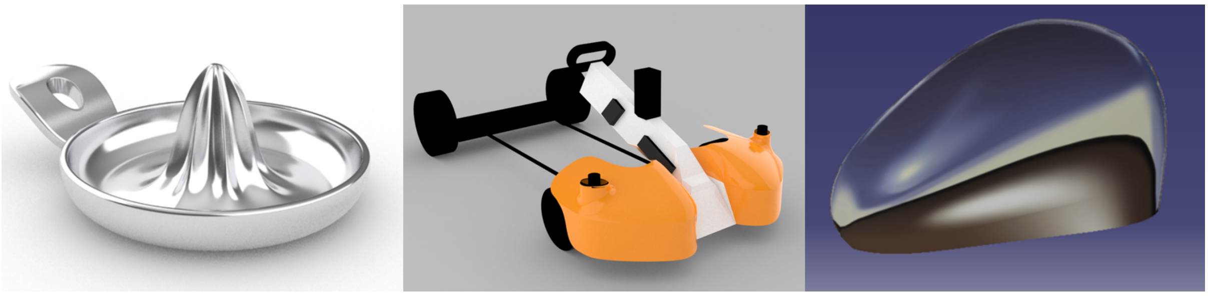

Usability Evaluation of Surface Modelling Software

– A comparison of surface modelling software's with an in-depth evaluation with an emphasis on usability

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DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE (IMS)

CHALMERS TEKNISKA HÖGSKOLA
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Cover photo: Examples of surface models

Preface

The following work presents the result and method of a bachelor thesis performed during the spring semester of 2021 at Chalmers University of Technology. It was done at the Department of industrial and material science on the Design and product development program.

This report shows the process and result of the case presented from the company Infotiv AB.

Tutor and examiner were university lecturer Andreas Dagman, contact persons at Infotiv were Martin Lindqvist, Nils Gangby and Maria Broberg.

Abstract

Usability evaluation of surface modelling software
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SUMMARY
Surface modelling is a way to create 3D-models on the computer. Today, there are many software's that offer surface modelling, but they can come at quite different prices and complexity. This thesis will create an understanding of the surface modelling software's (SMS) on today's market by looking at the most common ones used and give a detailed analysis of a few selected with an emphasis on usability.

The project followed a product development process: identifying a problem, gather solutions then eliminating until a few remained. The project began by creating a requirements list on what the SMS needs. Then a market research was made that gathered the most common SMSs on today's market in a matrix. This was to give an overview of the market containing basic information such as license cost, usability, support, functionality, compatibility, and system requirements.

Then the SMSs were eliminated based on how well they met the requirements which resulted in four SMSs: Fusion 360, Rhinoceros 3D, Alias Surface and Catia V5. These were evaluated by designing a body for a gokart. This allowed for an in-depth evaluation of the usability and the technical specification of the SMSs. The result is presented in two summarizing matrices containing technical specification and usability ratings.

Keywords: computer aided design (CAD), computer aided industrial design (CAID), surface-modelling, solid-modelling, modelling, digital-prototyping, rendering, surface-design, design

Table of Contents

Abbreviations

Computer Aided Design	CAD
Surface Modeling Software	SMS
Control Vertices	CV
Generative Shape Design	GSD

1. Introduction

In today's market, there are many software tools designed to create 3D models. It’s usually distinguished between software tools intended for solid modelling and for surface modelling, but some can perform both. The main difference between the two types is that solid modelling is better for simple geometric shapes, mechanical parts and for construction. Surface modelling is better for complex geometries and organic shapes. The differences are illustrated in figure 1.1. This project focuses on surface modelling.

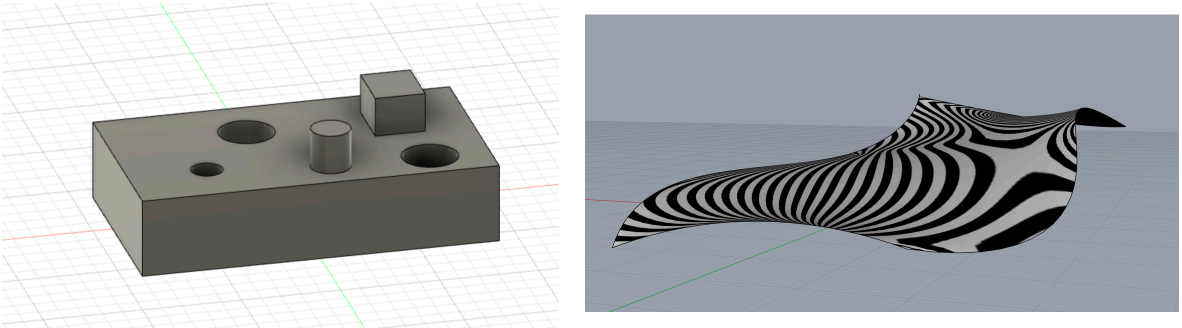

Figure 1.1: Simple solid model to the left and a simple surface model to the right.

1.1 Background

Today's market offers both free and expensive software. In most cases there is a relation between the price, the complexity, and the number of tools and functions of the program. The complexity and often the usability of surface modelling software’s (SMS) varies a lot. This thesis will mainly focus the evaluation on the usability aspect of the SMSs.

The wide range and big number of SMSs can make it difficult for companies to find the best suited software. The challenge for companies is to find software that offers the required functions and deliver at the right performing level to the lowest possible cost. The cost for licences can easily become expensive since there are different cost structures. For example, some software vendors offer licences where the user pays a subscription fee for a software license attached to one computer or personal account that can be used on different computers. One alternative to this is one-time payment or licenses where you choose specifically which functions and properties you want to pay for.

Other criteria when it comes to choosing the right license could also be based upon requirements on the finished result. These requirements could be aspects such as if the software can create production ready models or make high quality visualisation renderings. File compatibility might also be an important aspect if the company need so share files with many other software’s within the company or with their stakeholders. Then the possibility to export in a neutral format is essential.

This study takes a usability approach when evaluating SMSs. The Usability approach covers most of the user's experience of working with the software and are therefore decisive for how well a program can perform in practice. A program can be advanced and have high-level technical features but still be the opposite of user friendly. Therefore, usability become substantial when evaluating which program to choose.

1.2 The Case Company

The case company Infotiv is a middle-sized company with over 200 employs today. The company is mainly operating in the tech and engineering sector. The company offers both consultancy services but also conducts in-house development projects. This thesis originates from their desire to know about SMSs. Also, one of their ongoing projects will act as a test object to evaluate different SMSs. The project is designing a body for a gokart.

1.4 Purpose and Goals

The purpose of this thesis is to create an understanding of surface modeling softwares that are present on the market today and their strengths and weaknesses with a special focus on usability.

The first goal of this thesis is to provide SMSs with an evaluation matrix over the most used SMSs on today's market that clearly outlines software technical characteristics, similarities, and differences between software's.

The second goal of this thesis is to provide an evaluation of a selected number of the SMSs in general with emphasis on usability.

1.5 Scope and Limitations

The evaluation considers the most common and widely used programs for surface modelling on today's market. The thesis is limited by the fact that only free programs, programs that offer a free trial or offer a student license can be tested.

This thesis delimitates to only focus on usability since it's a fundamental aspect when using and choosing a software to this degree.

The design of the gokart body only acts as a case applied to test and evaluate the SMSs. The aim is not to provide an aesthetic or functional design proposal. The CAD model will mainly be used for visual presentation. The project will not do any physical evaluation of the design, no physical models will be built.

The thesis lasts for six months at half-speed. This corresponds to 15 ECTS. This outlines the frame of reference on how much time will be spent on the project.

