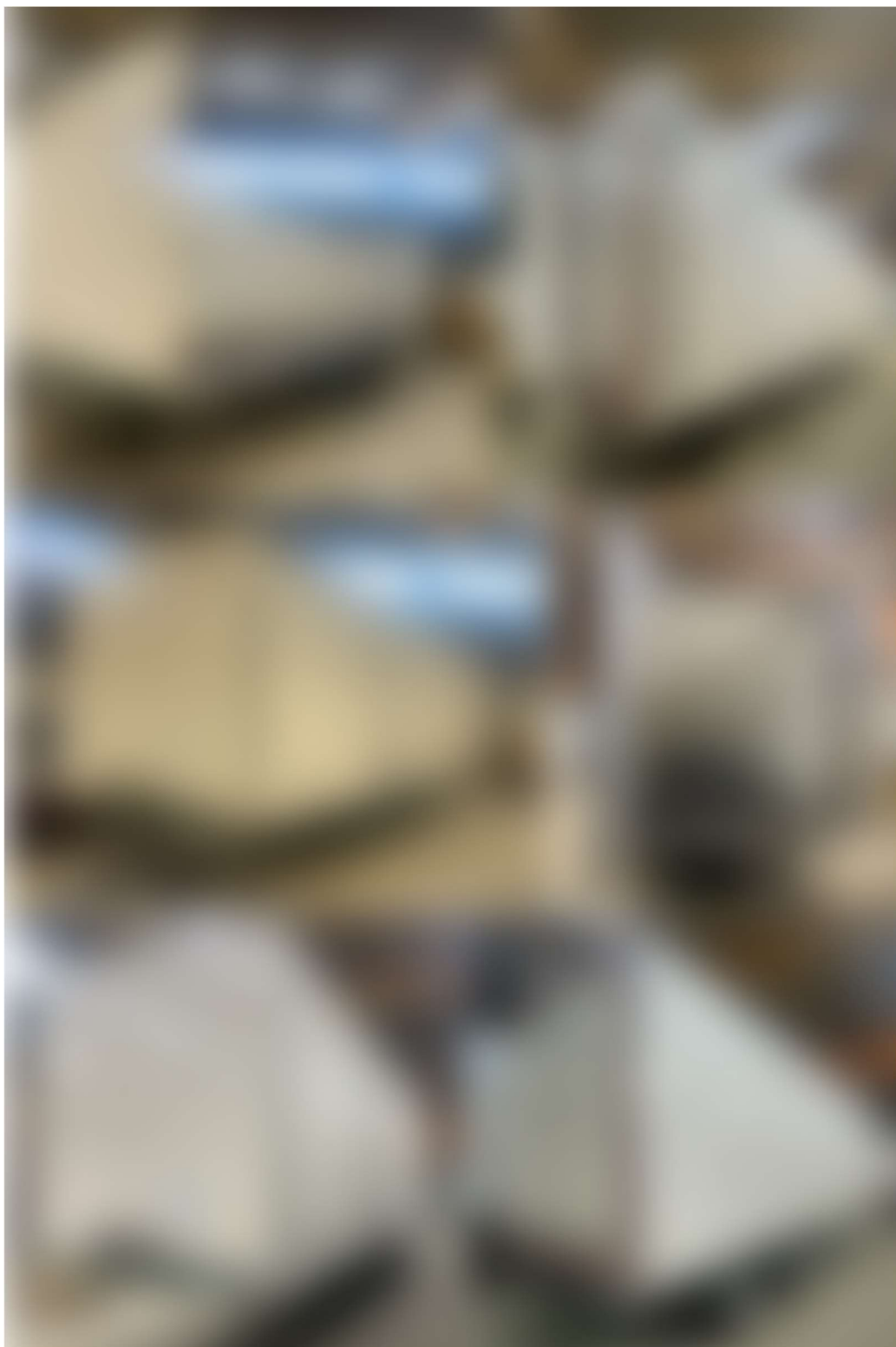


Image 17.



5.4.6.1. Observed Challenges during the Box Body Assembly

The observed challenges encountered during the box body assembly are presented below with descriptive pictures.



