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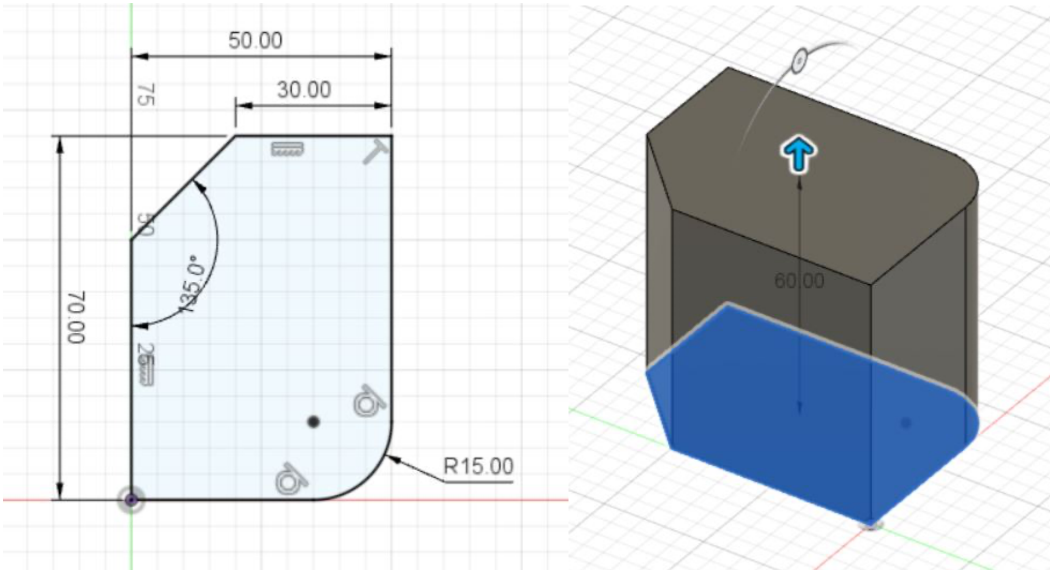

Tool analysis for design of complex prototype products

Bachelor thesis in Mechanical Engineering

LINUS HERMANSSON

MATTIAS WALLIN

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
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LINUS HERMANSSON, MATTIAS WALLIN

Examiner & Supervisor: Peter Hammersberg & Gert Persson, Department of Industrial and Materials Science

Bachelor Thesis 2021

Department of Industrial and Materials Science
Chalmers University of Technology
SE-412 96 Gothenburg
Phone: +46 31 772 1000

PREFACE

This thesis is carried out at Infotiv and written at Chalmers University of Technology at the Department of Industrial and Materials Science in the spring of 2021. The project was carried out by Linus Hermansson and Mattias Wallin, students at Bachelor Mechanical Engineering.

We would like to thank Infotiv for the opportunity to write our bachelor thesis at your company and for the opportunity to work safely on site with you during the COVID-19 pandemic. Thanks to Maria Broberg who made us feel included in the project, Martin Lindqvist who gave us technical guidance, Nils Gangby who gave us continuous advice and Pierre Ekwall who was involved in important decisions.

We would also like to thank our examiners, Gert Persson who was our examiner and supervisor until the end of April and Peter Hammersberg who took over and was our supervisor and examiner during the final phase of the project.

ABSTRACT

Infotiv is a technology consulting company operating in several cities in Sweden with headquarters in Gothenburg. They also conduct certain in-house projects, including a collaboration with RISE where the vision is to develop a self-driving vehicle in the form of a go-kart.

Infotiv has recently started a mechanics department where they offer services and consultants in mechanical design. They therefore have a need to find a suitable tool for solid modeling. The market for tools for solid modeling is today very widespread and it is expanding more and more. The aim of the project is therefore to make an analysis, which tool is best suited for prototype contexts with complex geometries in small to medium-sized companies.

Once the most suitable tool has been identified, a verification of this is performed by designing consoles for equipment for the go-kart mentioned above.

After a market research and testing of candidates, it was determined that Fusion 360 was the tool that best suited the target group due to its low cost and high user friendliness. With this knowledge, an education was made to ensure a smooth transition of the existing tool at the company to Fusion 360, without major knowledge gaps.

Table of contents

DESIGNATIONS

Term	Definition
CAD	Computer Aided Design, a tool for digital designing.
CAM	Computer Aided Machining, a tool for digital processing.
FEM	Finite Element Method, a tool for digital simulations.
CPU	Central Processing Unit
GPU	Graphics Processing Unit
RAM	Random Access Memory
.stl	File format for 3D-printers
STEP	File format for CAD-files.

1. INTRODUCTION

This chapter introduces the project where the background, purpose, limitations, and clarifications of the issue are presented.

1.1 Background

At present, there are many interesting tools for design and Infotiv wants to investigate which best suits their needs. Therefore, a tool analysis will be carried out where tools are evaluated according to solid modeling, license cost and compatibility. The tool should be suitable for small to medium-sized companies, which is the target group for this project.

Today, when choosing a tool for a company, it is often based on which tool has been used before and which tools well-established companies use. It is difficult for companies today to choose tools for CAD as the market around these has expanded greatly in the last decade and the chriteras for evaluation have not yet clearly been defined. Choosing the right tool for a business is essential to reduce time and licensing costs. It does not exist any clear process when choosing tools, as everyone values different features. A systematic way of choosing tools will therefore be investigated.

The analysis will result in a recommendation of a tool for the target group. A verification of the recommended tool is performed by designing chassis components for a go-kart. The components consist of brackets and consoles for ultrasound, radar, battery holder, moodlight, camera and computers. The go-kart will act as a test vehicle for analyzing various equipment and software, it is shown below in figure 1.1. The purpose of the verification is to test the tool and check that all requirements and wishes are met.

Fig.1.1 The go-kart that consoles will be constructed for.

1.2 Purpose

The assignment consists of two major parts. The first part contains a tool analysis. The idea is to analyse the pros and cons, with tools for prototype development in small to medium-sized companies and finally recommend a tool for the target group. The tool will be used for design, FEM-calculation, and solid modelling. The selected tool must not be overpriced compared to content and be user-friendly and intuitive as well.

The first part also includes a tool education, for the employees at Infotiv, will also be made. It should contain instructions on how the selected tool work as well as some information to increase understanding.

In the second part, design for the chassis will be carried out, more precisely brackets and consoles for the equipment required for self-driving (radar, camera, etc.). The purpose of the designing is to verify the choice of tool.

1.3 Clarification of the issue

Infotiv wants to investigate which tool best suits their needs and therefore needs an analysis of the existing tools on the market. The analysis should end with a recommendation on a tool for the relevant target group and thus reduce both time consumption and licensing costs. The new tool will be implemented in the company with the help of an education.

Internal Deliveries consists of a matrix including the tool analysis, a tool education document, to educate employees in the chosen tool, as well as prototypes and/or CAD-model for chassis. These are listed in table 1.1 below.

Tab.1.1 Deliveries for the project.

#	**External Deliveries**
1	Bachelor Thesis
	Internal Deliveries
2	Development of evaluation criteria
3	Matrix with recommendation of suitable CAD-tools
4	Tool education document
5	Prototypes and/or CAD-model for camera console
6	Prototypes and/or CAD-model for battery holder
7	Prototypes and/or CAD-model for radar console
8	Prototypes and/or CAD-model for ultrasound console
9	Prototypes and/or CAD-model for mood-light console
10	Prototypes and/or CAD-model for computer console
	Project Deliveries
11	Risk Assessment
12	Timeplan

1.4 Limitations

When analyzing and verifying tools, “test versions” may be forced to be used, which may not include all the functions and/or the access to the tools is time limited. The projects time limit consists of 400 hours/person, which corresponds to 20 hours/week. The analysis compares and evaluates the tool's functions in solid modeling. Surface modeling and other functions such as CAM and FEM are not evaluated more than the availability.

2 THEORETICAL REFERENCE

This chapter presents the theoretical background on which the work is based.

2.1 Computer Aided Design

To ensure the best results during product development and new designing, modeling is an absolute necessity. With the help of models, you can show results for all involved in the process, such as the product developers, customers, and the people responsible for manufacturing.

Since the 1980s, computer-based models have been completely dominant in the work of product development and innovation at manufacturing companies. This is called CAD (Computer Aided Design) where you design the desired geometries and shapes in a computer program. This revolutionized the manufacturing industry when it was possible to go from only making drawings with 2D views to seeing the entire product in 3D [1].

Within CAD, there are three main areas of use. These are solid modeling, surface modeling and drawings. Solid modeling is by far the most common in the manufacturing sector and is based on the desired geometry being developed in steps. Unlike subtractive manufacturing, where material is removed until you reach the desired shape, you instead start with nothing and add material until the desired shape is reached. This is done by drawing a closed geometry on a plane, a *sketch*, which is then *extruded* into space to create a volume (this is shown below in figure 2.1). The *extrude* can either add or remove material. In solid modeling, there are also many other functions that make it easier for the user to carry out the desired action. An example of such a function is *fillet* where you select a border on a body and specify which radius it should be rounded with, then the radius automatically follows the entire line, even if it is curved [1].

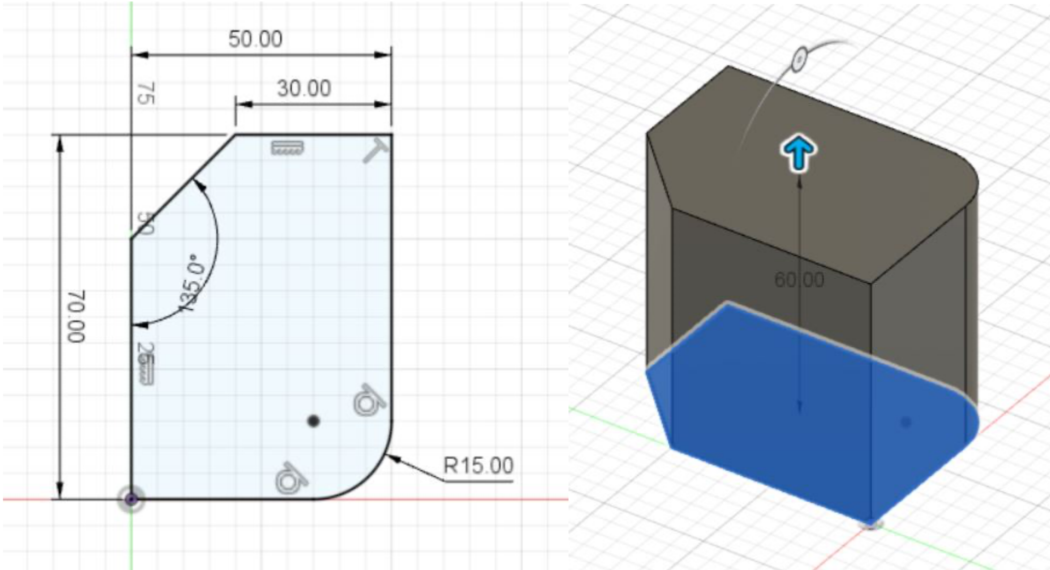

Fig.2.1 A sketch (left) which is extruded into a volume (right) in Fusion 360.

When several objects are created, these can then be assembled inside the program as an *assembly*. Then you can easily see if any piece's *clashes*, if something needs to be adjusted and how the kinematics work in the complete product. In this way, you save large costs by not having to make prototypes to see how the pieces fit together.

Surface modeling is common for e.g., industrial designers, filmmakers, and game developers. The working method is that you set out points which you then connect with a curve. Different curves can then be linked together to create surfaces. In this way, you can create very complex surfaces that are difficult to reach with traditional straight lines and circle segments [1].

Drawings are also used on a large scale in CAD. Usually, the detail is first designed in solid modeling and then used as a basis for drawing. Then you can easily choose which views to show in the drawing. Functions for dimensioning and tolerances are available to a large extent. Tools for sectional views and exploded views are also available. Today, it is almost customary to use CAD for drawings as it saves an enormous amount of time [1].

2.2 Additive manufacturing

In manufacturing, additive manufacturing is a very hot topic. The advantages of additive manufacturing are many, including the fact that you do not need expensive tools, the process from 3D model to physical product is very quick and the cost of production is much lower. The definition of additive manufacturing is "a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies" [2]. Thus, additive manufacturing is based on adding material from the ground up, instead of traditional manufacturing where you remove material until you reach the desired geometry.

The process from 3D model to finished product can be divided into different steps. First, a digital model of the product, which is done in CAD, is needed. This model must be processed, either in an external tool or in the CAD tool, to generate instructions on how to manufacture the product in the printer. This model then needs to be converted to a file format that the printer can read. The file is then sent to the printer via a network connection or a memory card. The printer then manufactures the product through the method for which the printer is adapted. After printing, the item is removed from the printer and any support that has been built for the structure is discarded. This is followed by any finishing and quality assurance [2].

In additive manufacturing, there are seven different techniques for the manufacturing itself. These are vat photopolymerization, material extrusion, material jetting, powder bed fusion, binder jetting, directed energy deposition and sheet lamination. The technology used to make go-kart consoles in this project is material extrusion, and the material to be used is ABS thermoplastic polymer. This is a process where the material (mainly thermoplastics) is fed in wire to a nozzle where it is melted and then applied to a bed. The printer places layer upon layer until the entire product is finished [2]. The printer currently used by Infotiv can be found below in figure 2.2.

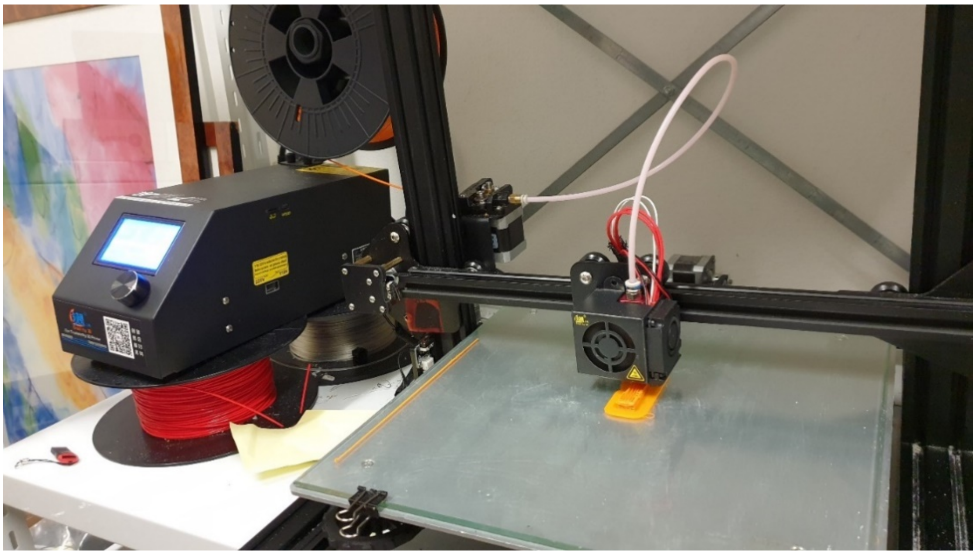

Fig.2.2 The printer currently used by Infotiv.