1.6 Problem Statements

These questions will be answered throughout the projects course and revisited at the end of the report.

- *What does the range of SMS on today's market look like? And what differs between the software's on a more comprehensive level (example license cost, hardware requirements)?*
- *How can a usability evaluation be structured to evaluate SMS?*
- *What distinguishes programs in terms of how well they meet different parts of the usability criteria?*

2. Theory

In this chapter the theory used in the thesis is presented. This includes the theory of product development, explains the definition of usability and what the differences between surface and solid modelling are.

2.1 Product development process

The product development process consists of several steps (Johannesson et al, 2004). It usually begins with an initial study to identify a problem or need of the user. Once the problem is identified the search for a solution begins. Starting with an idea-generating phase. Here the goal is to explore as many possible solutions as possible to cover the entire solution space. In this phase, different methods for idea generation can be used. What's important in this phase is to keep an open mind. Ideas are then evaluated. Solutions that do not meet the stated requirement are eliminated. One way of doing this is by using an Elimination matrix. This method is described later in this chapter. Solutions may also be joined to concepts. The solutions or concepts can now be compared to how well they solve the problem. For example, the Kesselring matrix can be used. This method is described later in this chapter. After choosing the concept or solution that solves the problem in the best way a refinement of the concept is made. A general illustration is showed in figure 2.1.

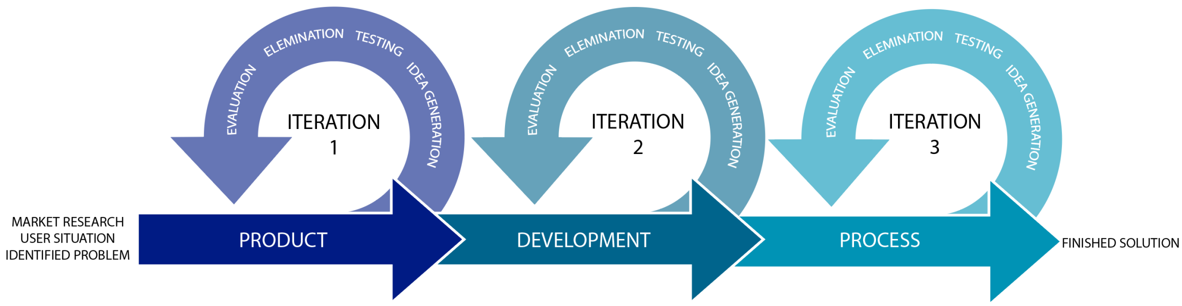

Figure 2.1: Illustration of the product development process. The loops illustrate the iterative loops. Each loop can include all different phases of the product development process, but it is not necessary.

Product development is characterized by the iterative process, which means that between every phase an additional iterative loop can be done. In practice, this means after eliminating concepts a new idea generation session takes a form that focuses on creating refinements on the concepts that passed the elimination. The new concepts can then again be evaluated and eliminated.

The iterative process is used to continually improve a design or product (Eby, 2019). In the practice, the user creates a prototype and tests it, then tweak the first outcome using the test input and results, then test the revised prototype again (Diels et al, 2015). This repeats until a solution is found or the developer is satisfied with the test results. The method can be used both in terms of finding a working solution but also implemented together with other developing methods when the goal is to find the best or optimal solution.

Iterative processes can take many forms. But what is always included is some type of creation, evaluation and then re-creation. In this study, an iterative process is used to evaluate

SMSs. By designing the study to follow an iterative pattern, accuracy is increased, and misjudgements are reduced about the programs to be evaluated.
An illustration representing this thesis process is shown in figure 2.2.

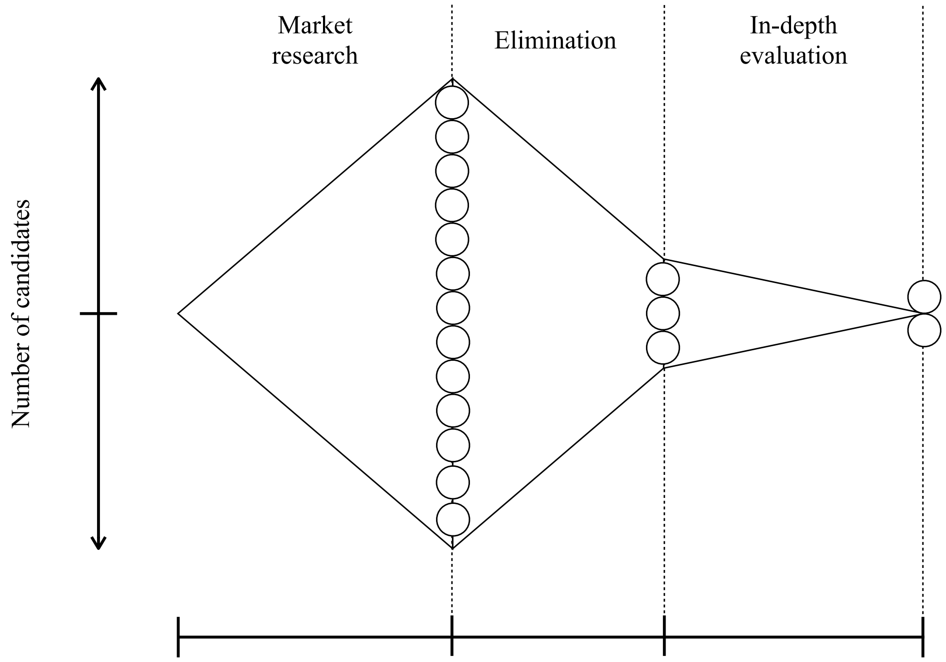

Figure 2.2: Project outline illustration

2.1.1 Requirements

The first step in a product development process is a requirements list (Ulrich & Eppinger, 2014). This is important to gather the necessary requirements for the user and to have a basis for the evaluation of the SMSs. The requirements are divided into two groups: requirements and wishes. The requirements are a must, and the wishes are weighted depending on how important they are. The wishes include factors such as price, license structure, available trial periods, usability, compatible file formats, system requirements, support, and functions.

2.1.2 Digital Prototyping

Prototyping is a fast way of creating test material to evaluate the so far developed product (Wiesen, 2021). There are different forms of prototype manufacturing, all suitable for different types of development projects. Classic is so-called rapid prototyping where sketch models in cardboard are made to be able to evaluate for example shape, size, functionality and so on.

Digital prototyping is a fast way of designing and testing designs. What starts as a simple 3D sketch reworks into something that is increasingly beginning to resemble a finished product. Sometimes different software or programs are used, but often everything can be done in the same program. Digital evaluation is often cheaper to carry out than physical, as it does not require material or the same amount of time. It is easier to make changes to a CAD-model than a physical model. In some cases, the iterative design process may take place completely digitally without being dependent on physical testing.

2.1.3 Elimination matrix

Elimination matrices is a way to make sure everything passes the stated requirements or most important demands (Johannesson et al, 2004). It is done by creating a matrix with the candidates/solutions at one column next to the requirements. Only the candidates who meets every requirement proceed to the next step. Originally, there are other aspects to consider like is it realisable, is it in within budget, is it secure and ergonomic etc. The elimination matrix that is used in this thesis is modified, meaning that it only considers the requirement listed in the requirements list. An example is presented in table 2.1.

Table 2.1: Example of elimination matrix

Candidates	1	2	3	4	**Decision**
A	OK	OK	OK	Fail	**Eliminate**
B	OK	OK	OK	OK	**Proceed**
C	OK	Fail	-	-	**Eliminate**
D	OK	OK	OK	OK	**Proceed**

2.1.4 Evaluation matrix

In this evaluation matrix, each candidate is judged and scored by how well it performs on specific requirements. It is a simpler form of a Kesselring matrix (Johannesson et al, 2004). The weight of the requirement is multiplied by the performance score. The candidate with the highest sum is the one that will perform best. An example is presented in table 2.2.