Figure 65. [Redacted]

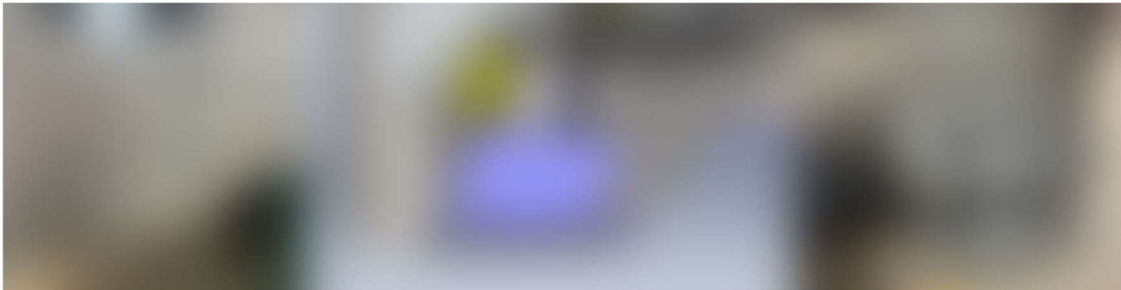


Image 18. [Redacted]

[REDACTED]

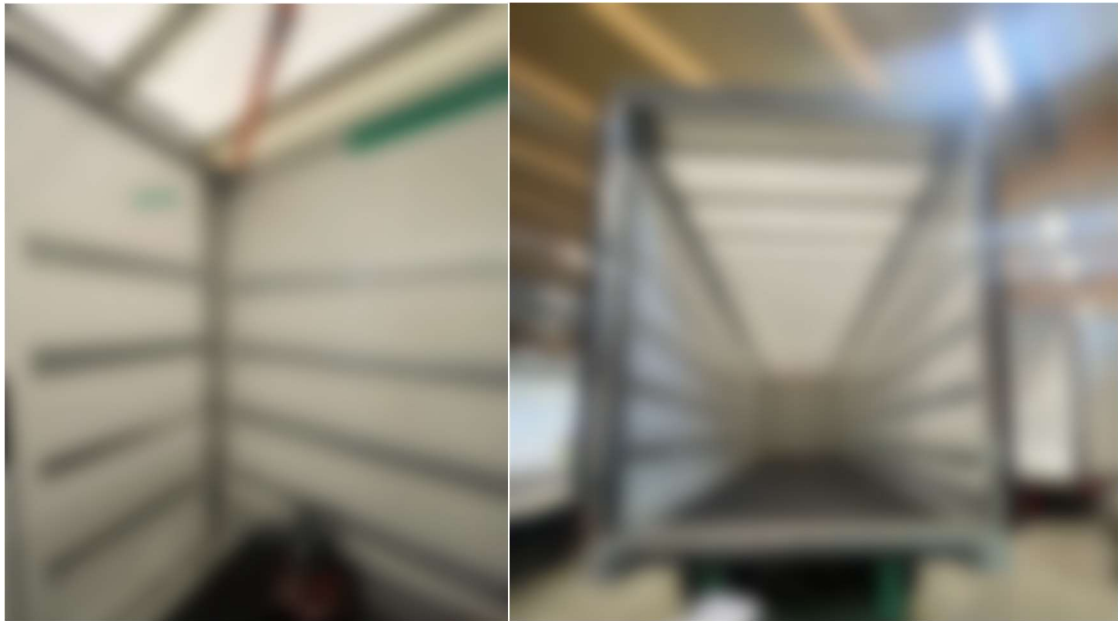


Image 19. [REDACTED]

5.4.7. Final Assembly

During the final assembly, the semi-trailer is completed by assembling [REDACTED]
[REDACTED]
[REDACTED]