2.3 Kesselring matrix

When screening concepts or ideas in product development, different matrices are often used, including the Kesselring matrix. When using these matrices, all criteria on the product are listed which are then weighted on a scale, e.g. 1-10. The concepts are listed and how well they meet the respective criteria. These two numbers are multiplied to give a score on each criterion. When all criteria have been awarded a point, these are summed up to see which concept receives the most points and thus is the winning concept [1]. This method is used to objectively compare the tools. An example of a Kesselring matrix is shown below in table 2.1.

Tab.2.1 Example of a Kesselring matrix.

Criteria		**Alternatives**					
		A		**B**		**C**	
Name:	w	v	t	v	t	v	t
Height	10	10	100	10	100	10	100
Net weight	7	6	42	4	28	10	70
Easy to clean	3	7	21	6	18	9	27
Chemical resistant	1	8	8	8	8	6	6
Low CO2 footprint	9	6	54	5	45	8	72
Low sales price	5	6	30	5	25	9	45
T (Total weighted value)		43	255	38	224	52	320
Average		7,2	42,5	6,3	37,3	8,7	53,3
Ranking		**2**		**3**		**1**	

3 METHOD

This chapter presents the methods used in the project.

3.1 Time Plan

For the project to continue as planned and minimize the risk of disruptions, a time plan is made at the beginning of the project. This specifies what should be done each week and clearly indicates any deadlines. The schedule is presented in a table, preferably in Microsoft Excel. In this way, it is easy to observe at an early stage if a certain part of the project takes longer to complete than planned and actions can be taken immediately.

3.2 Requirements specification

The requirement specification is created to easily get an idea of what requirements and wishes are set for the technical solution. This is done so that both parties, i.e. the developers and the clients, agree on the requirements that the project includes. A requirement specification consists of descriptions of requirements and wishes, these are obtained from the clients in collaboration with the developers.

3.3 Risk assessment

A risk analysis is carried out to draw attention to potential hazards during the project so this can be avoided. In this way, a lot of time can be saved by avoiding problems that may arise and the parties involved are aware of the risks that the project entails.

A table is created where all risks are listed and describes which people the risk affects if it should occur. Consequences if the risk occurs is also described and how devastating it would be on a scale from 1 to 3. Finally, preventive measures are described to avoid the problem and who is responsible for these actions.

3.4 Market research

The market for CAD tools has recently developed and competition among tools is higher than ever as more and more tools achieve increased performance. Therefore, a market research was conducted, with the help of the internet, to see which tools are relevant in solid modeling. Each tool was examined regarding price, system requirements, access to support, if it includes other important functions and whether the tool offers a trial version or the like. All of this was implemented in a table.

3.5 Evaluation by designing

To compare different tools, each tool is examined separately to identify advantages and disadvantages. It can be advantageous to, through a test model, evaluate similar functions in all tools and thus obtain an objective assessment.

3.6 Comparison of candidates

To compare different tools, with the conclusions reached through the evaluation, a table is created to list all the advantages and disadvantages. These are then weighted on a scale of 1-10 where 1 is least important and 10 is most important, and then multiplied by how well each tool met the problem on a scale of 1-10. All these advantages and disadvantages are then summed up to finally give each tool a score, where the tool with the highest score is the winner.

3.7 Verification by designing

To verify that the chosen tool is suitable for the target group, a verification is performed by designing components with the tool. In this way, the tool is further evaluated, and more time is given to identify possible flaws.

3.8 Education

For the target group to be able to learn the selected tool quickly and smoothly, an education document is done where the user gets started with the tool and learns simple functions. In the education, a comparison between the chosen tool, Catia V5 and Creo is included to highlight differences in functions etc.

3.9 Ethics, sustainability, and quality assurance

From previous work within CAD, experience has been gained mainly from Catia V5 but also from both Autodesk Inventor and Autodesk AutoCAD. This means that the assessment of these is affected due to previous knowledge and experiences from the tools, either positively or negatively.

The assessment of the tools have a risk of becoming subjective as the chosen method of comparison allows personal perception. A systematic evaluation is difficult to apply for this type of analysis because all users value different functions.

The tools are evaluated according to their current versions, which are constantly updated. This means that the analysis may become obsolete after the tools have been updated or released new versions with new or improved features.

4 RESULTS

In this chapter the results are presented.

4.1 Time plan

The schedule starts week 3, the start of the project. The time plan consists of *gates* and *development phases*. Development phases are divisions in the work and gates consists of meetings where the various development phases are approved to proceed with the project. To be able to move on and start with the next gate, you need to have the previous gate approved. This is done to find errors in the project as early as possible, so you do not have to redo unnecessary work. The project consists of nine different gates that are divided between week 4 and week 19. The complete time plan can be found in appendix 1.

4.2 Requirement Specification

Below you will find user case, user stories and requirements.

4.2.1 User Case

Who is the user: Employee at Infotiv

1. Infotiv is in the process of reviewing its license for solid modeling. To choose the tool that suits them best, in a market that has a lot to offer, they therefore look at the tool analysis that recommends tools for small to medium-sized companies in a prototype context.
2. The employee wants to learn the new tool for solid modelling, and therefore studies the tool education document. In no time, the user has gained knowledge and is ready to start working on his model.

4.2.2 User Stories

Table 4.1 below lists all the user stories created for the product.

Tab.4.1 User Stories

User Story ID	User Story Description
US001	As an employee at Infotiv I want to gain knowledge about solid modelling tools with help from the matrix to choose the best tool for our company.
US002	As an employee at Infotiv I want to be able to learn the new tool for solid modelling to expand my knowledge. This is achieved through an education where the selected tool is compared to two reference tools.
US003	As an employee at Infotiv I want to test the selected tool by designing consoles for camera, radar, ultrasound, computer, moodlight and battery holder.

4.2.3 Requirements

Table 4.2 below list all product requirement, which are derived from the user case and the user stories mentioned in earlier sections.

Tab.4.2 Requirements for the tool.

Requirement ID	Requirement Description
Req001	The tool must be able to model in 3D.
Req002	The license cost must not be overpriced compared to content.
Req003	The tool must be able to operate on Windows.
Req004	The tool must be user-friendly and intuitive.
Req005	The tool should be able to convert files to .stl.

Req006	The user shall be able to recreate consoles for camera, radar, ultrasound, computer, moodlight and battery holder using the education document in chosen tool.
Req007	The tool must be able to import .CATProduct, .CATPart, .asm, .prt which is the file formats for Catia V5 and Creo (employees at Infotiv currently works in projects with these tools).
Req008	The user shall be able to learn differences from the chosen tool, Catia V5 and Creo.

4.3 Risk Assessment

During the implementation of the risk assessment, all possible risks that could arise during the project were listed. Risks that could affect the delivery of the project were, among other things, *tools may have limited demo versions*. "Who is at risk?" was asked to identify who the risk is affecting. In this case, the risk affects everyone involved in the project because the consequence of this would be that promising tools could be discarded. Existing control measures were listed to make it clear how to check if the risk has occurred or not. Then the risk was weighted on a scale of 1-3 where the scale means:

1 - No judged customer impact

2 - Risk for customer impact

3 - Major functional or safety impact

This assessment was made to determine if the risk is worth investigating or if it can be ignored. For *tools may have limited demo versions*, the risk factor was assessed as 2 because information about the complete tool is more difficult to obtain, but it is also not devastating for the project. Finally, the preventative measures and who is responsible for any action were listed. In this case, there are no preventative measures as it is not possible to do anything about the availability of demo versions, therefore no one is responsible for this action.

The complete risk assessment can be found in appendix 2.

4.4 Market research

A market research was conducted to find out which tools are on the market and which are relevant for this project. Information about these was collected in a matrix found in table 4.3 below.

The information gathered about the tools included cost, whether there is a possibility of a one-time purchase and availability of demo versions or student versions on Chalmers computers. To get an idea of the tools user-friendliness and overall performance, reviews that users wrote about the tools were studied. These reviews were read on [3] and [4]. User-friendliness is meant how easy the tool is to learn and how simple the workbenches are, and overall performance means to what extent complex models can be designed. Each tool was given a score on a scale of 1-5 (*1 = worst, 5 = best*) in terms of user-friendliness and overall performance. The tools access to support was also examined where everything from forums, tutorials and exercises were noted, as well as whether the tool offers certification for users.

The system requirements for the tools were also studied where operating systems, minimum and recommended CPU, GPU, RAM, and needed diskspace were specified. Finally, the availability of important basic functions in the tool such as drawings, 3D printing, FEM, CAM, standard components library, material library and the ability to export files to Catia V5 and Creo were also checked.

Fusion 360 was chosen for further evaluation because it got the rating $^4/_5$ in user-friendliness and $^3/_5$ in overall performance. It also had all the basic features mentioned above and the cost was only 5200 SEK annually. Information about cost, system requirements etc. were taken from [5].

SolidWorks also had all the basic functions and received the same rating as the Fusion 360 on user-friendliness and overall performance and cost 16,200 SEK annually, which meant that this tool also were chosen for further evaluation. Information about cost, system requirements etc. were taken from [6].

Inventor, on the other hand, had no access to FEM or CAM, but received $^4/_5$ in user-friendliness and $^4/_5$ in overall performance and had a cost of 28469 SEK annually and thus was selected for further evaluation. Information about cost, system requirements etc. were taken from [7].

Creo was also chosen for further evaluation which also has all the basic functions and was assessed $^{3}/_{5}$ in user-friendliness and $^{4}/_{5}$ in overall performance at a price of 27500 SEK annually. Information about cost, system requirements etc. were taken from [8].

Finally, Catia V5 was also chosen for further evaluation, which has all the basic functions at a price of SEK 38025 annually with $^{2}/_{5}$ in user-friendliness and $^{5}/_{5}$ in overall performance. Information about cost, system requirements etc. were taken from [9].

Thus, five tools proceeded to the next stage, which were Fusion 360, SolidWorks, Inventor, Creo Parametric and Catia V5. These tools also cover different price ranges, which were interesting for the evaluation.

Information about cost, system requirements etc. for: AutoCad were taken from [10], Rhino [11], Onshape [12], Siemens NX [13], SolidEdge [14], Microstation [15] and Blender [16].

Tab.4.3 The table of which the market analysis resulted in.

		Cost				Useability		
Tool	**Main area of work**	**Demo-version available**	**Annual license cost**	**One-time purchase**	**License structure**	**User friendly (1-5)**	**Overall performance (1-5)**	**User (beginner, intermediate, advanced)**
AutoCAD	Architecture, 2D- and 3D-modelling	Yes	23088 SEK	-	Stand alone Single-user	4	4	Intermediate
Fusion 360	Solid modelling	Yes	5200 SEK	-	Stand alone Single-user	4	3	Intermediate
Inventor	Solid modelling	Yes	28469 SEK	-	Stand alone Single-user	4	4	Advanced
Autodesk Bundle (Product Design & Manufacturing Collection)	Solid modelling	-	37144 SEK	-	Stand alone Single-user	-	-	-
SolidWorks	Solid modelling	Yes	16200 SEK	-	Stand alone Single-user	4	3	Intermediate
Rhino 7	Solid modelling	Yes	10069 SEK	-	Stand alone Single-user	2	2	Intermediate
Onshape	Solid modelling	Yes	17745 SEK	-	Stand alone Single-user	4	2	Beginner
Creo Parametric	Solid modelling	Yes	27500 SEK	-	Stand alone Single-user	3	4	Intermediate
Siemens NX	Solid modelling	Yes	45000 SEK	100 000 SEK + 20000 SEK/year	Stand alone Single-user	4	5	Intermediate
Solid Edge Classic	Solid modelling	Yes	35000-40000 SEK	60-80000 SEK + 15-18000 SEK/year	Stand alone Single-user	3	5	Advanced
Microstation	Infrastructure, solid modelling	Yes	25741 SEK	-	Stand alone Single-user	3	4	Intermediate
Blender	Solid modelling, animation, rendering	Yes	Free	-	Stand alone Single-user	4	1	Beginner
Catia V5	Solid modelling	Yes	38025 SEK	94640 SEK + 16900 SEK/year	Shared License Single User	2	5	Advanced

Support		System requirements					Functions						
Tutorials availability	**Certificate**	**OS**	**CPU**	**GPU**	**RAM**	**Disk space**	**Drawings**	**3D-printing**	**FEM**	**CAM**	**Standard components library**	**Material library**	**Available to import/export from Catia V5 and Creo Parametric.**
Tutorials available from Autodesk. Autodesk community, support.	Available	Windows and Mac	2,5-2,9 GHz/3+GH	-	8GB/16GB	7.0GB	Yes	Yes	Yes	No	Yes	Yes	Yes
Tutorials available from Autodesk. Autodesk community, support.	Available	Windows and Mac	1.7 GHz	-	4GB	3GB	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tutorials available from Autodesk. Autodesk community, support.	Available	Windows	2.5GHz / 3.0GHz	1GB/4GB	16GB/32GB	40GB	Yes	Yes	No	No	Yes	Yes	Yes
-	N/A	-	-	-	-	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Support forum, tutorials, training, e-learning.	Available	Windows	3.3 GHz	-	16GB	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Videos, tutorials, exercises.	N/A	Windows and Mac	-	-	8GB	600MB	Yes	Yes	No	Yes	Yes	Yes	Yes
Online guides with videos, forum.	Available	All, browser only (Googl	-	-	-	None	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tutorials, help support.	N/A	Windows	-	-	4GB	2GB	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tutorials, training.	Available	Windows	-	-	4GB/16GB	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Support center, forum, articles and learning services	Available	Windows	-	-	4GB/8GB	10GB	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Training, consulting, mentoring	Available	Windows	2.0 GHz	512 MB/6 GB	8 GB	-	Yes	Yes	No	No	Yes	Yes	Yes
Tutorials, community support	N/A	Windows, Mac, Linux	2.0 GHz	1GB/4GB	4GB/16GB	-	Yes	Yes	No	No	No	Yes	Yes
Support forum, tutorials, training, e-learning.	Available	Windows	-	-	4GB/8GB	10GB	Yes	Yes	Yes	Yes	Yes	Yes	Yes

4.5 Evaluation by designing

To evaluate the five tools that proceeded from the market analysis, modeling was done to compare the tools and find differences. The approach was to model the same design in all the tools to easily see which functions stood out from the rest. All consoles presented in chapters 4.5 and 4.7 were already modeled by the company. At the same time as the verification of the tool was done, an improvement of already existing consoles would also be carried out. The consoles presented are thus improved versions of the previous ones.