Table 2.2: Example of Evaluation matrix

Requirements	Weight	A	B	C	D
1	5	2	4	2	3
2	4	2	3	3	3
3	3	4	1	4	3
4	2	5	1	5	4
Sum		**40**	**37**	**44**	**44**
Decision		Discard	Discard	Keep	Keep

2.2 Usability

Usability is a term first meant to replace the vague term "user friendly" by defining the aspects of it (Bekan et al, 1991). There are often five aspects that now define usability. According to Interaction Design Foundation (2021) usability contains these different elements:

> Effectiveness - It supports users in completing actions accurately.
> Efficiency - Users can perform tasks quickly through the easiest process.
> Engagement - Users find it pleasant to use and appropriate for its industry/topic.
> Error Tolerance - It supports a range of user actions and only shows an error in genuine erroneous situations. You achieve this by finding out the number, type, and severity of common errors users make, as well as how easily users can recover from those errors.
> Ease of Learning - New users can accomplish goals easily and even more easily on future visits.

Usability can easily be confused with user experience. A design's usability depends on how well its features accommodate users' needs and contexts. An iconic example is the case of Norman doors, which are doors that are so poorly designed that a user pulls on a door that is pushed (Norman, 2013). Norman means that even something so simple as a door could have poor usability which leads to users not knowing how to use it properly. In this study all five elements will be considered together with other criteria.

2.3 Surface modelling

Surface modelling is defined by Spatial (2021) as "Surface modeling gives you the ability to build out a visual representation of an object's exterior and its contours". Surface modelling is mathematically two dimensional and therefore not a "real" object.

2.3.1 Differences between surface and solid modeling

A solid model is defined by Chang (2015) as having "information about the faces, edges and the interior of the part". A solid model is mathematically three dimensional, there cannot be any object without a thickness. This is a better representation of the real world. Solid modelling is often used to test strength and production of the parts.

Surface modelling can in general create more complex shapes than solid modelling and is therefore used on for example car bodies. The surface model can then be extracted to a solid model (i.e., be given a thickness) so it can be used in production purposes.

2.3.2 Surface Continuity

In surface modelling, the surfaces must be built in a way that generates correct alignments between connecting surfaces (Autodesk, 2018). There are three levels of alignment: position (G0), tangent (G1) and continuity (G2) (illustrated in figure 2.3, 2.4 and 2.5 respectively). Commonly zebra-stripes are used when evaluating surface continuity. In the reality the product, most commonly a car, is put into a room where numerous fluorescent lamps with the same directions in the roof as well as on the walls will create reflections in the painted body of the car. In computer software this is in some cases possible to simulate creating the same visualisation result. In figure 2.3-2.5 two parts are attached to each other. Zebra stripes simulation (continuity simulation) is shown as black and white stripes. Dependin on how well the black and white stripes are matching to each other in the connection between the two parts will show the alignment level.

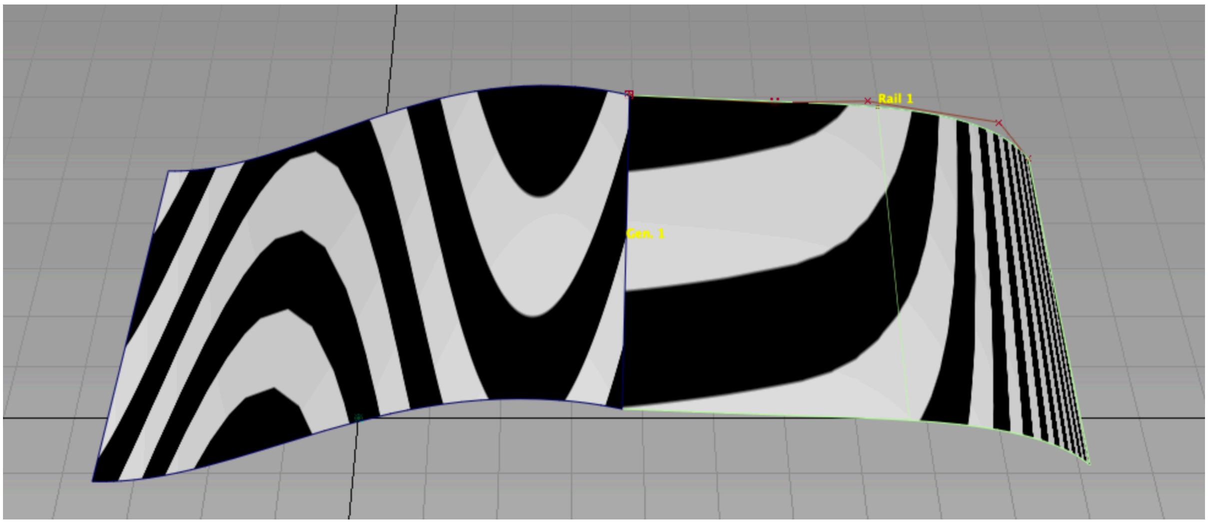

Figure 2.3: Position alignment. The pattern does not connect between the surfaces.

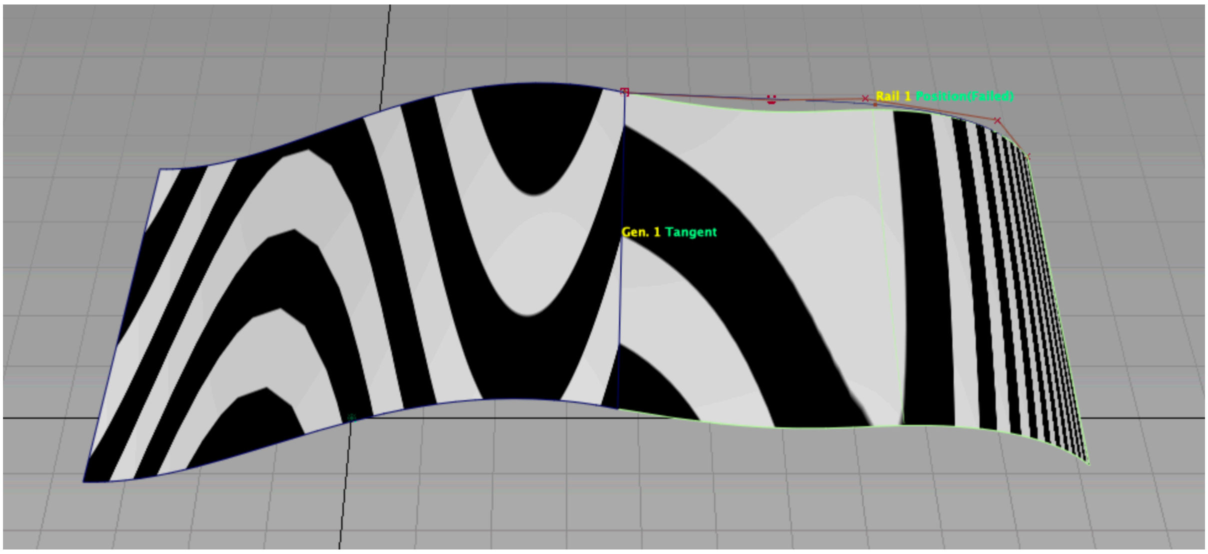

Figure 2.4: Tangent alignment. The pattern meets between the surfaces but not smoothly.