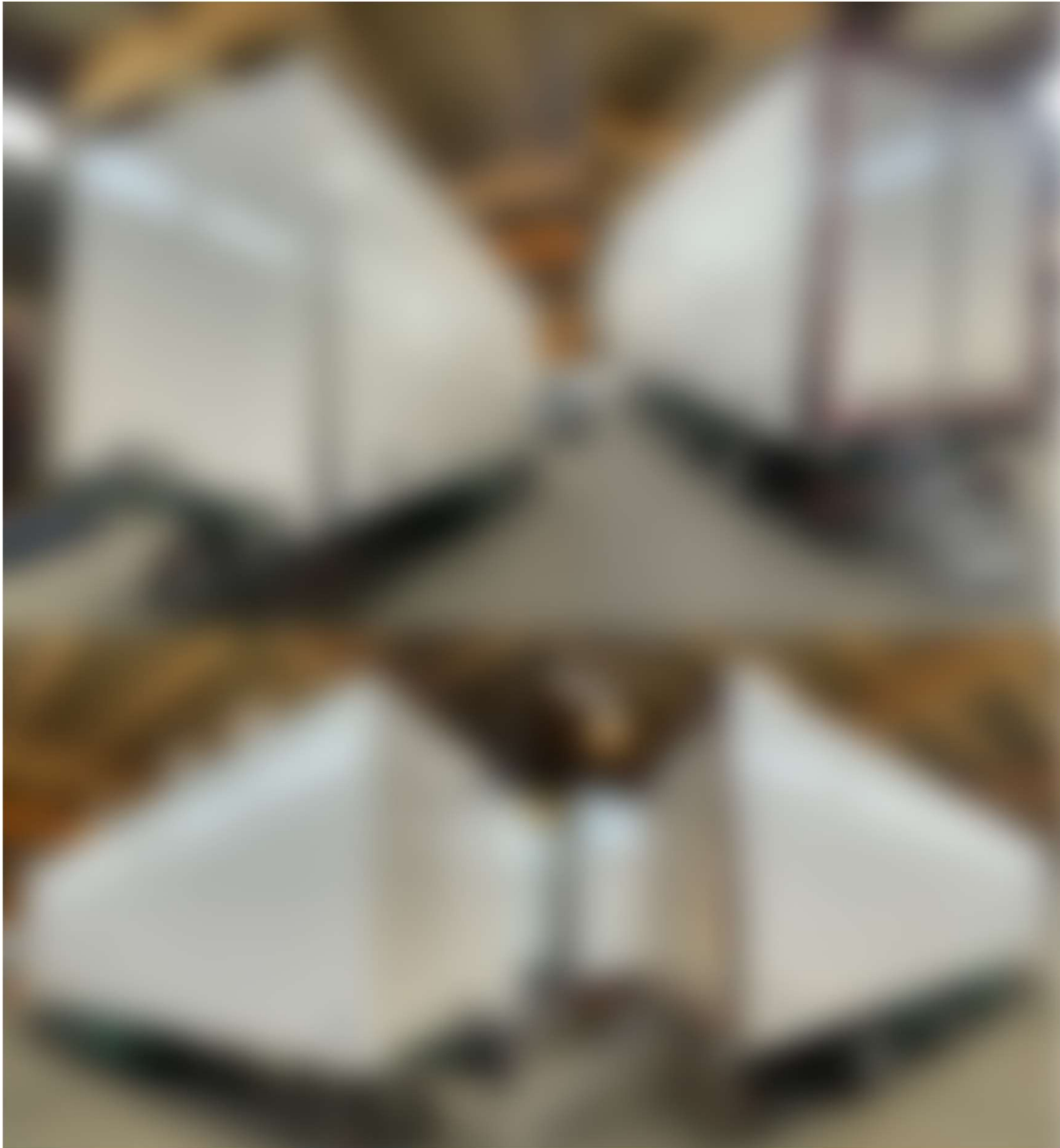


Image 20. [REDACTED]
[REDACTED]

5.4.7.1. Observed Challenges during the Final Assembly

The observed challenges encountered during the final assembly are presented below with descriptive pictures.

[Redacted text block]

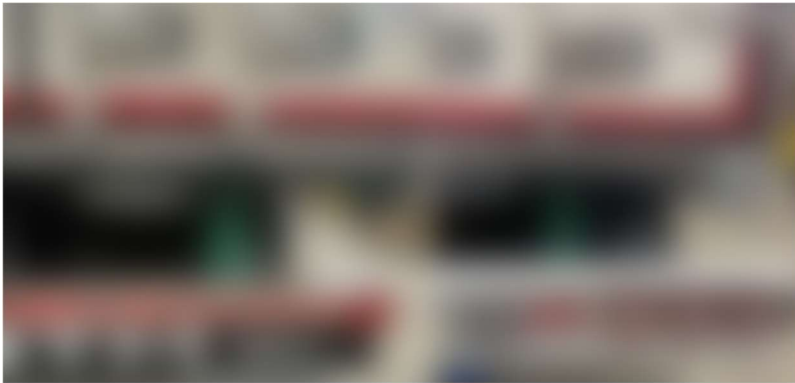


Image 21. [Redacted text]

[Redacted text block]

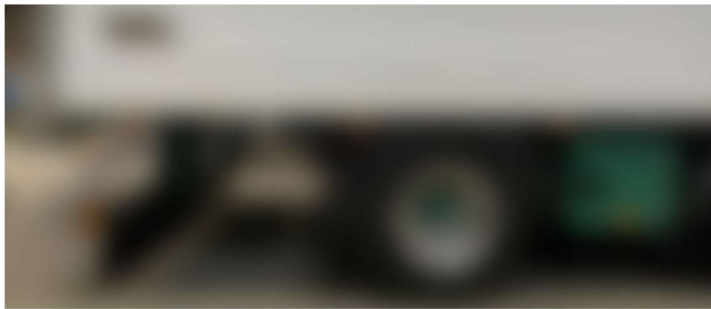


Image 22. [Redacted text]

[Redacted text block]

5.5. Manufactured Semi-Trailer Ready for Delivery

This chapter presents images of the semi-trailer after production and when it was ready for delivery to the end customer.