4.5.1 Camera console

First, one of the consoles for the go-kart was made, the camera console. Pictures of this from the various tools can be found below in figure 4.1 as well as printed and mounted on the go-kart in figure 4.2. Here it was decided to proceed with Fusion 360, SolidWorks and Creo and to eliminate Catia V5 and Inventor from the analysis. This is justified under heading 4.6.1.

The console for the camera consists of four parts, a lower part with “wings” that are attached to the body, a “tower” that lifts the camera high, a house in which the camera is placed and a lid for the house. The lower part with “wings” is attached to the body with double-sided tape, the “tower” is mounted on the lower part using two M4 screws with nuts, the house is mounted on the tower using two M4 screws with nuts and the lid is attached to the house using friction. A complete drawing and an exploded view of the console is found in appendix 3.

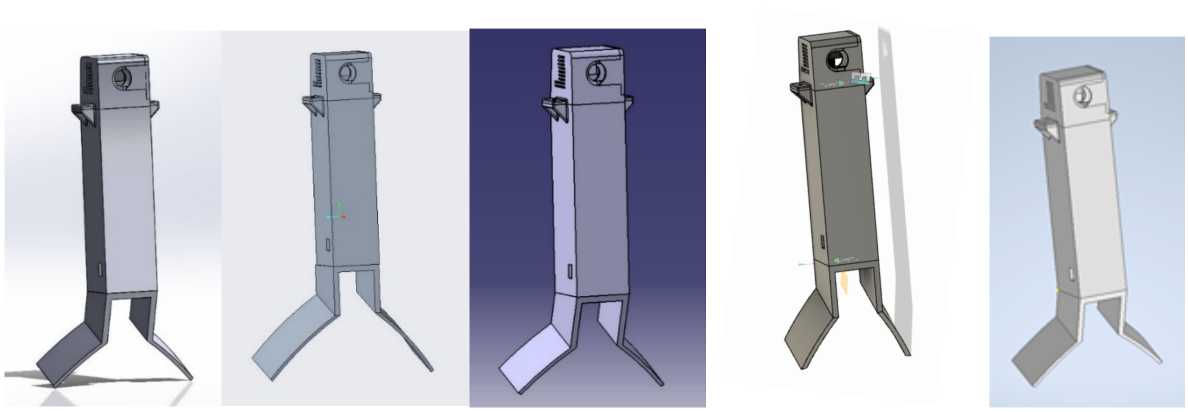

Fig.4.1 The camera console designed in (from left to right) SolidWorks, Creo, Catia V5, Fusion 360 and Inventor.

Fig.4.2 The camera console mounted on the go-kart.

4.5.2 Electric mixer

To further evaluate the tools, a product with a complex design, an electric mixer, was designed. This product had such a complex design that made it possible to find weaknesses in the tools and compare them. After the design of the electric mixer, it was decided that Fusion 360 is the tool that is best suited for the target group. This is justified under heading 4.6.2. Below are pictures of the electric mixer in the various tools in figure 4.3.

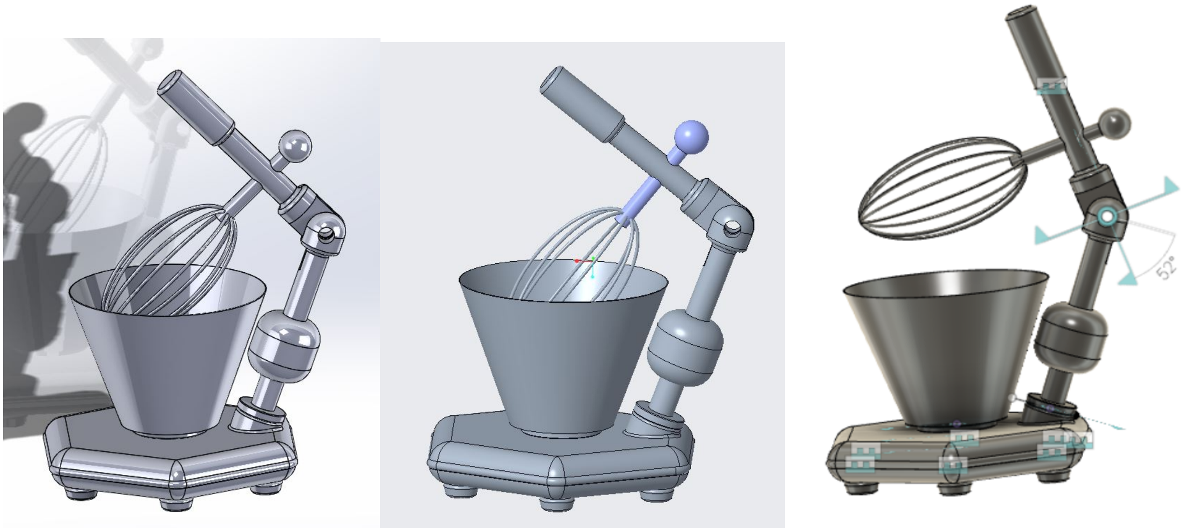

Fig.4.3 The electric mixer designed in (from left to right) SolidWorks, Creo and Fusion 360.

4.6 Comparison of candidates

Here, differences between the tools are listed to then be able to compare and evaluate the tools. After designing a product, functions that separates the tools are listed in a matrix which are then scored to compare the tools. The point system works so that each function gets a score between 1-10, where 10 is very important and 1 is very unimportant. Then the tool's ability to solve this function is assessed on a scale of 1–10. The score from all functions is summed and then gives a final score that determines the tools that proceed to further evaluating, and eventually becomes the winning tool. When making this matrix, inspiration was taken from the Kesselring matrix.

4.6.1 Advanced comparison, design of camera console

After designing the camera console in Fusion 360, SolidWorks, Inventor, Catia V5 and Creo, a matrix was made to describe the differences in the tools. Differences found were, *how to choose a desired view, how to see that a sketch is fully constraint, what happens if you overconstrain a sketch, how to work with several parts at the same time* and *which shortcuts* *exist and how well do they work*. How the tools solved the problem is described in the matrix to then give the solution a certain score.

In addition, there are features that some tools lacked while others could do. These were; *Are you able to extrude from offset of sketch? Are you able to "go back" in part and add features?* The answer to these is either yes or no, where yes means 10 points and no means 0 points. Finally, the time was also considered for the total score, it was also set on a scale of 1-10 where 10 is the fastest and the lower the score the tool gets, the longer it took to design the camera console.

The tools total score then compared all functions. After that, price, if the tool includes FEM/CAM and user-friendliness based on personal opinions were also included. With all this taken into account, a final score is obtained for each tool where the highest point is the best tool, and the lowest point is the worst tool. SolidWorks got the highest score, Fusion 360 was second, Creo was third, Inventor fourth and last was Catia V5. The tools which proceeded to the next evaluation were SolidWorks, Fusion 360 and Creo, in addition to these, Catia V5 was also included. This is because it must be part of the education of the tool that is selected to then be able to compare functions.

The matrix can be found in appendix 4.

4.6.2 Further comparison, design of electric mixer

The electric mixer was designed to be able to evaluate the tools even more than before as it has such a complex design. The evaluation was done in a similar way as for the camera console with a couple of differences such as timing each individual part, subassemblies were made, and a drawing was created in each tool. After each part or assembly, the time and the pros and cons were listed for each tool. This is shown in appendix 5.

To get as fair comparison as possible, the evaluation was copied with points and functions from the camera console matrix. Problems that arose and functions that differed between the tools, during design of the electric mixer, were then added. The new functions added to the matrix were divided into designing of parts, assemblies, and drawings. The time for each subgroup is displayed to see what differentiate the different tools. In this matrix, the final score is so high, in order for the tools time to stand out in the total score, this was weighted by 30 instead of between 1–10. This was done because time is a very important factor when it comes to work in CAD. The matrix can be found in appendix 6.

After all points were added up, the result was that Creo got 1205 points, Catia V5 got 1471, Fusion 360 got 1480 and SolidWorks got 1743. This means that SolidWorks got the most points and Fusion 360 was in second place. This total score does not consider the cost of the tool, which is also very important. Fusion 360 has a cost of 5200 SEK and SolidWorks has a cost of 16200 SEK. Fusion has 85% of the points that SolidWorks has, at a third of the price. With this in mind, Fusion 360 is the winning tool and is selected for verification.

4.7 Verification by designing

After Fusion 360 was concluded to be the tool that best suits the target group, the verifying of the tool began. This was done by designing consoles for equipment for the go-kart as the tool is intended for designing prototypes. A total of five consoles were designed which were then printed and mounted on the go-kart. These are presented below. One of these were the camera console which is presented under heading 4.5.1.

When designing the consoles, it was important to consider where the equipment would be placed, as space was often limited. How the equipment was attached and how the cables would go were also to be considered.

4.7.1 Console for battery holder

The battery holder consists of one part that is attached to the left front of the go-kart. It holds two batteries. The battery holder is attached to a plate that is attached to the body on the front left of the go-kart. It is attached with four M3 screws. The batteries are standing on the plate and the battery holder holds the batteries in place. There are holes on the top of the battery holder which you can thread a band into to fasten the batteries, so they do not move upwards. The battery holder mounted on the go-kart are shown below in figure 4.4. A complete drawing of the console is found in appendix 7.

Fig.4.4 Console for battery holder mounted on the go-kart.

4.7.2 Console for ultrasound

The ultrasound consoles consist of six parts that is placed on the front, back, right front, left front, right back and left back of the go-kart. The ones on the front and back share the console with the radar. All the three on the back are mounted on the body, the one in front is mounted on the body and the ones on the right- and left front are mounted a chassis component. All the ultrasound consoles are attached with double-sided tape.

The ultrasound in the front and back are sharing consoles with the radars where the ultrasound has a housing with two holes where the transmitter and receiver are to be placed. To prevent the ultrasound from coming loose, a lid is placed on the back.

The ultrasounds on the right and left fronts are located on a chassis component. The housing is the same as in the front and back, but the lid is shaped to fit on the chassis. The lid angles the ultrasound, so it points horizontal and 45˚ to the sides.

Finally, the ultrasounds on the right and left back are mounted on the body and use the same housing as all other ultrasounds. The lids on these are angled so that they follow the body and point horizontal at an angle of 45˚.

All ultrasound mounted and unassembled are shown below in figure 4.5, 4.6 and 4.7. Complete drawings of all the ultrasound consoles are found in appendix 8.

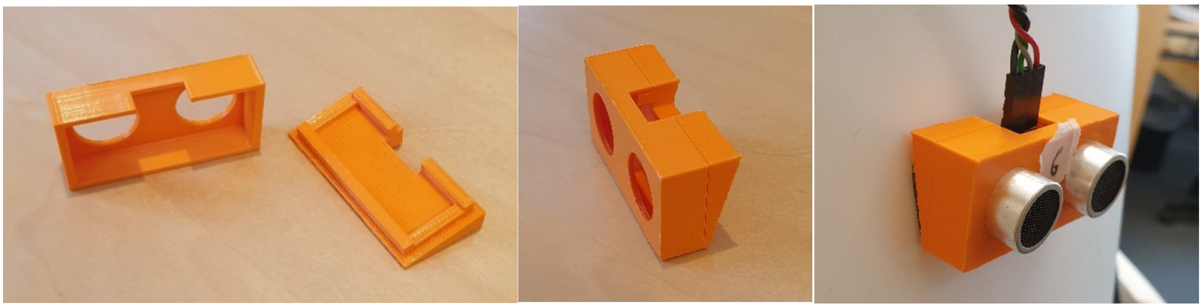

Fig.4.5 One of the three ultrasound consoles mounted on the go-kart.

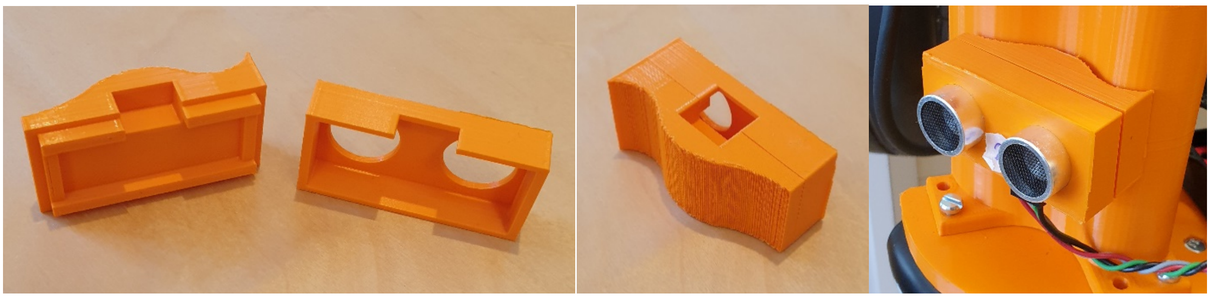

Fig.4.6 One of the three ultrasound consoles mounted on the go-kart.

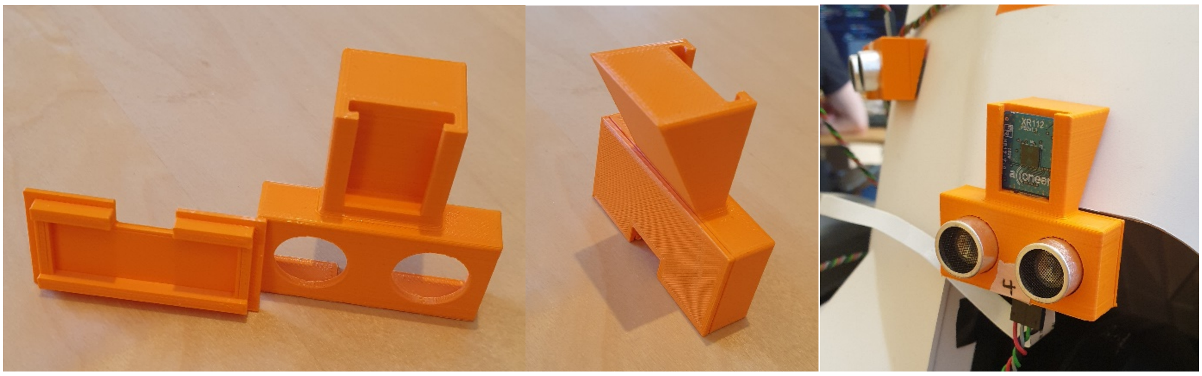

Fig.4.7 One of the three ultrasound consoles mounted on the go-kart. Console for the radar as well.