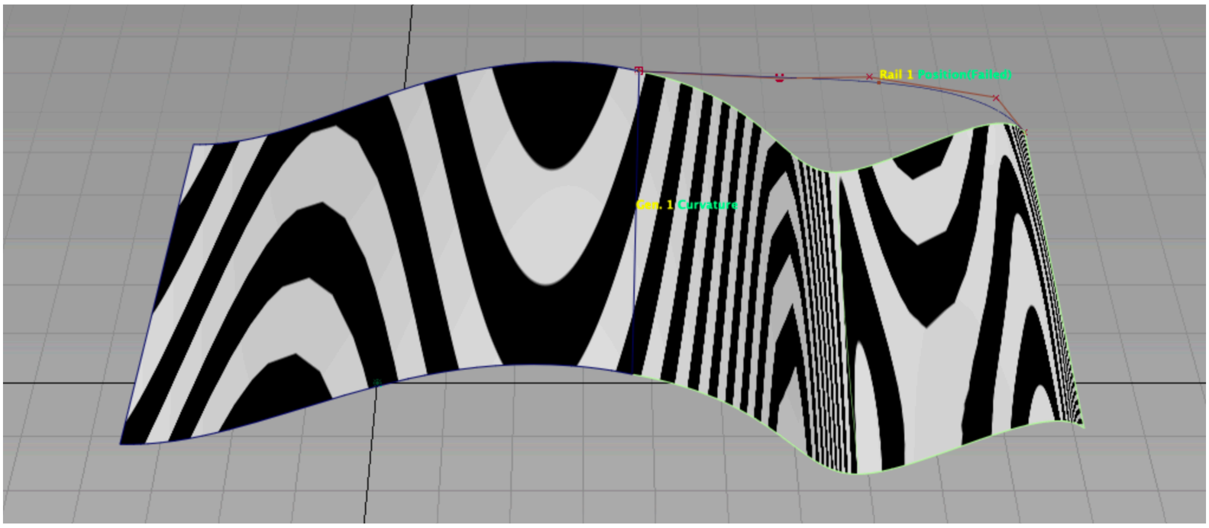

Figure 2.5: Continuity alignment. The pattern meets smoothly between the surfaces.

Continuity means that the surfaces align perfectly and there are no visual signs that there are two different surfaces as seen in figure 2.5. This is important both for the visual aspect but also production because the surface model determines the final product. According to Autodesk (2018), G2 continuity and the more advanced version G3 is often important in the automotive industry.

2.3.3 Generative design

Generative design is a process for exploring complex design through the application of rules or algorithm (Akella, 2018). A specialized software that will generate outputs that meet required constraints, and a designer that will fine-tune the feasible region by selecting specific output or changing input values, ranges, and distribution. This means that it is an iterative design process completely implemented by a computer. Generative design is not only used by designers, but it can also be used in a test environment by artificial intelligence.

2.3.4 Parametric design

Parametric design means that the model is created in a certain way using a special kind of constraint to create relationships between elements of the design (Engle, 2020). If the model is parametrically created, one part of the model can be manipulated, and the rest of the model will follow these new measurements. Parametric modelling is useful when creating and editing complex geometries and structures.

3. Method

The following method is presented chronologically. In the market research, the most common surface modeling software's (SMSs) were gathered in a matrix with factors like price, license, usability, support, and system requirements. A requirements list was also established. Then the SMSs were eliminated based on the requirements list, until only a few remained. Then, those few SMSs were evaluated by designing a body for a gokart to establish technical details and usability.

3.1 Market research

From the software distributor website G2 (2021) information was retrieved regarding which the most common SMSs were. A list of SMSs on the Wikipedia page on surface modelling software's was also used to find more SMSs (Freeform surface modelling, 2021). Every SMS on the list were examined to ensure that that surface modelling was possible. Additional websites such as other software distributors (Novedge, 2021), tech-websites (3D Natives, 2019) and niche CAD-websites (Cadalyst, 2015) were also explored to find more examples, but none could offer an SMS that did not exist on either Wikipedia or G2.

The information that was gathered was whether a free version was available, license cost, license structure, usability ratings, support tutorials, certification available, system requirements, functions, and compatibility. The information was gathered in a matrix.

To access information about the software's, the originator of the software needed to be contacted. Most companies are open with their information, but some did need to be contacted through email and phone to offer a price.

To complete the usability ratings in the matrix every program was tested by making an exercise in surface modelling. It is an exercise used in a surface modelling course at advanced level (Chalmers, 2021). This exercise was an easy task meant to explore the SMS and its capabilities. Only those SMSs with a trial version or those who offered student versions could be tested and rated (those programs who did not offer a trial version were eliminated anyway).

3.1.1 Reference Programs

To have something to use as a reference in the program evaluation, two reference programs were selected. The choice of the reference programs was based both on information from the case company and general assumptions about programs used in the industry. Based on this information Catia V5 and Alias Surface was chosen as reference programs in this evaluation study. Catia V5, well known for its wide abilities within many fields of engineering, and Alias Surface, developed by market-leading Autodesk, are both used by Volvo, according to the case company.

3.2 Requirements for the SMSs

The requirements were stated together with case company, including both concrete requirements directly formulated by the company and requirements based on their wishes. The requirements are stated to match the size and needs of the case company but are not exclusive to them. The requirements are relevant for any small to a middle-sized company in a similar business. Their needs are first and foremost low cost since the company cannot afford expensive programs for something they are not using extensively. The second most important thing is usability because when they have purchased an SMS, they need it to be easy enough to use and utilize.

Large companies tend to influence what programs are locally used. This applies both to schools, universities, and other smaller companies. If other companies want to cooperate with the larger companies, it might be beneficial for them to use the same software.
In general, smaller companies have more freedom in choosing software, compared to company groups where there often is an internal policy for what software is to be used.
Consulting companies needs to have the knowledge and ability to use different SMSs since their current customer might have requirements for that.

3.3 Exercises

Two exercises were done to explore SMSs. The purpose was to begin at a basic level to test a large number of SMSs, then eliminate based on which passed the requirements. Then another iteration of exercise and elimination was made. The first exercise is an MC-tank which has a simple geometry and is meant to explore the basics of an SMS. The second one is a citrus press which is a more advanced shape meant to give a deeper exploration. Both exercises originate from a surface modelling course at Chalmers which is why they were chosen, both for the convenience and for their credibility.

3.4 Elimination methods

The first elimination method was a simplified version of an elimination matrix. Normally in product development, in an elimination matrix all requirements must be met as well as some other things like is it suitable, is it feasible and is it within budget. In this case only the requirements were interesting since this is not a product development, only an evaluation where all candidates already exist.

The second elimination was a derivative of a Kesselring matrix. This is a simplified version which is better suited to the data in this thesis. Normally all requirements are given a scale of how well it can be met. In this version, all requirements have a 1–5 scale for simplicity's sake.

3.5 Creating the gokart body

The gokart is an in-house project from the case company. The purpose of the gokart project is to develop education methods and knowledge in autonomous technology. The gokart is smaller and less complex compared to a real car, which makes a more appropriate learning platform. The gokart is a Ninebot Gokart Kit which is equipped with added on components such as lidar, cameras and computers, to convert it to an autonomous vehicle (figure 3.1). At this stage, the gokart needs a body that will protect the added components.

The gokart body was made to evaluate the SMSs on usability and to find out technical aspects about the program. Usability was evaluated on the five aspects (effectiveness, efficiency, ease of learning, error tolerance and engagement) on how to create surfaces and how to edit surfaces. The technical aspects were history, structure, curvature, rendering studio, general use and production ready surfaces.

The geometry in the models from the different programs were therefore different. This was mostly because the focus was on the evaluation of usability and technical aspects and not on a unanimous design. A unanimous design would give an advantage to those SMSs equipped with tools for that purpose. The design choices were therefore individual for each SMS to make each one shows its capabilities. Secondly, the programs had different capabilities which limited the designs.