Image 23. Shows the left side of the semi-trailer viewed obliquely from the front.



Image 24. Shows the left side of the semi-trailer viewed obliquely from the rear.



Image 25. Shows the left side of the semi-trailer.



Image 26. Shows the right side of the semi-trailer.



Image 27. Shows the right side of the semi-trailer viewed obliquely from the rear.



Image 28. Shows the semi-trailer from the front to the left and from the rear to the right.

6. Summary of the Research Questions

This chapter presents a summary of the research questions addressed in this thesis. The first research question focused on adaption, compromises, and design challenges during the design phase with SolidWorks. The first research question, R1, was:

How has the design been tailored to address customer requirements, potential customization needs, production efficiency, regulatory compliance, and quality standards?

The semi-trailer has been dimensioned and equipped according to the end customer's wishes and needs. These requests have been carefully checked to ensure they are kept within the framework of applicable laws and EC directives relevant to the specific design. The design for the semi-trailer's frame, side doors, and right wall has been adapted according to the slope of the floor, while the front wall and rear doors were not affected by this slope.

Due to the low loading height at the rear of the semi-trailer, I designed customized wheel housings to allow for maximum lowering of the axle's ride height. These wheel housings also required a recess in the left steel edge profile to provide sufficient space for the wheels in their lowest position. These recesses were covered with a customized cover sheet metal to provide additional headroom within the wheel housings. Additionally, the low frame beams on the semi-trailer also required the design of customized centre beams, as standardized centre beams would have been too high and would have interfered with the plank floor underneath. The slope of the floor is determined by the upper edge of the frame beams, which has a slope of \blacksquare degrees, while the lower edge follows a straight line that is parallel and aligned to the ground. To facilitate the assembly of centre beams and various brackets during frame welding, the laser-cut components for the frame have been customized with pre-made laser-cut hole markings indicating where the beams and consoles should be placed on the frame. Additionally, standardized components have been used to the greatest extent possible.

The side doors and right wall follow the standardized structure, except for their bottom edges and recessed lashing rails, which are adapted to the slope of the floor. At the right wall, the insulation in the centre determines the slope at the bottom, while the door frame for the respective side door determines the slope at the bottom for the eight side doors.

The second research *question* focused on FEM/FEA analyses using SolidWorks Simulation. The second research question, R2; was:

Which specific area of the structure experiences the highest stress concentrations and the greatest displacement?

The result of the SolidWorks Simulation strength analysis shows that the maximum displacement is [REDACTED], which corresponds to the maximum load that the axles and the coupling pin can bear. The permissible maximum displacement according to the company's standards is [REDACTED] which means that a displacement of [REDACTED] is within the approved limit.

The stress calculation shows that the design is not exposed to high stress concentrations. The highest stress was measured to be [REDACTED] in the area around the first axle. A slightly higher tension was also observed [REDACTED]
[REDACTED]

The third research question focused on construction-related difficulties during the manufacturing process. The third research question, R3; was:

What construction-related challenges were observed during the manufacturing process and how were these challenges addressed?

In the chapter production follow-up, it becomes clear that there were some design challenges and mistakes in the drawings, including forgotten dimensions and other minor oversights. Despite this, no significant flaws were found in the drawings that required a complete redesign. Challenges that arose were typically addressed verbally on-site, and any quality deficiencies noted by the production department on the drawings were immediately addressed to enable and facilitate the manufacture or assembly of the affected components.

The fourth and final research question focused on the final evaluation and reflection of the collected data. The fourth research question, R4, was:

How can the design be further refined and optimized based on the final collected data?

As mentioned in the third research question, some design challenges and quality deficiencies were identified during the production follow-up. The first step to improve the design of the semi-trailer and optimize its production process is to carefully analyze all the challenges and quality deficiencies discovered during the production follow-up. Subsequently, further considerations and explorations should be made to identify if there are better and more innovative solutions to these problems that can be used to further optimize and refine the design and the production process. Alternatively, evaluations should be conducted to determine whether the best solution is to address only the issues identified during the production follow-up and make necessary adjustments to the drawings accordingly.

7. Final Discussion

The implementation of this thesis has significantly deepened my knowledge in the process of design and development of customized products and production follow-up. This work has also broadened my knowledge of how SolidWorks can be utilized to develop and design various customized components and assemblies. Writing the theoretical part has given me valuable knowledge that has been of great use for carrying out this work. The theoretical part has also given me a solid understanding of the various laws and directives that impose requirements on structures of this kind. It has also strengthened my knowledge of strength theory, CAD design, standardization, and mechanical manufacturing processes.