4.7.3 Console for radar

The console for the radar consists of two parts. One part that is mounted on the front body and one part that is mounted on the back body of the go-kart. The two parts share the console with the ultrasound. Both the one on the front and the one on the back are mounted using double-sided tape. The radar is attached in a groove that is slightly larger than the side of the radar, this means that it will not be able to move in any direction while driving. The back of the console is angled so that the radar should point horizontal when mounted on the go-kart. Both the back and the front have the same design. The mounted radar is shown in figure 4.7. A complete drawing of the console is found in appendix 8.

4.7.4 Console for moodlight

The moodlight console consists of two parts. The first part is attached to a pipe at the back of the go-kart using a snap function and two M5 screws with nuts. The other part is mounted on the first in a groove and two M4 screws with nuts. The second part holds the moodlight stick and to hold this in place, two M4 screws are used which are screwed in and presses on the stick so that it cannot move vertically. The mounted moodlight console is shown in figure 4.8. A complete drawing of the console is found in appendix 9.

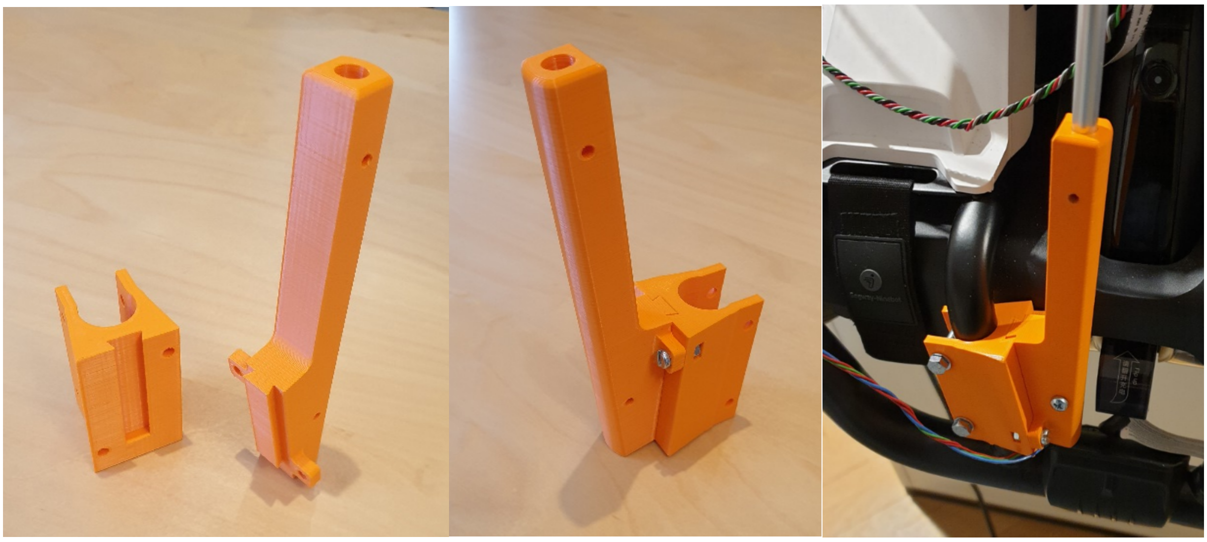

Fig.4.8 The moodlight console mounted on the go-kart.

4.7.5 Console for computer

There were so few opportunities for improvement for the computer console that it was decided to ignore it. There was also so much equipment mounted on the existing console that it would have been more work to replace the console than it would have been useful with a new one.

4.8 Education

After completing the design of the consoles, an education of the tool was accomplished with all the knowledge gained after designing. The education will be used by the company to educate employees in the new tool to ensure a smooth transition from the old tool to the new one without any major knowledge gaps. After completing the education, the user should be able to create and join projects, create parts with simple geometries as well as create assemblies.

The education resulted in a theory chapter where important functions were explained, as well as a chapter with exercises where the user's knowledge was put to the test by designing parts which were then assembled into a product.

With the help of the part and the assembly shown in figure 4.9 below, it was demonstrated how the following features are performed and used in Fusion 360:

- Sketch: Most features require a sketch. This is a 2D drawing that you can then choose to extrude to a 3D volume.
- Extrude: To extrude your sketch in space and thereby create volume, *extrude* is used.
- Pattern: To repeat a feature, *pattern* is used.
- Revolve: *Revolve* is often used to make cylindrical geometries.
- Hole: *Hole* is often used to make holes, especially with threads.
- Fillet: *Fillet* is used to round corners.
- Chamfer: *Chamfer* is used to chamfer corners.
- Sweep: To sweep a cross section around a curved line, *sweep* is used.

- Mirror: To copy a feature, you can use *mirror*.
- Joints: To create constraints between the pieces, *joint* is used.

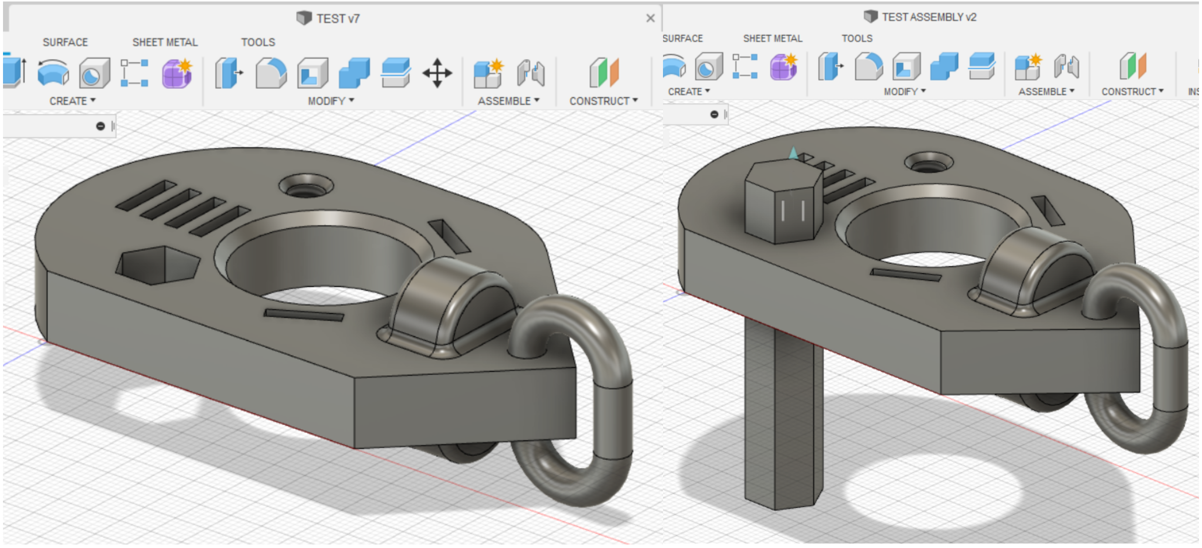

Fig.4.9 The part and assembly used for the education.

5 DISCUSSION

This chapter discusses the results of the work.

5.1 Requirements

In retrospect, we feel that the requirements we placed on the tool from the beginning, which are found in table 4.2. were reasonable. Req001, Req003 and Reg005 are met by the tool as the answer is only yes or no to these requirements. Req006 and Req008 were verified after a person with no previous experience of Fusion 360 managed to complete the education. Req002 and Req004 can be considered subjective because it requires some personal assessment. After our evaluation that resulted in matrices, the assessment was made that Fusion 360 was the tool that best meet these requirements. Req007 is fulfilled by Fusion 360 because it can easily import files from both Catia V5 and Creo. Exporting files to these tools is also possible if this is done via STEP. Therefore, we find that the requirements specification is met for Fusion 360.

5.2 Market research

The market analysis went according to plan and we feel confident that we have found all the candidates. However, our way of measuring “user friendly” and “overall performance” has some room for improvement because these are only based on other people's reviews of the tools. At this stage of the project, as well as the schedule we had to follow, this was the most effective way to quickly assess these properties of the tools. The scale for these grades was set at 1-5 to give an overall view. In a best-case scenario, we would have liked to evaluate all the tools by ourselves, but the time did not simply exist.

5.3 Evaluation by designing

A rough screening of the market analysis led to five tools that we evaluated ourselves with the help of student- and demo versions. This led us to getting a much better picture of the tools as we created our own perceptions and were not influenced by other people's reviews. By designing the camera console and the electric mixer, we noted the advantages and disadvantages of each tool that was listed in a matrix. All differences were weighted, and a score was given to the tools based on how well they met the problem. These weights and the points given to the tool are very personal and the total points then have a risk of not giving an objective comparison. The time it took to design the camera console and the electric mixer was very highly weighted, as in our opinion this is a very fair comparison as we perform exactly the same tasks in the tools. To compare the full potential of the tools, it would also have been desirable to design more complex geometries and evaluate more functions, again it was the lack of time that prevented us from this. It was intended to only design the consoles for the go-kart to evaluate the tools, but we realized that these had a lack of complex geometries and therefore we decided to design the electric mixer instead.

5.4 Verification by designing

When Fusion 360 was named the winning tool, the verification began by designing go-kart consoles. The design of these consoles was severely limited by the available space on the go-kart as there was already a lot of equipment mounted. We had planned to design one console per week, which meant that the design had to be determined relatively quickly. All the equipment that the consoles would hold were available so dimensions on these were always at hand.

After designing the consoles, these were also manufactured with the 3D printer that Infotiv uses. Some time was spent troubleshooting the printer as it did not always print as wanted. However, it was very fun for us to learn how to prepare a file for 3D printing and learn how it works. Due to the many consoles that were designed, it took a long time to print these, but this went relatively smoothly as it could be done partly outside working hours. Since all consoles were to be printed for use on the go-kart, this was something we had to consider when designing the consoles. We had to plan, for example, how support material could be removed, how the heating plate affects the surface and that the nozzle lays the plastic with a certain thickness that can be compensated with a little margin.

5.5 Education

The education was made so clear that someone with basic knowledge of CAD could complete the education without major problems, this was also verified with a person without any experience of Fusion 360. The education demonstrated various functions and so on to be able to reach the required level of knowledge to redesign the consoles for the go-kart. Given that the go-kart is a real project, and the tool aims to function in a prototype context, the education was assessed to be at a reasonable level.

6 CONCLUSION

The main task of this project was to analyze existing CAD tools on the market and in a systematic way recommend and present the advantages and disadvantages of different tools. This was done through several matrices where tools were screened and compared until a final tool was recommended for the specified target group. The winning tool in this case was Fusion 360 where the target group consists of small to medium-sized companies and the tool is intended for the design of complex prototypes.

After completing the analysis, a verification of the tool was done by designing consoles for a go-kart. A total of five consoles were designed, manufactured and mounted on the go-kart. Since these consoles are prototypes for an in-house project, the verification was considered approved when the tool is to be used for this type of work. However, the console for the computer had to be leaved out because it did not add anything essential to either the verification or the go-kart.

When the design of consoles was completed, an education for the tool was made. This education will be used internally in the company for employees with no experience in the tool. With the help of this education, the transition between the existing tool and Fusion 360 will go smoothly. After completing the education, the user will achieve the level of competence required to recreate the consoles and similar geometries with the same type of complexity.

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APPENDIX

1. Time plan.

Project Time Plan

Year				2020																		
Month				Jan				Feb				Mar					Apr				May	
Week				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Gate	Description	Estimated time	Status																			
G1-G3	**Pre-Study OK**																					
	Project Description		Done			x	x															
	Time Plan		Done				x															
	FMEA		Done				x															
G4	**Development Start**																					
	Technical Specification (All Requirements and System Description)		Done				x															
	DP1 - Development Phase 1																					
	Search for tools		Done				x	x	x													
	Analysing tools		Done					x	x													
	Choose 5 tools for verification		Done						x													
G5	**DP2 - Development Phase 2**																					
	Analyse requirements for console to camera		Done							x	x											
	Generating concepts for console to camera		Done							x	x											
	Further development of winning console to camera		Done							x	x	x										
	Modelling/3D-printing of console to camera		Done							x	x	x	x									
	Choose 3 tools for verification		Done										x									
	Further analysing tools by designing a complex model from Chalmers		Done										x	x	x							
	Choose tool		Done												x							
G6	**DP3 - Development Phase 3**																					
	Analyse requirements for console to battery holder		Done												x							
	Generating concepts for console to battery holder		Done												x							
	Further development of winning console to battery holder		Done													x						
	Modelling/3D-printing of console to battery holder		Done													x						
	DP4 - Development Phase 4																					
	Analyse requirements for console to radar		Done													x						
	Generating concepts for console to radar		Done													x						
	Further development of winning console to radar		Done														x					
	Modelling/3D-printing of console to radar		Done														x					
G7	**DP5 - Development Phase 5**																					
	Analyse requirements for console to ultrasound		Done														x					
	Generating concepts for console to ultrasound		Done														x					
	Further development of winning console to ultrasound		Done															x				
	Modelling/3D-printing of console to ultrasound		Done															x				
	DP6 - Development Phase 6																					
	Analyse requirements for console to computer		Blocked															x				
	Generating concepts for console to computer		Blocked															x				
	Further development of winning console to computer		Blocked																x			
	Modelling/3D-printing of console to computer		Blocked																x			
	DP7 - Development Phase 7																					
	Analyse requirements for console to mood light		Done																x			
	Generating concepts for console to mood light		Done																x			
	Further development of winning console to mood light		Done																	x		
	Modelling/3D-printing of console to mood light		Done																	x		
G8	**DP8 - Development Phase 8**																					
	Verify tool		Done																	x		
	Education for chosen tool		Done						x	x	x	x	x	x	x	x	x	x	x	x	x	
G9	**Final Product Freeze**																					
	Technical Specification (HW/SW Description, HMI Design, Drawings, BOM)		Done				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