Before starting to design the gokart body, the chassis and underlaying components needed to be measured. From measurement on the modified gokart a simple CAD-model was created in Catia V5 for its solid and surfacing modelling capabilities (figure 3.2). This model served as an underlying reference model which the design was created on top of. The use of the base model ensured that all the fixed measurements, such as distances between wheels, axis, steering equipment, and driver seat, matched between the chassis and the gokart body. It also ensured that it would be enough space under the body to fit the components.

Figure 3.1: Ninebot gokart with added equipment for convert it to an autonomous vehicle

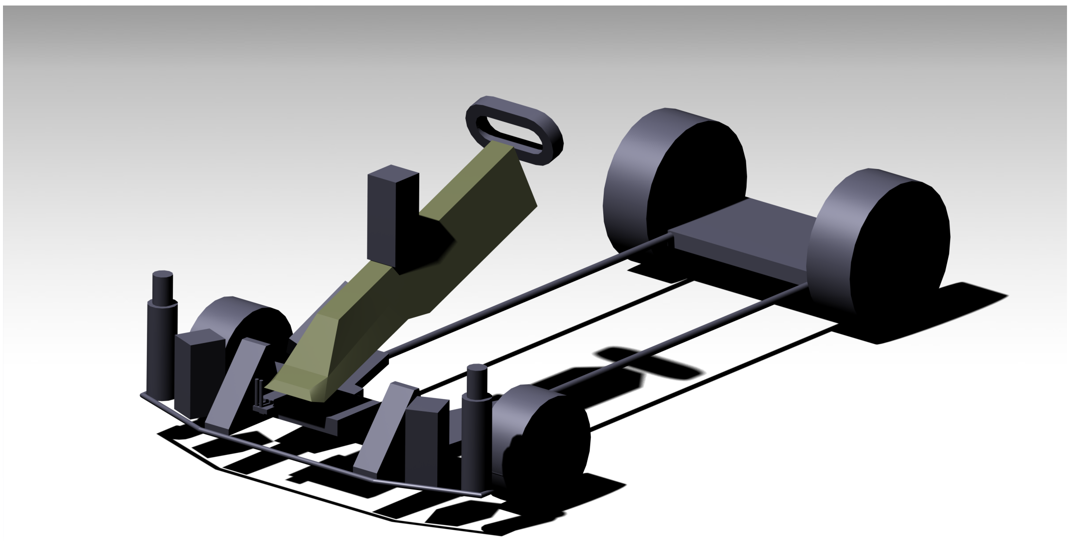

Figure 3.2: Simple gokart CAD-model

3.5.1 Specific design requirements for the gokart design

The design needs to be constructed to fit the underlying components of the gokart. Some of the underlying components must not be covered. This applies, among other things, to some sensors and transmitters. The goal of the whole gokart project is that the gokart will manage to navigate completely autonomous on a gokart court. Still, the body of the gokart will be designed for allowing one driver inside the car. There is no final requirement for the design to be presented as a physical model. This will set the conditions for what the design will look like.

These specific requirements were originated from the employees at the case company, who expressed their needs. The specific requirements are shown in table 3.1.

Table 3.1: Design requirements for the gokart model, developed based on the case company's requirements and wishes.

Req ID	Requirement text
Req 1	Protect components (technical equipment located mainly in the front section of the car)
Req 2	Enable replacements of parts:
·	Body consists of individual parts that separately can be removed or displaced
·	Part lines are positioned appropriately
·	Parts that are more likely to be exposed in the event of a collision should be able to be replaced more easily
Req 3	Parts are easily replaced and dismantlable
Req 4	Easy to get in and out of the vehicle
Req 5	Designed with aerodynamic principles
Req 6	Aesthetically pleasing
Req 7	Does not block lidar sensors
Req 8	Enable accessibility to computer in the middle
Req 9	Integrate front LED-lights
Req 10	Integrate display
Req 11	Leave front hatch for batteries open
Req 12	Model is a realistic design proposal that with further development will be able to be produced
Req 13	Integrates without blocking elevated 360 camera (placed in the middle of the steering axis)

4. Result

In the first phase of the project, an overall market research is performed. The market research aims to create an overview of the most common surface modelling software's (SMSs) in today's market and line up basic facts about these programs.
The result is divided in two parts: the requirements list and the selection matrix.

After gathering necessary information about the SMS on today's market, the practical test and elimination process began. The SMSs was tested through different surface modelling exercises. If the SMS completed exercise sufficiently it moved to the next step, otherwise it was eliminated from the process. The exercises used in this phase is material that is used in a university-level surface modelling course.

4.1 Requirements

Below is the requirements list (table 4.1). It has requirements which are a must for the SMS and wishes which are weighted depending on how important they are.

Table 4.1: Requirement's list

Nr.	**Description**	**Requirement/Wish**	**Weight**
Req. 1	Free trial period	Requirement	
Req. 2	Surfaces are created from curves	Requirement	
Req. 3	Low cost	Wish	5
Req. 4	High usability	Wish	4
Req. 5	Support	Wish	3
Req. 6	Functional	Wish	2
Req. 7	Compatibility	Wish	2
Req. 8	System requirements	Wish	1

The reason a trial period is important is because SMSs are expensive. This means that the user must know the program for it to be a sound investment. Otherwise, it would be a waste of money buying an SMS. Therefore, the user must try the SMS to simply know the basics and can then decide to invest or not in the SMS.

The most important factor is cost, which is why it is weighted five. As mentioned before, a trial period is needed to decide to invest or not and this is all because of cost. A small or medium sized company do not have the money to buy an SMS just to try it.

Usability is an important factor that decides how well someone can use an SMS. Therefore, it is weighted four. Support also factors in here, since with the help of videos or tutorials one can perform better.

The functionality means what functions does the SMS have. This is less important since there is almost always a solution to everything, but the right functions can make it easier. The functions of common SMSs are similar, meaning that only the more advanced SMSs have more functions.

Compatibility measures how well the SMS can cooperate with other SMSs and file-types. It is important in the business since different companies use different SMSs, so there must be a bridge between them.

System requirements define what you need to run the SMS. Most SMSs does not require highly advanced computers, so it is less important.

4.2 Selection Matrix

The result is presented in form of a two parted matrix (appendix A). The matrix evaluates the fifteen most used SMSs on today's market (G2, 2021) that can be used for surface modelling, either from scratch or for surface editing.

The first sheet of the matrix evaluates the main area of work, cost, usability, support, system requirements and functions. The second sheet includes compatible file formats.

4.3 Elimination matrix

The elimination process eliminated SMSs, from the selection matrix, that did not have a trial version or could not create surfaces from curves. The SMSs without trial period were eliminated based on the disability to practically evaluate them further. The SMSs that create surfaces out of curves and had any sort of free trial version were tested in the first exercise, creation of a simple MC-tank (figure 4.1). illustrations from different SMSs are in figure 4.1). The elimination process is shown in Table 4.2.