The goal was to develop a design and conduct production follow-up on a customized semi-trailer with a floor that is tilted so that the loading height was 150 mm lower at the rear compared to the front, which I consider has been fulfilled. Throughout the work, I primarily worked independently to solve various challenges that arose along the way. For more complex challenges, I typically consulted a colleague with more experience in the field.

The most challenging aspect of the design process was to ensure and align the connection between all components, where some needed to follow the slope of the floor while others had to remain parallel aligned to the ground. This required a systematic approach to ensure that all the components were properly connected, either aligned with the slope of the floor or straight aligned. The most challenging assemblies to design were the frame, side doors, and right wall because they were directly affected by the slope of the floor.

Through strength analyses and simulations, I gained new skills in using SolidWorks Simulation to analyse stress concentrations and displacements for various structures. Since I had not previously conducted so many strength analyses and simulations with CAD programs, this part of the work was particularly instructive and rewarding.

Through observations and interviews during the production and quality follow-up, I got many new ideas on how the product can be further improved. Interviewing the personnel who manufacture the components was particularly instructive as it gave me valuable insight into their perspectives and experiences regarding the developed product.

Finally, I can say that I have previously developed several customized trailers for different customers, but I can confidently say that this semi-trailer has been the most demanding and complex so far.

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9. Appendices

Appendix 1. Chassis + Box Body Drawing



Appendix 2. Front Wall Drawing



Appendix 3. Right Wall Drawing



Appendix 4. Insulation Right Wall Drawing



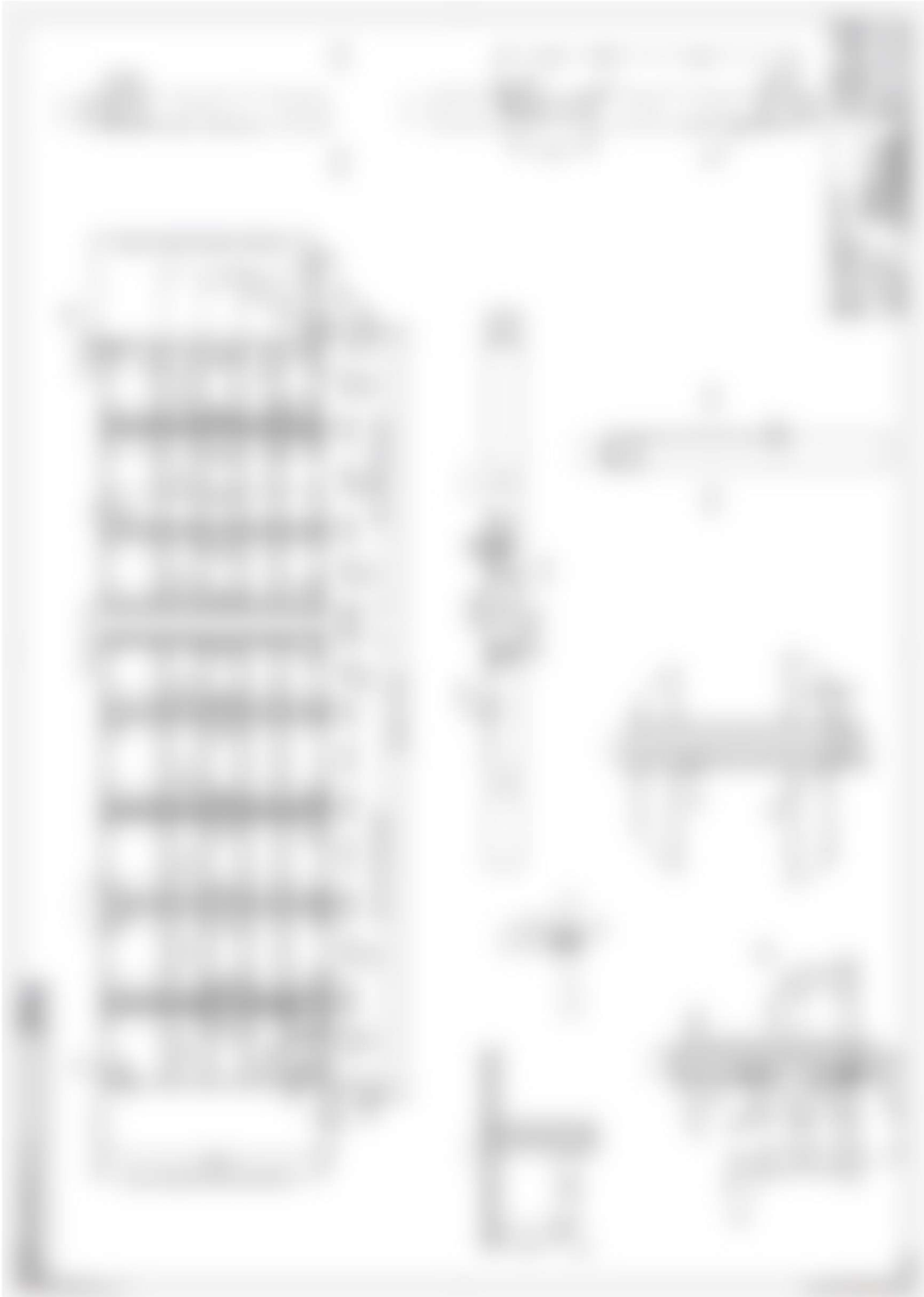
Appendix 5. Side Doors Package Drawing



Appendix 6. Side Doors Element Drawing



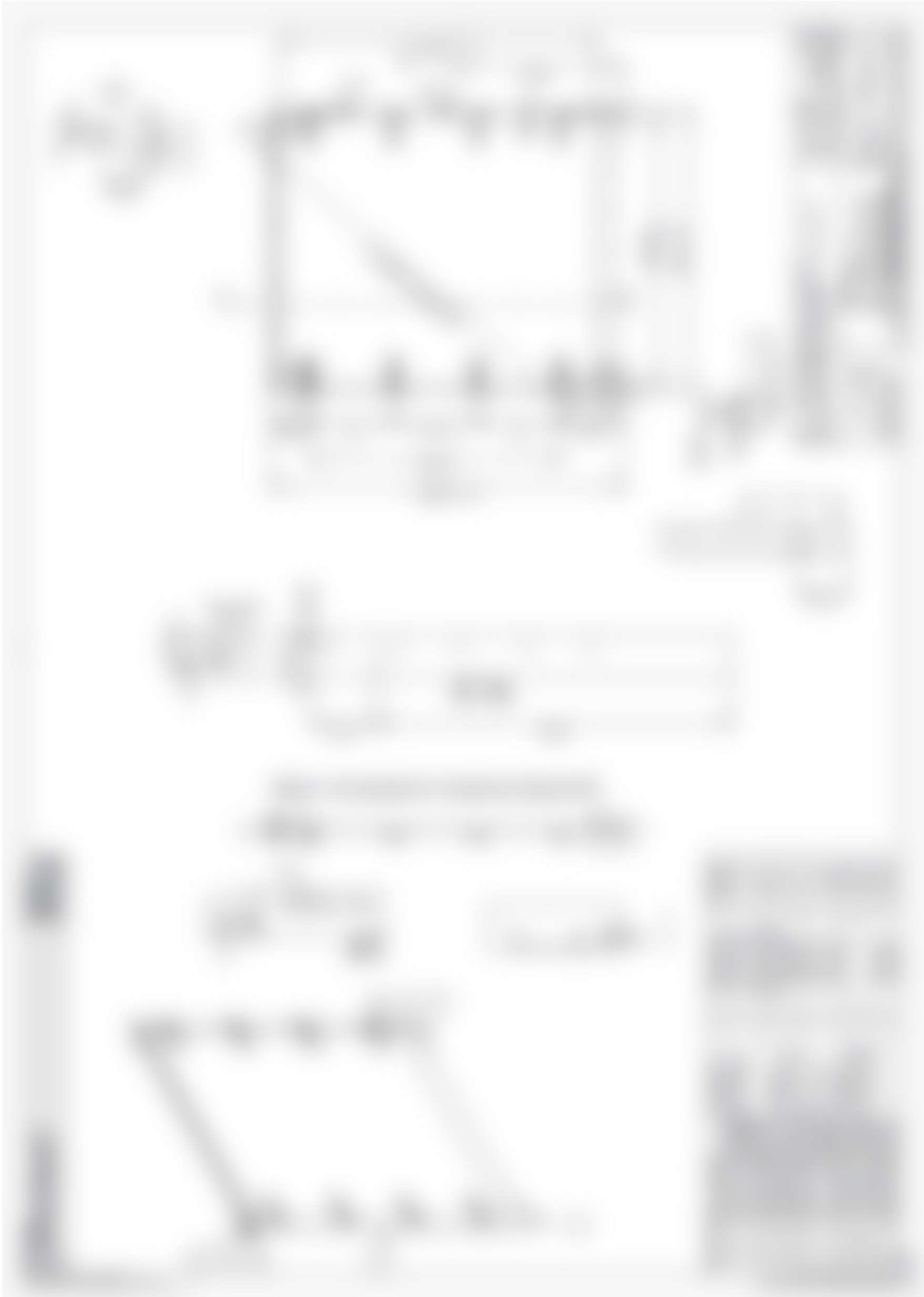
Appendix 7. Structural Frame for the Side Doors Drawing