2. Risk Assessment.

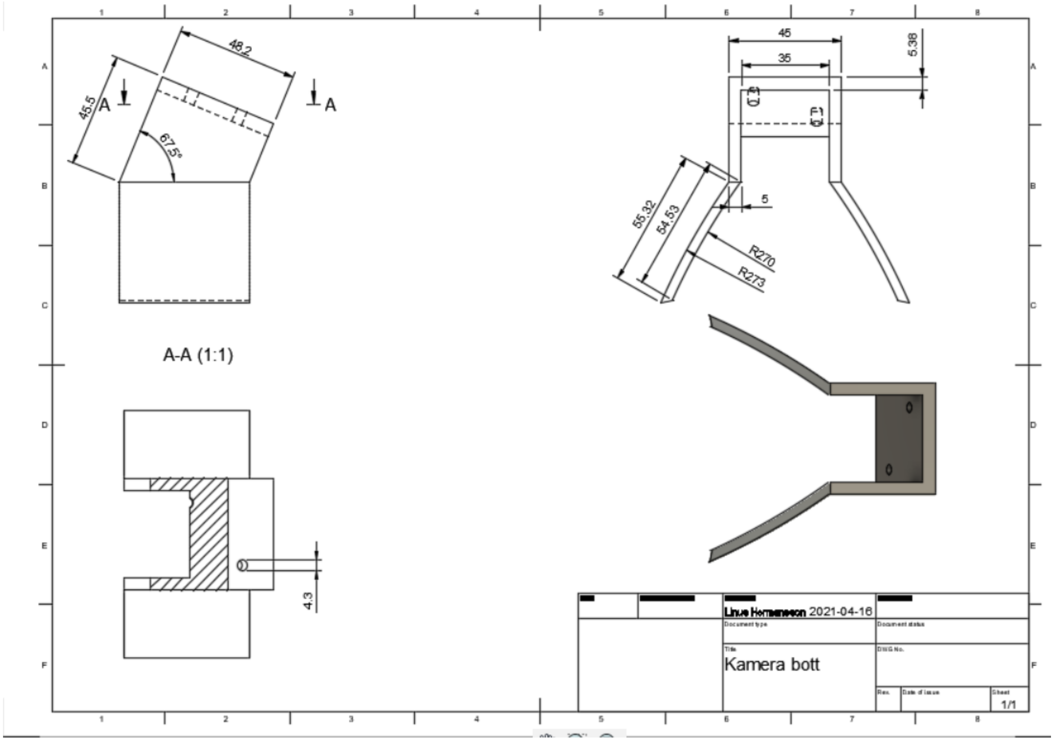
Risk assessment

Project name:	Tool analysis for design of complex prototype products
Last updated:	2021-01-25

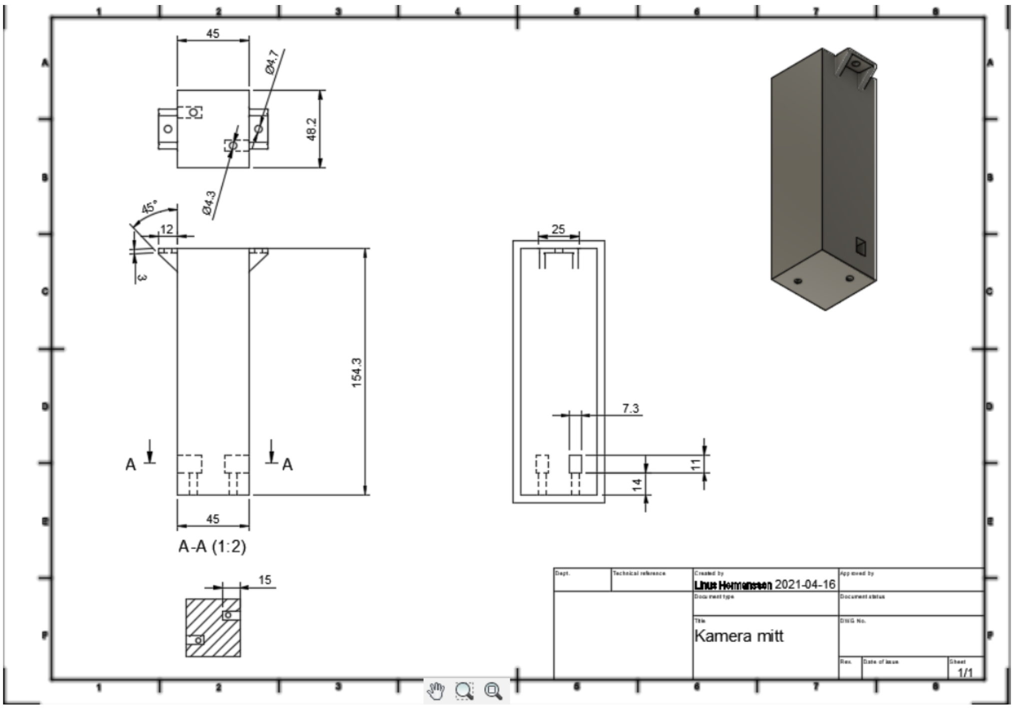
Risk #	Potential Hazard	Who is at risk?	Consequences
1	Worsening of COVID-19	Everyone in project	No access to office
2	Tools may have limited demo-versions	Everyone in project	Promising tools may be discarded
3	Promising tools may not be found	Everyone in project	Missing out on promising tool
4	Risk for same work being made twice	Linus & Mattias + people working with the body	Unnecessarily work being done
5	Consoles breaking during test-drive	Everyone in project	Consoles have to be reprinted
6	Consoles do not fit with the body	Linus & Mattias	Consoles have to be redesigned
7	Consoles do not fit with the equiment	Linus & Mattias	Consoles have to be redesigned
8	3D-printer is broken	Everyone in project	Consoles can't be printed
9	Time is not enough to construct all consoles	Everyone in project	Some consoles is not constructed

Risk #	Existing Control Measures	Risk Rating	Preventative Measures	Responsible
1	N/A	3	Follow recommendations	All
2	Test	2	None	None
3	N/A	2	Make a wide search	Linus & Mattias
4	N/A	2	Communicate with people working with the body	Linus & Mattias
5	N/A	2	Implement robust design	Linus & Mattias
6	Test	2	Communicate with people working with the body	Linus & Mattias
7	Test	2	Find out equiment dimension	Linus & Mattias
8	Test	3	Make sure 3D-printer works	Infotiv
9	Time plan	3	Follow time plan	Linus & Mattias

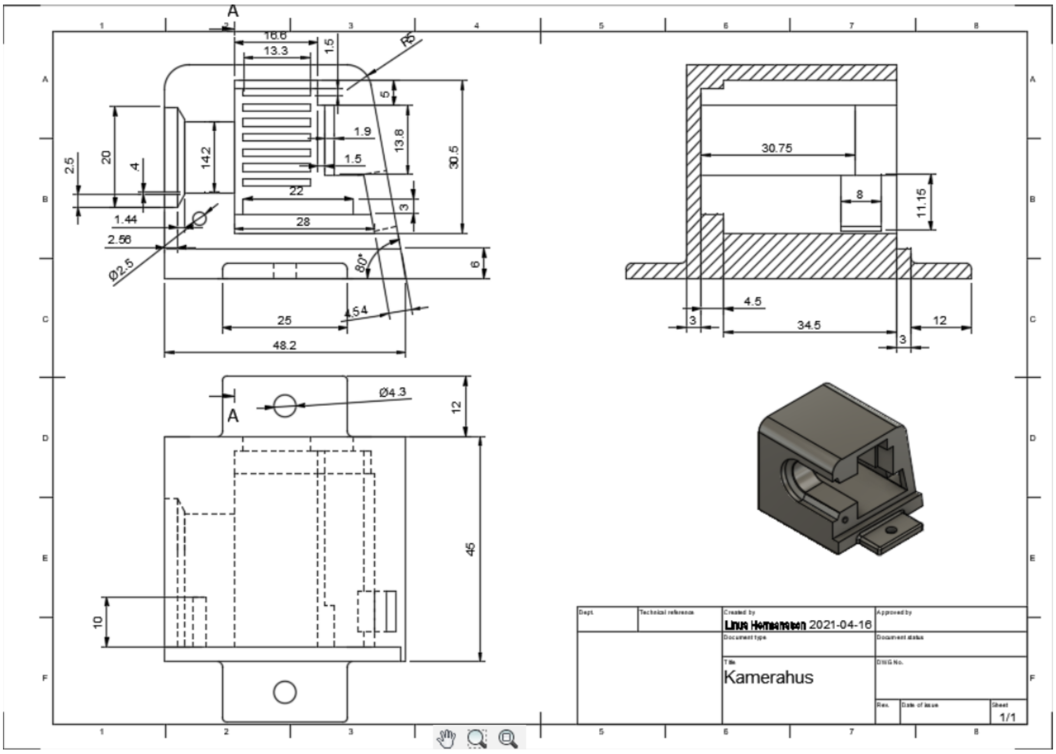
3. Drawings of the cameraconsole.



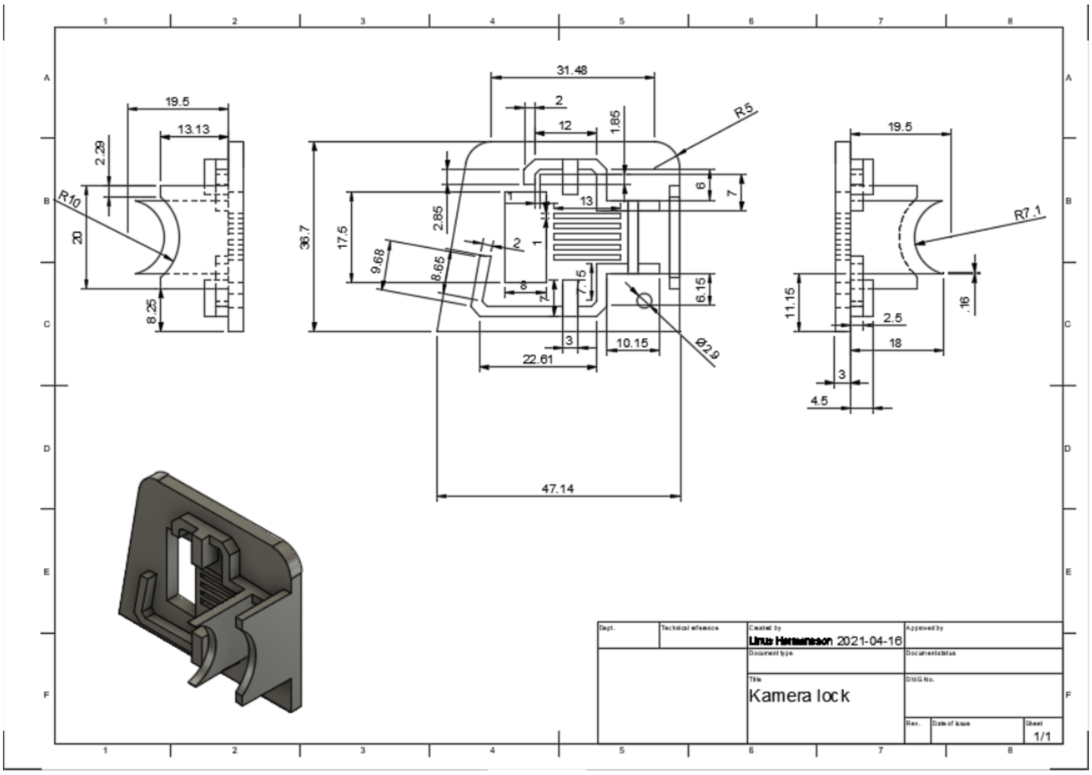
Drawing of the base of the cameraconsole which is placed on the body.



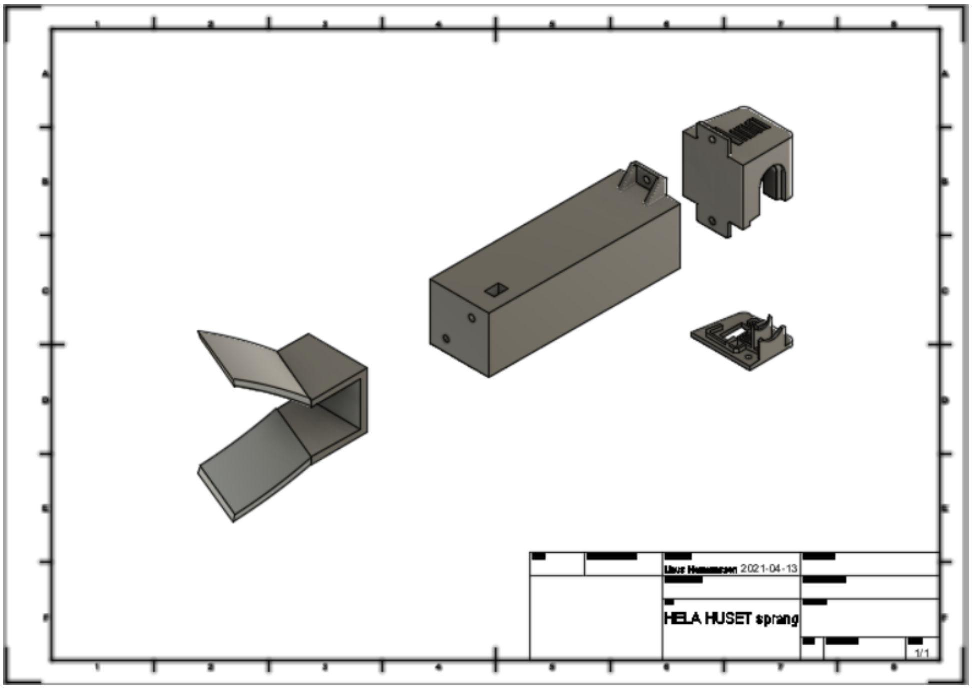
Drawing of the tower of the cameraconsole which is placed on the base.



Drawing of the house for the camera which is placed on the tower.



Drawing of the lid for the house of the cameraconsole which is placed on the house.



Drawing of an exploded view for the cameraconsole.