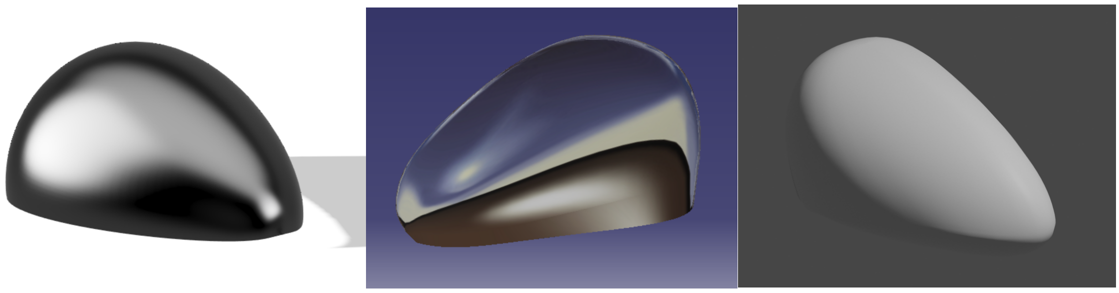

Figure 4.1: A selection of the MC-tanks modeled. From left to right: Fusion 360, Catia V5 and Blender

Table 4.2: Elimination matrix

	Requirements	Free trial period	Surfaces are made from curves	Decision
Reference programs	Alias Surface	No	Yes	
	Catia V5, surface modeling work bench	No	Yes	
Programs for evaluation	Alias Autostudio	No	Yes	Discard
	Catia V5, surface modeling work bench	No		Discard
	Alias Surface	Yes	Yes	Keep
	Alias Concept	Yes	Yes	Keep
	Blender	Yes	Yes	Keep
	Cobalt	Yes	No	Discard
	Form-Z	Yes	Yes	Keep
	Fusion 360	Yes	Yes	Keep
	ICEM surf	No		Discard
	KeyCreator	Yes	Yes	Keep
	NX	No		Discard
	Onshape	Yes	Yes	Keep
	CREO Parametric 3D Modeling Software	No		Discard
	PTC Creo elements/pro	No		Discard
	Rhinocereos 3D	Yes	Yes	Keep
	Solid Edge	Yes	Yes	Keep
	Solid Works	No		Discard

4.4 Evaluation matrix

The SMSs that passed the elimination matrix were explored once again with another exercise to test them before the second elimination. The exercise used was to create a citrus press. The citrus press is a more advanced model with more complex shapes to create. A selection of the successfully modelled citrus presses are shown in figure 4.2 below.

Figure 4.2. Citrus press made in (from left to right): Catia V5, Rhinoceros 3D, Fusion 360

The Evaluation matrix evaluated the rest of the attributes from the selection matrix: price, usability, support, basic functions, compatibility, and system requirements. These were given values between 1–5 and multiplied with the weight of the whish, which is seen in table 4.3. The SMSs with the best score moved on to the next phase. The Evaluation matrix is shown in table 4.3.

Table 4.3: Evaluation matrix

	Weight	Reference programs		Programs for evaluation								
Wishes		Alias Surface	Catia V5	Alias Surface	Alias Concept	Blender	Form-Z	Fusion 360	Keycreator	Onshape	Rhinoceros 3D	Solid Edge
Price (trials, licence cost, structure of license etc.)	**5**	2	1	2	3	5	3	5	1	2	4	3
Usability based on *Effectiveness, Efficiency, Engagement, Error Tolerance, Ease of Learning.*	**4**	3	2	3	3	2	2,4	2,8	2,4	3,2	2,6	1,2
Support (user communities, online courses, help centers etc.)	**3**	4	3	4	4	3	2	4	3	3	3	3
Basic functional level (rendering studio etc.)	**2**	5	4	5	4	1	3	2	3	2	3	4
Compatibility (export, import file formats)	**2**	4	5	4	3	2	2	3	2	3	5	3
System requirements (OS, CPU, RAM, GPU, storage)	**1**	2	1	2	2	4	3	4	3	4	4	3
Sum		**54**	**41**	**54**	**55**	**52**	**43,6**	**62,2**	**36,6**	**45,8**	**59,4**	**45,8**
Decision				Keep	Keep	Discard	Discard	Keep	Discard	Discard	Keep	Discard

Four SMSs were kept for the next phase. As seen in the table above, both Alias Surface and Alias Surface Concept moved on. Since they are remarkably similar and Alias Surface is one of the refence programs, it was not necessary to keep them as candidates since the reference program would be tested anyways. Therefore, only Fusion and Rhinoceros 3D were kept as candidates and Alias Surface and Catia V5 remained as references.

The remaining SMSs were evaluated using the case application. The result from this part of the evaluation is presented in the following analytical part for each individual programme. It is not the aesthetic appearance or the geometric shapes of the model that is the result that is assessed. What is tested is how well the programs perform in terms of usability. Each program is evaluated by usability both for the creation of models and for the editing of models.

4.5 Autodesk Fusion 360

Fusion is the cheapest variant of the candidates, with a lower capability of creating surface models. The program does have solid modelling capabilities. In figure 4.3 the result from Fusion 360 is presented.

Figure 4.3: Concept/design model constructed in Fusin360. Pictures made in the programs rendering workbench.

One simple way of creating surface models in Fusion 360 is to proceed from an existing form. In this case, a sphere was manipulated to create the shape of the front side (blue part in the rendering). The shape was mirrored to create the other side. To create the middle part of the model most of the program's tools for surface modelling were tested. This involved sketching of curves, creations of planes and tool for making round transitions. The final look of the model's shape can be explained by the program's few tools and the limitations they entail in modelling.

4.5.1 Structure of the program

Autodesk Fusion 360 can be used for many kinds of modelling and 3D model editing. The program has workbenches for solid modelling, surface modelling, shape/form editing, mesh editing, sheet metal and tools for pre-manufacturing. For creating surface models, the workbenches Surface and Form are relevant (figure 4.4).

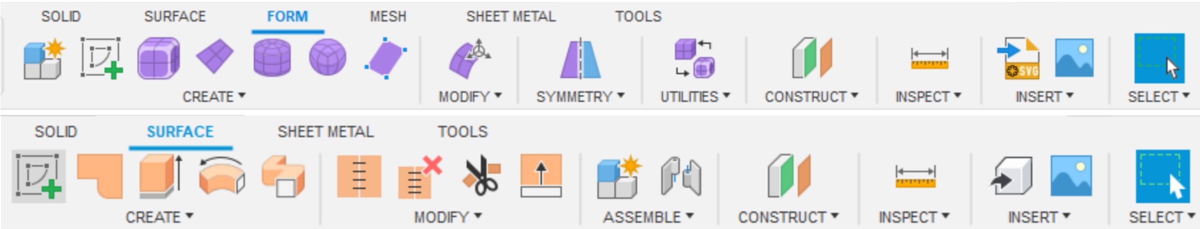

Figure 4.4: The work benches used in Fusion360 for surface modelling.

The program's simplicity and clean interface make it well suited for rapid modelling, 3D sketching and rapid production of visualization material. At the same time, the program can achieve a sufficient model level to function as a production basis.

The clarity of the interface allows a user with a moderate background proficiency in modelling to quickly familiarize themselves in how the program works.

The program uses a so-called tree structure (figure 4.5). This gives an overview of the model's parts and its features. A timeline of events is also presented (figure 4.6).

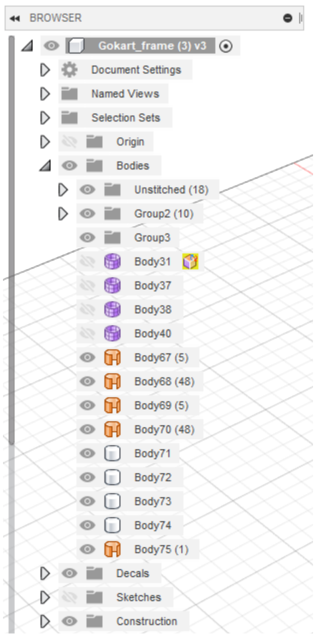

Figure 4.5: The tree structure. Here al sketches, bodies, components can easily be found.