Appendix 8. Rear Doors and Their Outer Frame Drawing



Appendix 9. Outer Frame for the Rear Doors Drawing



Appendix 10. Rear Doors Drawing



Appendix 11. Structural Frame for the Rear Doors Drawing



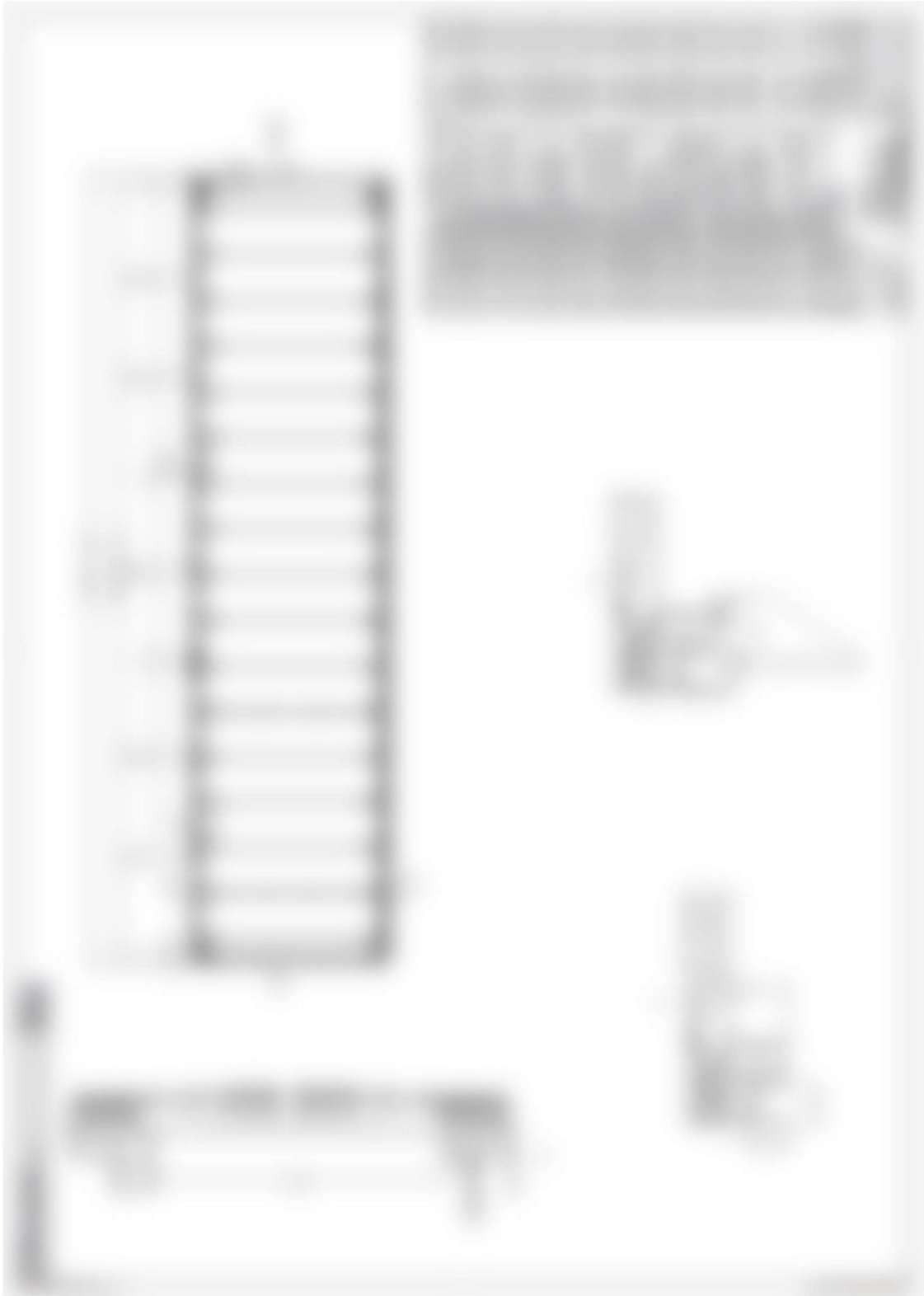
Appendix 12. Stainless-steel Lintel Drawing