4. Advanced comparison, design of cameraconsole.

Tool	How do know if your sketch is fully constrained?	6	What happens when you overconstraint a sketch?	6	How do you select desired view?	8	Are you able to extrude from offset of sketch?	3
Fusion 360	All lines turn from blue to black.	8	Error message appears, option to make a driven dimension.	7	You're able to switch view using scrollwheel and shift as well as click on the cube in the top right corner to get a view normal to the axis. When entering a sketch you're automatically switched view to normal to sketch.	9	Yes.	10
Inventor	All lines turn from blue to black.	8	Error message appears, option to make a driven dimension.	7	You're able to switch view using scrollwheel and shift as well as click on the cube in the top right corner to get a view normal to the axis. When entering a sketch you're automatically switched view to normal to sketch.	9	No, you need to create an offset plane.	0
SolidWorks	All lines turn from blue to black.	8	Error message appears, option to make a driven dimension.	7	You're able to switch view using scrollwheel, ctrl and shift. When entering a sketch you're not automatically switched view to normal to sketch (can be changed in settings). You're also able to use "Normal To" to switch view to normal from desired surface.	7	Yes.	10
Creo	Creo automatically put dimensions when sketching so the sketch is fully constrained at all times. In order to lock dimensions however, you must do a change in settings.	9	Error message appears, shows clearly which dimensions and constraints that is in conflict and option to either delete one or make one a reference dimension.	10	You're able to switch view using scrollwheel, ctrl and shift. When entering a sketch you're not automatically switched view to normal to sketch (can be changed in settings). You're also able to use "View Normal" to switch view to normal from desired surface.	7	No, you need to create an offset plane.	0
Catia V5	All lines turn from white to green.	8	Lines that are in conflict turns to purple, still able to put dimension and edit dimensions but no changes appears in sketch.	5	You're able to switch view using scrollwheel, right click and release of right click. When entering a sketch you're automatically switched view to normal to sketch. You're also able to use "Normal View" to switch view to normal from desired surface.	7	Yes.	10

Design of cameraconsole

Are you able to edit shortcut keys?	7	Are you able to "go back" in part and add features?	7	In an assembly, how do know if a part i fully constrained? How do you see the degrees of freedom?	6	In an assembly, are you able to see clashes between parts?	8	How does the tool deal with multiple parts open at once?	3	Total time for designing camera console, 10	Total
Yes, default shortcuts for most used features.	8	Yes.	10	Fusion 360 automatically locks all degrees of freedom upon the first constraint and you can then unlock some if wanted.	5	Yes, using "Interference".	5	Multiple tabs.	7	8	489
Yes, default shortcuts for most used features.	8	Yes.	10	Enable "Deegrees of freedom". For every part that some degree is free, a respective arrow will appear.	8	Yes, using "Analyse interference".	8	Multiple tabs.	7	7	491
Yes, very few default shortchuts.	7	Yes.	10	(-) will appear in front of part in tree if not fully constrained. You can also check in "Assembly Visualisation" if part is fully mated (need to add column).	7	Yes, using "Interference detection".	8	Multiple windows within tool.	7	9	512
Yes, default shortcuts for most used features.	8	Yes.	10	When constraining a part, the STATUS shows if the part is fully constrained or not.	7	Yes, using "Clash" or "Global interference".	7	Multiple windows.	5	6	469
Yes, no default shortcuts.	5	Yes, using "Define in work object".	6	Right click part and choose "Component degrees of freedom" to see the current degrees of freedom.	8	Yes, using "Check clash". You can also see which surfaces that are in contact with eachother.	9	Multiple windows within tool.	7	5	432

Annual license cost	10	FEM/CAM availability	7	Useability	3	**Total when including these aspects**		
5200 SEK	9	Both (each calculation cost credits).	7	Pros: Easy workbench. Simple to learn. Assembly is quick when it´s simple joints. Cloud based software. Simple timeline (you can go back and fix mistakes). Good default shortcuts. Cons: Assembly locks every degree of freedom directly.	7	649		2
28469 SEK	5	None.	0	Pros: Simple to learn. Assembly is quick when it´s simple joints. Simple timeline (you can go back and fix mistakes). Good default shortcuts. Cons: Simular to Fusion 360 but harder to find feutures	7	562		4
16200 SEK	7	Both.	10	Pros: easy to learn, straightforward, easy to add constraints, easy to see respective feature in part when selecting in tree, adding mates in assembly works fine	7	673		1
27500 SEK	5	Both (CAM needs Creo Advanced for 49770 SEK).	5	Pros: easy to add constraints, easy to find wanted feature (nice toolbars) Cons: high risk to get unwanted constraints when drawing sketch	6	572		3
38025 SEK	3	Both.	10	Cons: takes long time to learn, features are hard to find and keep track of (regulary needs to reset toolbars), always needs to project 3D-geometry ontop of sketch plane when drawing	3	541		5

5. Design of electric mixer, pros and cons.

Fusion 360

Part	Time	Benefits	Difficulties
Bottendrev	24	-	-
Bunke	12	-	● You can´t extrude/revolve from a single line. You have to close the sketch.
Drivplatta	11	● The thread feature was simple to use.	-
Fundament	87	● Easy to change direction in every extrude, draft ● Extrude with an angel worked very well ● Sketch and contrain a hexagon worked well	● You can´t choose an old sketch to extrude
Gummifot	3	-	-
Handtag	4	-	-
Motor	40	-	● Problem with quartz circle in the sketch, but if you use tangent att the end of the circle it´s no problem
Motoraxel	3	-	-
Överliggare	19	● You can use a center line from an other feature to create a new feature	-
Stötlist	10	-	● You can´t you fillet to fuse two edges togther automatically. You need to know the distance.
Visp	47		● Problems with the elips, I couldn´t fully constrain it.
Botten (subass)	10	-	-
Drivlina (subass)	40	-	● Problem with animations, when you want to control a movement of a part with another part.
Överdel (subass)	15	● Constrain simple constraints works easy and goes fast ● Easy to choose degrees of freedom ● Simple and fast to add new parts in an assembly	-
Elvisp (assembly)	60	● "Collision detection" works good. ● STEP-files can be added in assembly.	● The lags animations in the full assembly is unreal ● Not that easy to see what degrees of freedom you have
Överliggare (draw)	11	● The drawing works good with views, dimentions and title block	-
Sprängskiss (draw)	20	● Explode view is possible to do both manully and automatically ● BOM (Part list) with ballon list is easy to do.	● When you have subassemblys and want BOM of all parts in the subassemblys, you have to add it to the drawing and then delete it.
Total time (hour)	6,93333		

Creo

Part	Time	Benefits	Difficulties
Bottendrev	20	-	-
Bunke	10	● Revolve "thin" worked very well, option to extrude inwards, outwards or both. Same for Extrude "thin".	-
Drivplatta	10	-	● Screw diameter with "Hole" is wrong.
Fundament	85	● Taper worked good inside Extrude feature.	● Hexagon in sketch works very bad, doesn't lock the obvious constraints. ● You can't choose the same sketch for multiple features, the sketch is locked in the corresponding feature. ● Not able to use "thin Extrude" in both direction, you had to do one direction and then mirror the feature.
Gummifot	5	● "Sketch fillet" is very good inside Sketch.	-
Handtag	8	-	● Screw diameter with "Hole" is wrong.
Motor	45	-	● Puts "equal" constraints where you don't want them when sketching. ● Screw diameter with "Hole" is wrong.
Motoraxel	3	-	-
Överliggare	45	-	● Hard to choose inclined dimension in sketch, only gets vertical or horizontal. ● Not able to choose hole surface in "revolve cut", had to insert an axis manually. ● Two rounds can't be fused together.
Stötlist	30	● Full round worked good.	● Hexagon in sketch works very bad, doesn't lock the obvious constraints.
Visp	30	● "Delete segment" works very good.	● A lot of constraints are in the way when dimensioning, you're able to hide them however.
Botten (subass)	10	● Easy to copy parts (feet).	-
Drivlina (subass)	15	-	-
Överdel (subass)	20		● Can't find surface contact constraint, had to use centered constraint.
Elvisp (assembly)	40	● "Collision detection" works good. ● Easy to see degrees of freedom.	● "Global interference" is not the best but works. ● STEP-files can't be added in assembly.
Överliggare (draw)	60	● You can make your own templates with many options so drawings can be made quickly. ● You're able to add dimensions automatically for chosen feature or for whole part.	● Sections have to be made in part for "section views" in drawing.
Sprängskiss (draw)	25	● Easy to make an exploded view.	● Bill Of Material is extremely complicated.
Total time (hour)	7,68333		

SolidWorks			
Part	**Time**	**Benefits**	**Difficulties**
Bottendrev	20	-	● You can´t choose the coordinates system for revolve axis
Bunke	10	● Revolve "thin" worked very well, option to extrude inwards, outwards or both. Same for Extrude "thin".	-
Drivplatta	11	● Hole is simple, works good with ISO threads. Dosen´t have to make a point in a sketch	-
Fundament	78	● Extrude with taper works good ● Extrude offset from sketch is nice	-
Gummifot	3	-	-
Handtag	5	-	-
Motor	39	-	-
Motoraxel	3	● When you put out the first dimension in a sketch all the geometries keep it´s shape, it´s only the relation that´s changing	-
Överliggare	35	-	-
Stötlist	4	● Fullround fillet works good	-
Visp	20	-	-
Botten (subass)	9	● Copy with mates works fine	-
Drivlina (subass)	4	-	-
Överdel (subass)	3	-	-
Elvisp (assembly)	10	● Interference works good ● Easy to drag components to check contraints	-
Överliggare (draw)	15	● Easy to learn, easy to find what you looking for and all the options you want	-
Sprängskiss (draw)	40	● BOM and ballon works good	● Complicated to make an explode view
Total time (hour)	5,15		

6. Further comparison, design of electric mixer.

Design of cameraconsole

Tool	How do know if your sketch is fully constrained?	6	What happens when you overconstraint a sketch?	6	How do you select desired view?	8	Are you able to extrude from offset of sketch?	3
Fusion 360	All lines turn from blue to black.	8	Error message appears, option to make a driven dimension.	7	You're able to switch view using scrollwheel and shift as well as click on the cube in the top right corner to get a view normal to the axis. When entering a sketch you're automatically switched view to normal to sketch.	9	Yes.	10
SolidWorks	All lines turn from blue to black.	8	Error message appears, option to make a driven dimension.	7	You're able to switch view using scrollwheel, ctrl and shift. When entering a sketch you're not automatically switched view to normal to sketch (can be changed in settings). You're also able to use "Normal To" to switch view to normal from desired surface.	7	Yes.	10
Creo	Creo automatically put dimensions when sketching so the sketch is fully constrained at all times. In order to lock dimensions however, you must do a change in settings.	9	Error message appears, shows clearly which dimensions and constraints that is in conflict and option to either delete one or make one a reference dimension.	10	You're able to switch view using scrollwheel, ctrl and shift. When entering a sketch you're not automatically switched view to normal to sketch (can be changed in settings). You're also able to use "View Normal" to switch view to normal from desired surface.	7	No, you need to create an offset plane.	0
Catia V5	All lines turn from white to green.	8	Lines that are in conflict turns to purple, still able to put dimension and edit dimensions but no changes appears in sketch.	5	You're able to switch view using scrollwheel, right click and release of right click. When entering a sketch you're automatically switched view to normal to sketch. You're also able to use "Normal View" to switch view to normal from desired surface.	7	Yes.	10

Tool	Are you able to edit shortcut keys?	7	Are you able to "go back" in part and add features?	7	How does the tool deal with multiple parts open at once?	3	Total time for designing camera console, 10
Fusion 360	Yes, default shortcuts for most used features.	8	Yes.	10	Multiple tabs.	7	8
SolidWorks	Yes, very few default shortchuts.	7	Yes.	10	Multiple windows within tool.	7	9
Creo	Yes, default shortcuts for most used features.	8	Yes.	10	Multiple windows.	5	6
Catia V5	Yes, no default shortcuts.	5	Yes, using "Define in work object".	6	Multiple windows within tool.	7	5

Design of electric mixer

Are you able to Extrude/Revolve from a single line (thin)?	5	How well does the "hole" function work with thread?	8	Are you able to use the same sketch for multiple features?	4	Polygon feature, good/bad?	4	Are you able to use a center line from an other feature to create a new feature?	4	Are you able to do a full round fillet?	2	Ellips feature, good/bad?	4
No.	0	Very well.	10	No.	0	Good.	10	Yes.	10	No.	0	Bad, couldn't fully constraint.	1
Yes.	10	Very good	10	Yes.	10	Good.	10	No.	0	Yes.	10	Good.	10
Yes.	10	Hole is fine, but thread diameter is wrong for ISO-threads, not changeable.	3	No.	0	Bad, doesn't lock the obvious constraints.	3	No.	0	Yes.	10	Good.	10
Yes.	10	Very well.	8	Yes.	10	Good.	10	Yes.	10	No.	0	Good.	10

Does the tool automatically add desired constraints when sketching?	8	Are you able to choose horizontal, vertical or incline dimension when dimensioning?	5	Trim feature, good/bad?	4	Are you able to extrude with an angle (taper)?	5	Does the geomerty stay the same when the first dimention is changed when sketching?	4	Total time for designing electric mixer (only parts)	10	**Total for designing**
Yes.	10	Yes.	10	Good.	8	Yes.	10	No	0	4,33	8	875
Yes	10	Yes	10	Very good, able to delete multiple lines at the same time.	10	Yes.	10	Yes	10	3,80	10	1036
Yes, but often adds equal constraint where you don't want them.	5	Yes, but takes some effort.	5	Very good, able to delete multiple lines at the same time.	10	Yes.	10	No	0	4,85	6	732
Yes.	10	Yes.	10	Average, must click on each line and sometimes separate them first.	5	Yes.	10	No	0	6	2	806