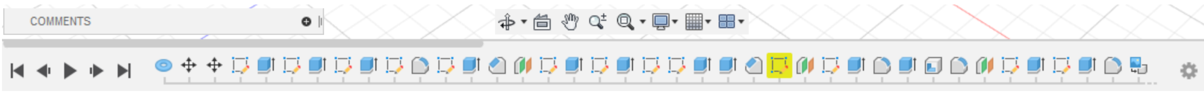

Figure 4.6: The timeline.

4.5.2 Creation of History

All edits in the model are shown in chronological order on display. The program creates historical connections automatically between most events. The history-creating feature sometimes fails. If a surface is generated from a few curves, minor changes in the curve sketches can be made without further complications. If major changes are made the program might not still be able to perform the after following generation of the surface out of the manipulated curves.

4.5.3 Rendering studio

Fusion 360 includes a rendering studio where material, light, background, and perspective can be set. The rendering studio comes with a default environment with standard background and lights. The user can choose between rendering local on the computer or cloud rendering. The user also chooses image size, format, and resolution after their preferences. Rendering on the cloud creates pictures significantly faster than local on the computer. In general, Fusion's rendering studio works significantly faster than other leading programs on today's market and are at the same time easier to use and creates high quality pictures.

4.5.4 Cloud features

Fusion 360 is an Autodesk program. To use the software, an account and a license are required. When starting the software, the user uses their Autodesk account to sign in and access the software. The user has an online library of their models linked to the account. The user can choose between modelling in online or offline mode. In online mode, all changes are automatically saved in the cloud.

4.5.5 Program weaknesses

The major disadvantage is that the surface workbench only has a few tools compared to other programs. Fusion 360 only has two tools for creating surfaces out of curves or sketches that is not an existing edge on a surface in comparison with the reference program Alias Surface has around 15 different tools.

Additionally, no tool in Fusion 360 can generate a more complex surface out of sketches or points in three dimensions. It is, therefore, impossible to create or edit models that have continuity. The consequences are that the designer cannot achieve their desired result.

Another disadvantage with the program is that no history is created. Neither is any timeline over the editing events. This makes it hard to go back and perform changes in the model. Still, there are a few ways to change an existing surface object. For example, if a surface generated out of lines or sketches is to be changed, changes can be made in the sketch. But then a new surface needs to be generated from the updated sketch, and the old one needs to be removed. Because no history is saved, there is nothing that connects sketches with the creation of a surface or the subsequent edits.

The program is not natively 3D parametric. Neither can the SMS create generative design.

Double-curved surfaces

The way to create a double-curved surface is to either start from an existing surface or shape and edit it in the workbench form or generate one from scratch in the surface workbench. In the workbench Surface, there is only one tool that can create surfaces out of more than one spline or sketched line. In the tool, the designer uses two boundary edges, and this creates a flat surface. The designer can also choose to use interior rails or points to create a more complex and double-curved surface. The tool has few settings and the result of the created shape, therefore, depends solely on the state of the input lines or points. The designer can easily create a shape, but it is difficult to get it exactly according to their wishes (illustrated in figure 4.7). This makes the tool both clumsy and unwieldy to use. In other words, the tool has a low error tolerance. In the form workbench, there are more editing tools for existing surfaces.

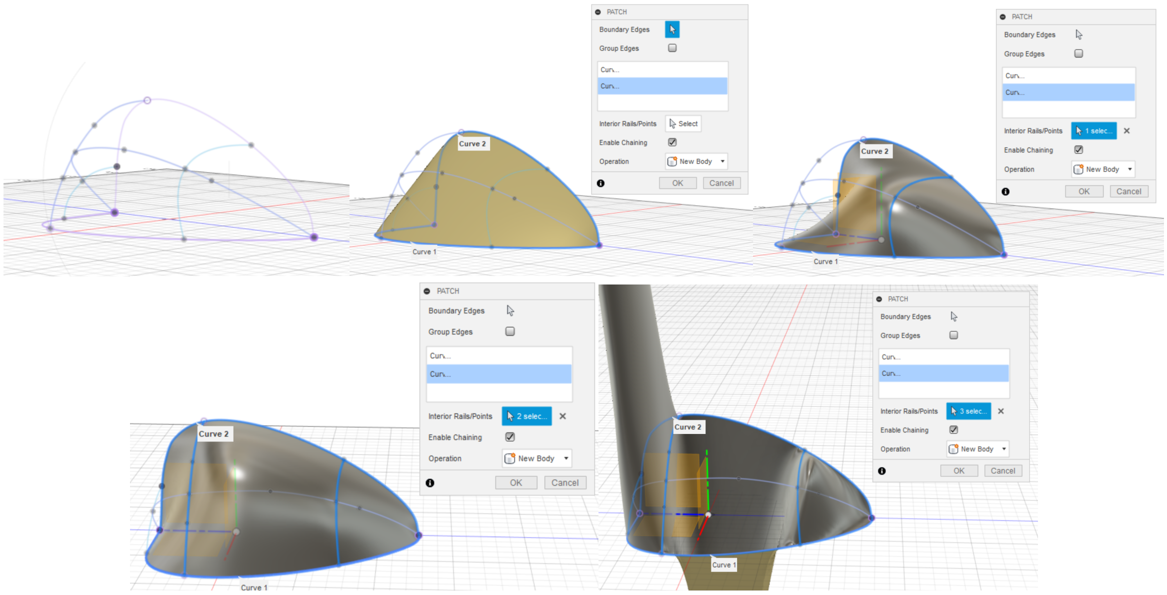

Figure 4.7: Start with created sketches/rails. Choose boundary edges in the tool. Choose one interior rail. Choose of second interior rail. Choose of the third rail, her something happens, and the shape does not turn out as expected, probably bur to imprecise sketches

Create Surface Continuity

The program has a tool for visualizing whether the model or shape has surface continuity, using a tool that applies a zebra looking pattern. If the shape is generated as a form from the start, it will most likely have continuity automatically (figure 4.8). It is possible but difficult to create something close to surface continuity between joined surfaces. The error tolerance is exceptionally low. There is no tool or setting for this, but with precisely designed surfaces and underlying sketches, it is possible to create merges between surfaces continuity between joined surfaces.

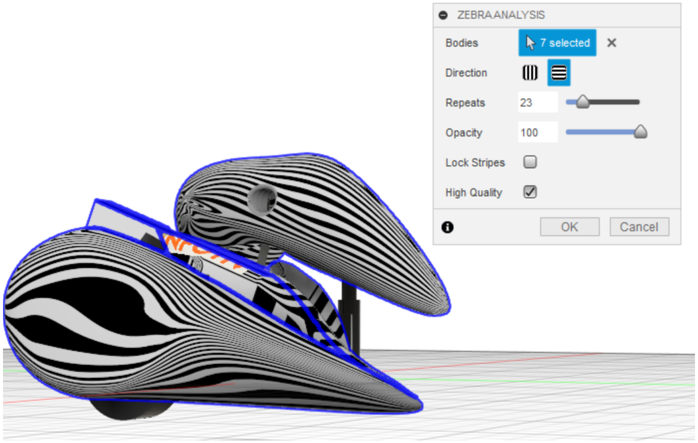

Figure 4.8: Tool for evaluating surface continuity.

4.5.6 Usability in Fusion 360 - Creating models

In Fusion there are two starting ways to start creating a model:

- Start with creating sketches (two or three dimensions), generate surfaces out of the sketches by using different tools.
- Insert a predefined form, for example, a sphere or cube, manipulate the form until the desired result is achieved.

The different ways can be combined in the same model. When manipulating a shape, you work in the Form workbench. The form is then converted to a surface object and can be edited in the surface workbench together with the rest of the surface model.