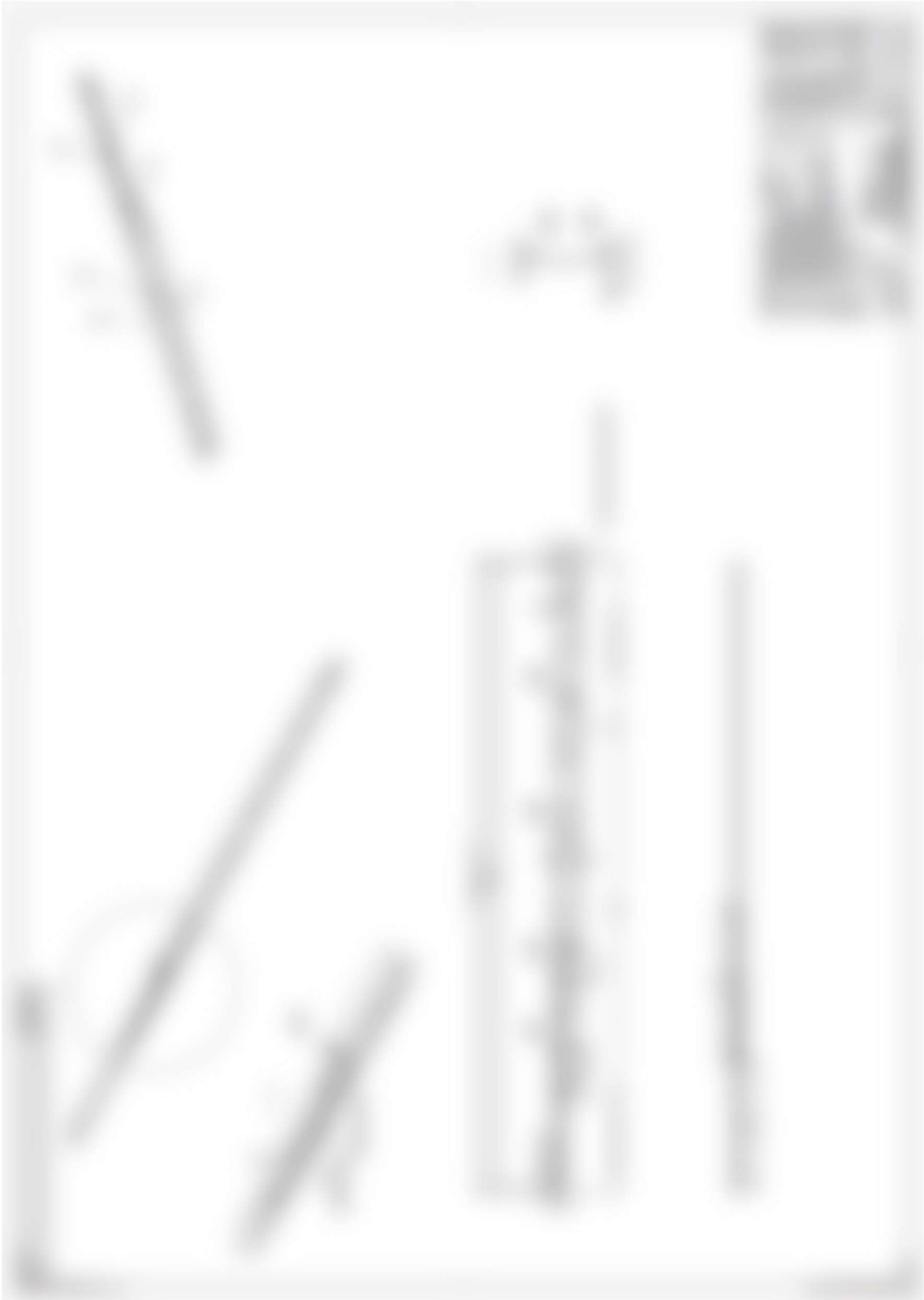
Appendix 13. Stainless-steel Bumper Drawing



Appendix 14. Tarpaulin Roof Drawing



Appendix 15. Frame Drawing

Appendix 16. Frame Beam Drawing

Appendix 17. Front Sheet Metals for Frame Beam Drawing



Appendix 18. Rear Sheet Metals for Frame Beam Drawing



Appendix 19. Right Wheel Housing Drawing



Appendix 20. Left Wheel Housing Drawing



Appendix 21. Front Stainless-steel Edge Profile Drawing



Appendix 22. Rear Stainless-steel Edge Profile Drawing