Drawings of electric mixer

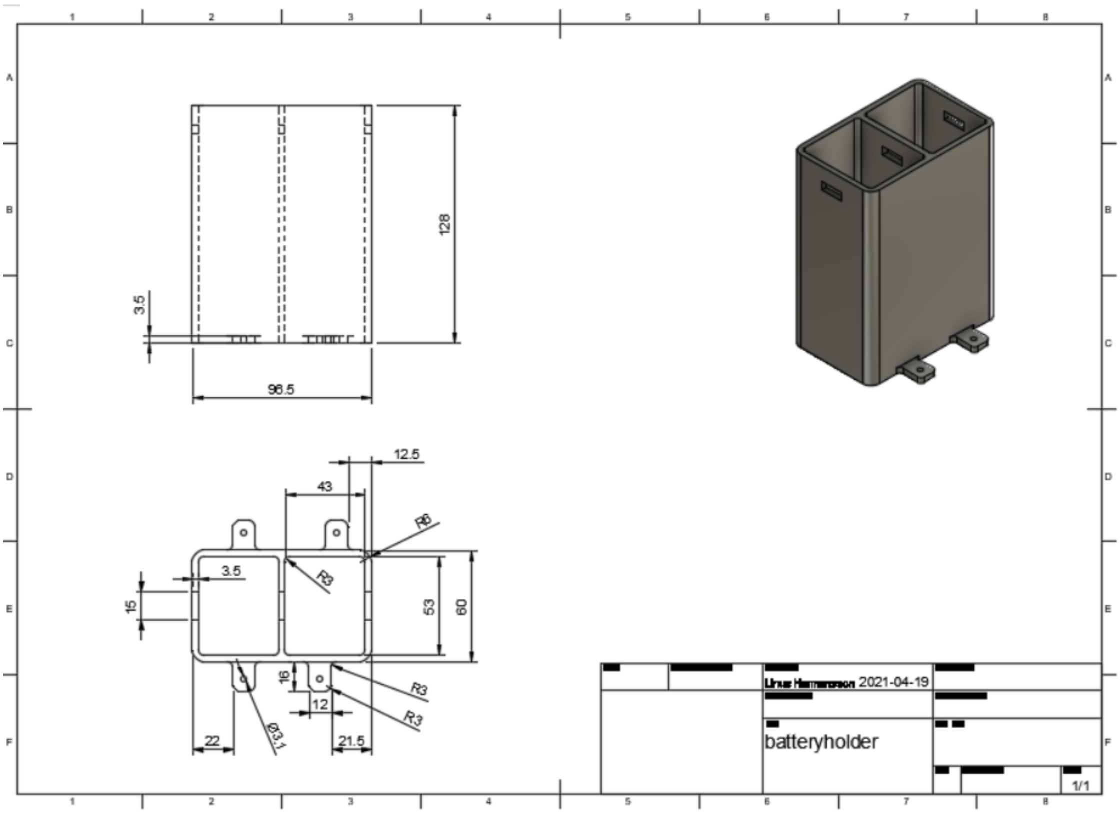
Is there default templates for drawing? Titleblocks, margins, etc.	5	Is it easy to add a BOM?	4	Is it easy to add an different views?	5	Is it easy to add dimensions?	5	Total time for drawings of electric mixer	10	**Total for drawings of electric mixer**
Yes, looks very good.	8	Yes.	10	Very easy.	10	Yes.	7	0,517	10	539
Yes, looks very good.	8	Yes.	10	Very easy.	8	Yes.	7	0,917	8	605
Very limitied default templates, you have to make your own which can be nice but takes a lot of effort.	3	Very complicated.	1	Very complicated.	2	Yes, you can select different features or the whole part to automatically assign all dimensions.	10	1,417	6	369
Easy to add.	6	Yes.	10	Very easy.	8	Yes.	7	1	8	445

Assembly of electric mixer

Lags in assembly?	7	Can you use Step files in assembly?	5	In an assembly, how do know if a part i fully constrained? How do you see the degrees of freedom?	6	In an assembly, are you able to see clashes between parts?	8	How good is collision detection?	8	Total time for assembling electric mixer	10	**Total for assembling electric mixer**
Yes, there is alot.	10	Yes.	10	Fusion 360 automatically locks all degrees of freedom upon the first constraint and you can then unlock some if wanted.	5	Yes, using "Interference".	5	Works good, you can see interfered parts and volume.	7	2,08	7	316
No.	10	Yes.	10	(-) will appear in front of part in tree if not fully constrained. You can also check in "Assembly Visualisation" if part is fully mated (need to add column).	7	Yes, using "Interference detection".	8	Works good, you can see interfered parts and volume.	7	0,43	10	382
No.	10	No.	0	When constraining a part, the STATUS shows if the part is fully constrained or not.	7	Yes, using "Clash" or "Global interference".	7	Works good, you can see interfered parts and volume.	7	1,42	8	304
No.	10	Yes.	10	Right click part and choose "Component degrees of freedom" to see the current degrees of freedom.	8	Yes, using "Check clash". You can also see which surfaces that are in contact with eachother.	9	Really good, you can see if there is a clash or contact.	10	2	7	390

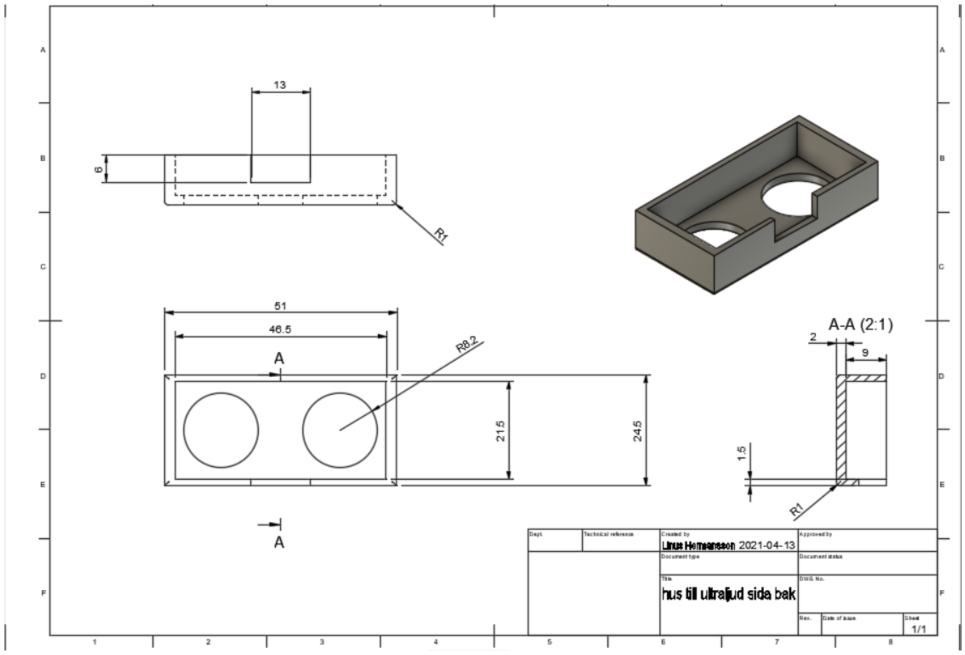
Total time "Electric mixer" (hours)	30	FEM/CAM availability	7	Total without cost		
6,93	7,5	Both (each calculation cost credits).	7	1480		2
5,15	10	Both.	10	1743		1
7,68	6,5	Both (CAM needs Creo Advanced for 49770 SEK).	5	1205		4
9	5	Both.	10	1471		3

7. Drawing of the battery holder.

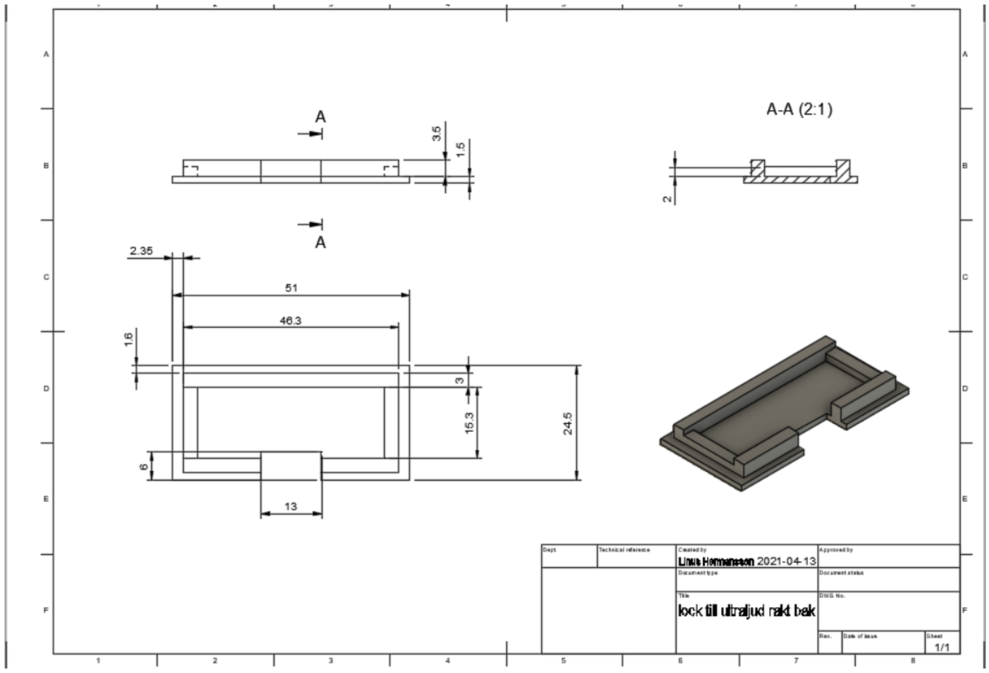


Drawing of the batteryholder which is placed on the front left of the go-kart.

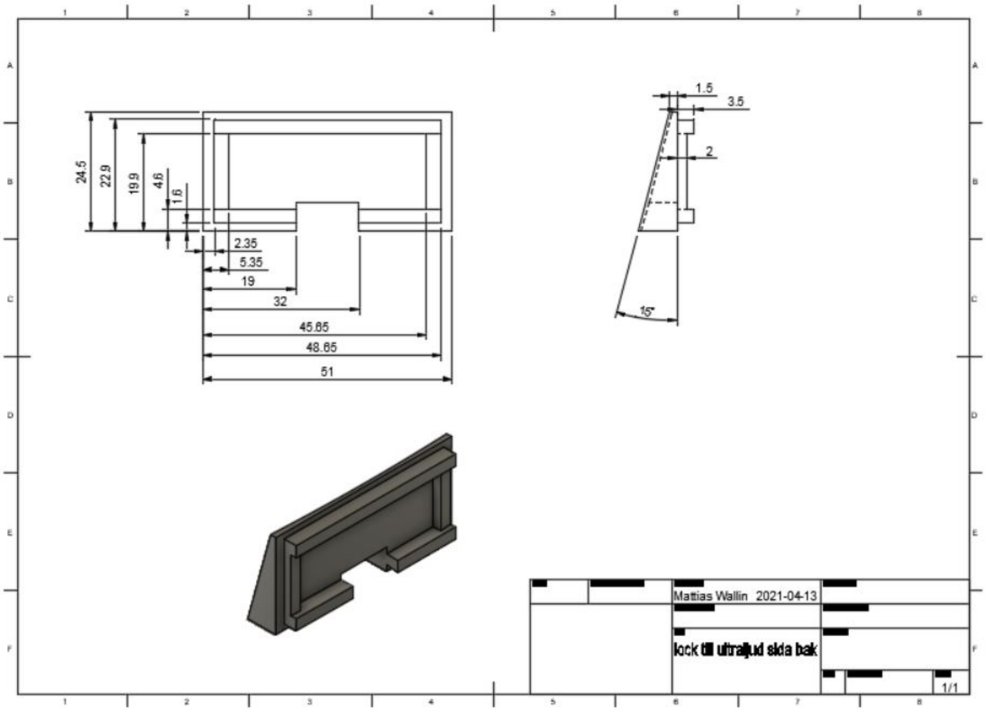
8. Drawings of all the ultrasound and radar consoles.



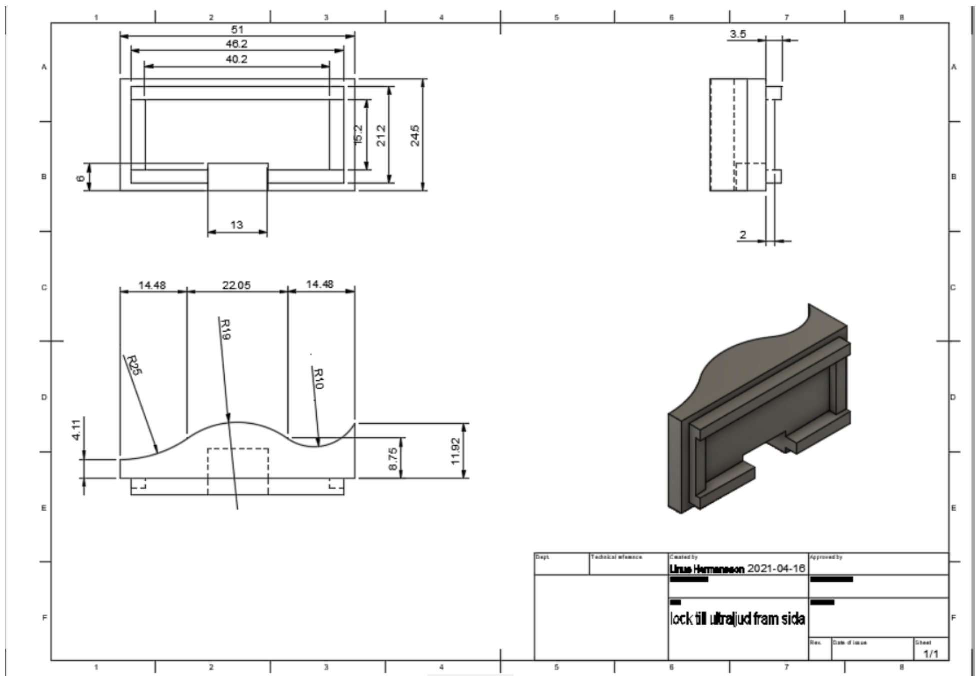
Drawing for the ultrasound house which is placed on the sides of the front and back of the go-kart.



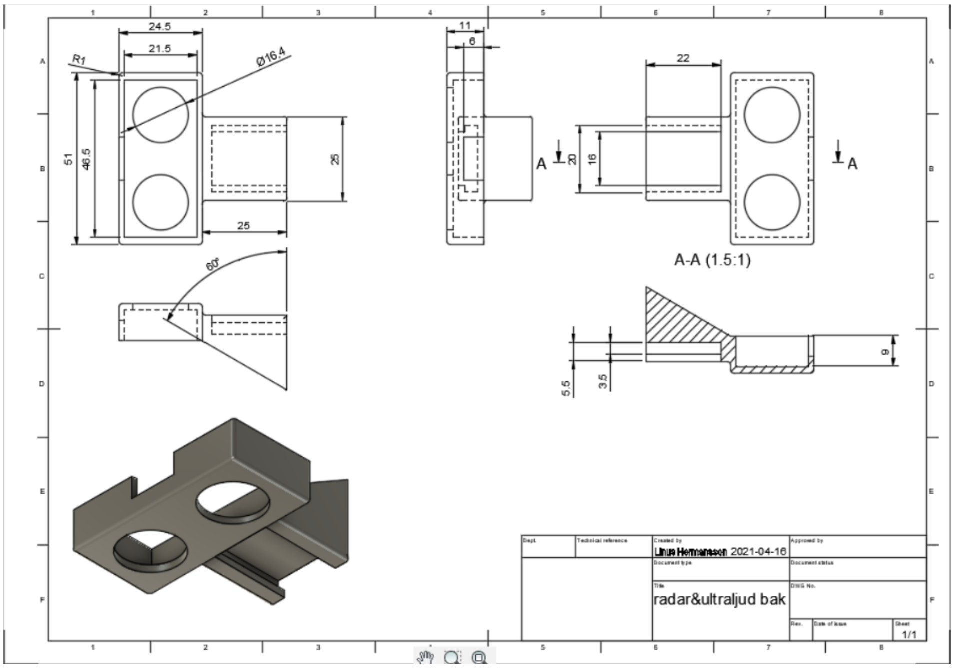
Drawing of the lid of the house for the ultrasound which is placed on the front and back of the go-kart.



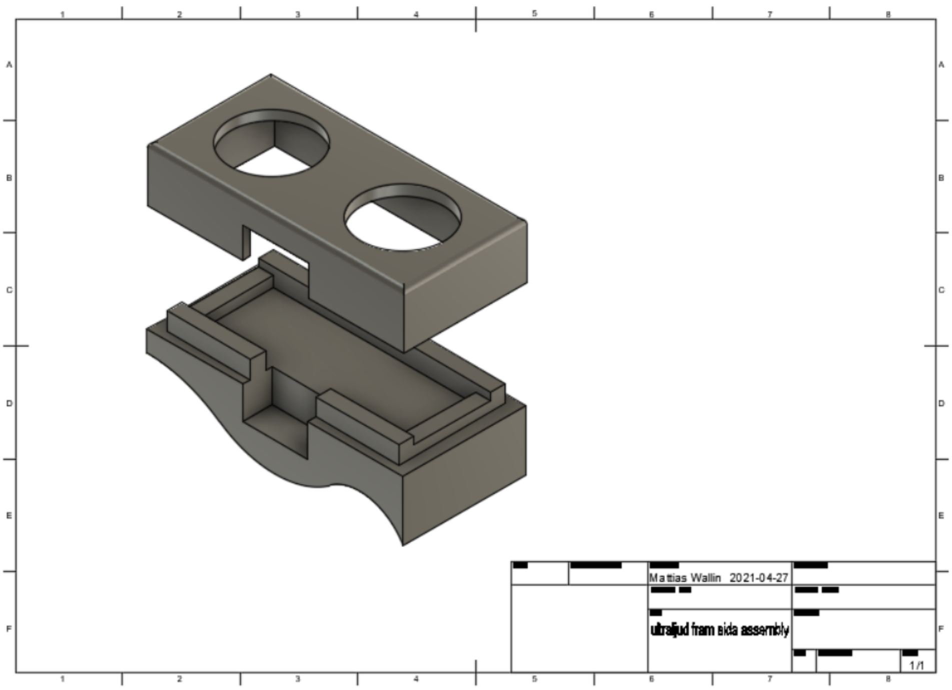
Drawing of the lid of the house for the ultrasound which is placed on the sides of the back of the go-kart.



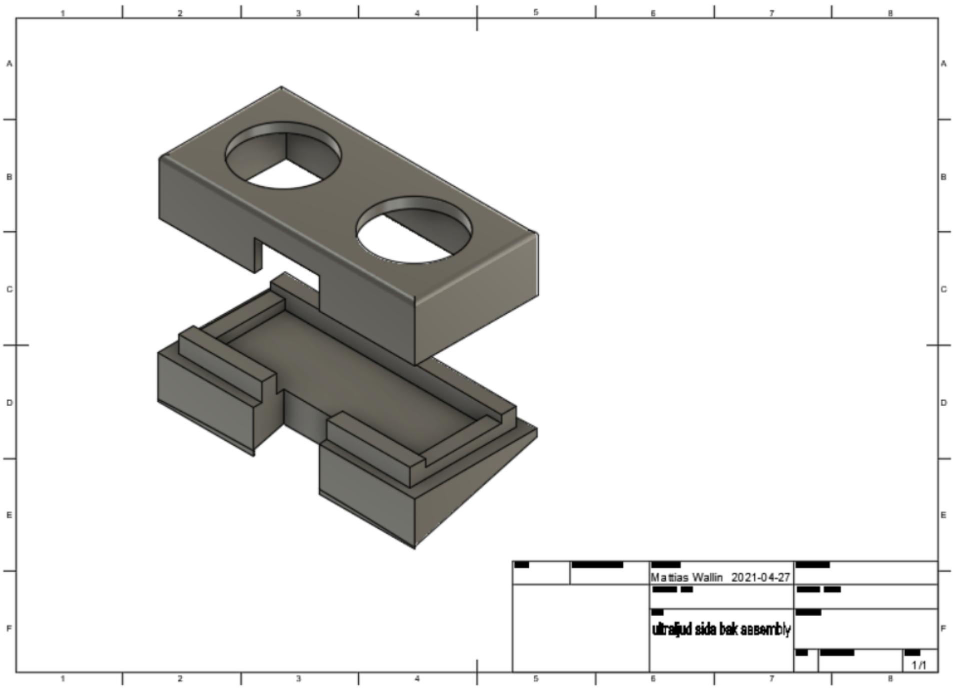
Drawing of the lid of the house for the ultrasound which is placed on the sides of the front of the go-kart.



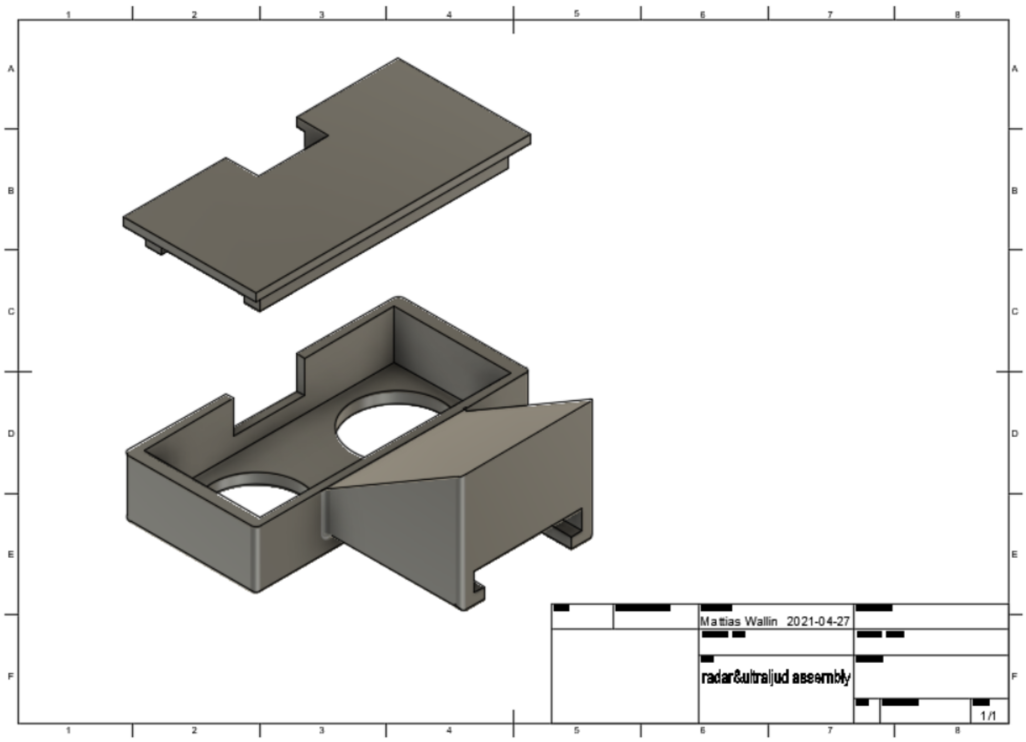
Drawing of the house for the ultrasound and radar which is placed on the front and back of the go-kart.



Drawing of an exploded view for the ultrasound console for the front sides of the go-kart.

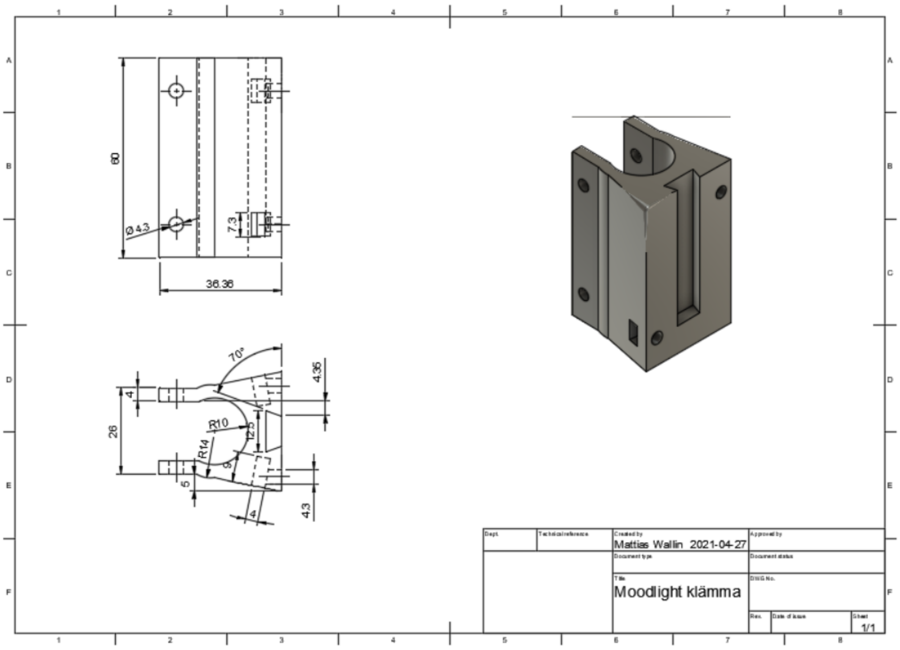


Drawing of an exploded view for the ultrasound console for the back sides of the go-kart.

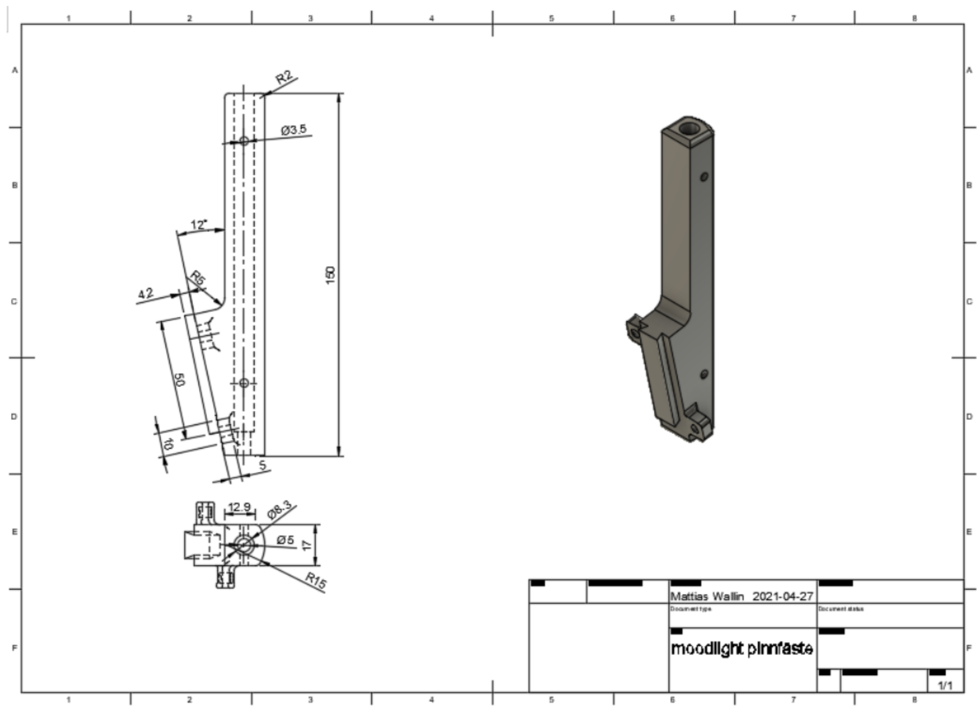


Drawing of an exploded view for the combined radar & ultrasound console.

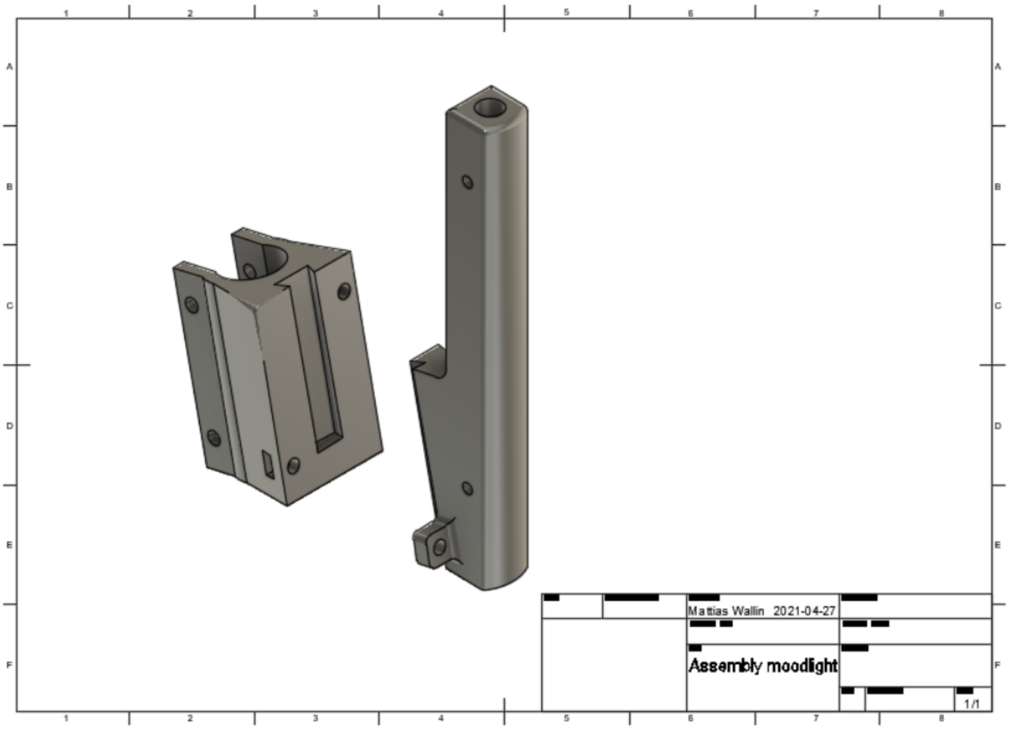
9. Drawings of the moodlight console.



Drawing of the first part of the moodlight console which is mounted on the back of the go-kart.



Drawing of the second part of the moodlight console which is mounted on the first part using the groove and two screws.



Drawing of an exploded view for the moodlightconsole.