Ease of Learning

The tools are relatively easy to use, small texts or dialogues are available in several tools. Each tool has a clear icon that illustrates what it does and when the mouse hovers on the icon, an explanation for the tool pops up. This facilitates ease of learning, which means that new users can accomplish goals easily and even more easily on future visits.

Error Tolerance

The program supports a range of user actions but can sometimes warn if an error occurs or refuse to perform if the user tries to do something that will not be able to be implement. Minor errors that the program warns of can be ignored to some extent, but this is due to the subsequent changes to the model.

One thing to keep in mind when editing a surface object in the Form workbench is that complex geometry can be created without any warnings for errors. But when the form is then going to be converted to a surface object, the program refuses to implement it. This is because a shape object can have significantly higher complexity in geometry with intersecting surfaces, for example. The program cannot convert such shapes into surfaces.

Effectiveness and Efficiency

As a result of the programme's clear interfaces, relatively few tools, dialogue boxes, the non-existent requirement of constraints, the users can create models and perform tasks quickly.

Fusion 360 does not have any sketch sniping tools like most common SMSs have. The user can create constraints in sketches, but there is no alternative tool that facilitates finding common points, background grid, or known curves like snapping tools in, for example, Rhinoceros 3D or Alias Surface.

There are no keyboard shortcuts available in Fusion 360. For a user well versed in a program, shortcuts can facilitate modelling and shorten the time even further. The use of shortcuts has a greater effect in a program that has more tools, tool variants or less clear interfaces. The need for shortcuts in Fusion 360 is not significantly large in terms of the program's simplicity and purpose.

Engagement
The fulfilment of the engagement criteria depends on the user's purpose. If the goal is to rapidly create a model with less complex shapes, geometries or details, the user will find the SMS pleasant to use. If the user aims to create more complex models the user will probably be disturbed by the lack of variation in the toolbox and that there are few tool settings.

4.5.7 Usability in Fusion 360 - Editing models

Effectiveness and efficiency
The tree structure facilitates finding the exact component or the associated sketch that is to be edited. The user double clicks the desired event/object then the tool's dialogue box reappears.

The timeline facilitates overviewing the consequences of edits. The program will mark events in the timeline that are negatively affected or can no longer be implemented with yellow or red.

History and Error tolerance
The program creates historical connections automatically between most events. This feature sometimes fails. If a surface is generated from a few curves' minor changes in the curve's sketches can probably be made, without further complications. But if major changes are made the program might not still be able to perform the after following generation of the surface out of the new manipulated curves. The program response in this kind of situation varies depending on the nature of the case. The surface might disappear and a new one needs to be created, using a different tool.

The impact on other parts of the model depends on how the model is structured and the order in which it was created.

4.6 Rhinoceros 3D

Rhinoceros 3D is a SMS primary developed for surface modeling usage. The SMS has a variety of different tools both for creating and editing surfaces and surface models. The program can be used for simple solid modeling. Compared to the reference programs Rhinoceros 3D is a less complex SMS.

An illustration of the gokart made in Rhinoceros 3D is shown in figure 4.9.

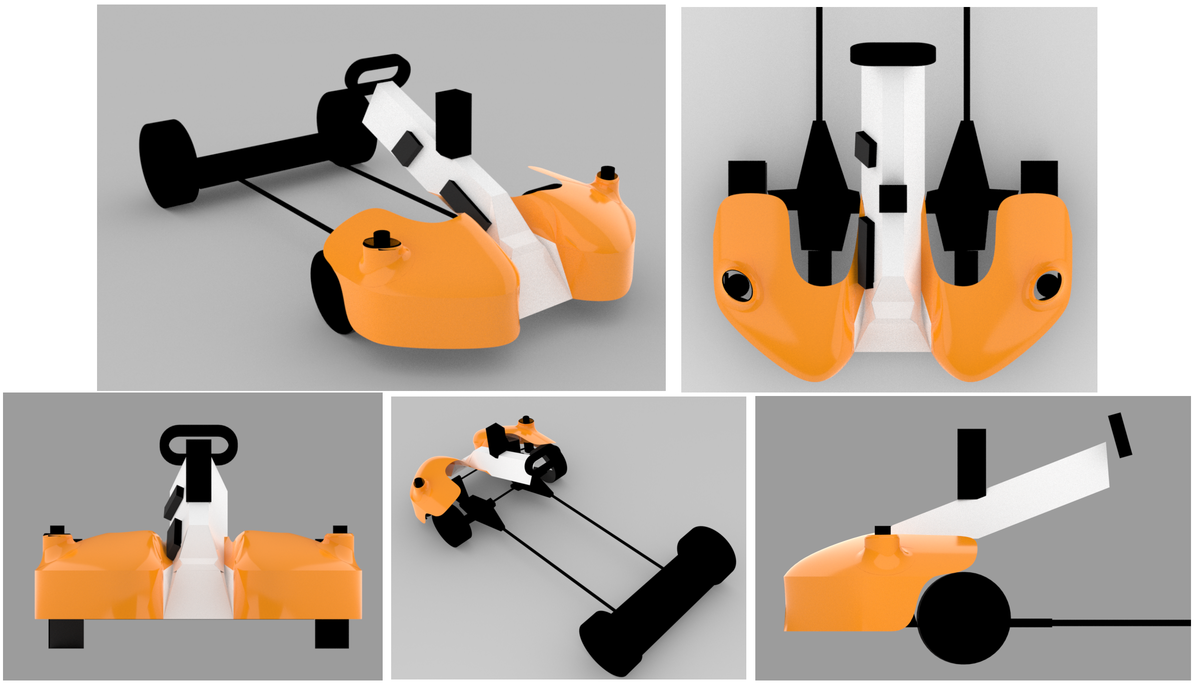

Figure 4.9: Gokart front created in Rhinoceros 3D

To encapsulate the added parts of the gokart, the model was created out of different sketches and curves which was the basis for the profile of the front. by using the different sketch- and sketch snapping tools the base of the curves could easily be produced at the same time as they were adapted to the dimensions of the existing chassis.

Out of the curves, the main surfaces were created. The bigger surfaces were connected and trimmed. Edges were smoothed out. Half of the model was built then the mirror tool was used to create the other side. The building process tested most of the common tools and basics of the program. When patching the two sides of the model together the surface continuity ability of the program was tested. This effort included testing more advanced tools and tool settings.

The final shape of the model can be explained by the nature of the tools of the program. Since no specific shape was sought, the model was built to as simple as possible to meet the design requirements of having a front fender that would wrap around the lidar sensors, continue the front, leave space for the pedals, and then meet the centre console.

4.6.1 Structure of the program

Rhinoceros 3D is an SMS primary developed and attended to use for surface modelling. There is a workbench for solid modelling, which enables the user to switch between the different modelling techniques easily and quickly in the same model. The program also has workbenches for mesh editing, rendering, and drafting. The program offers a high compatibility with a lot of file formats and other common CAD programs. The surfaces are built by curves, which are built with points or CVs (control vertices).

4.6.2 The interface

The interface is divided into several workbenches all for different purposes. The workbenches in turn consist of several tools. The structure of the interface makes it easy to navigate and find the required editing tools. A dialogue box at the top of the interface informs the user of how certain tools operate. The user can write shortcut commands in the box and the program will support the user's actions. This interaction supports both the effectiveness, efficiency, and engagement parts of the usability of the program.

4.6.3 History

The user can choose to create history saving by activating it in a small dialogue box (figure 4.10). History is then created between different events and edits in the model. Activation of history creation is a prerequisite for later being able to make parameterized changes to the model.

Figure 4.10: Toolbar with icon for activating history record.

4.6.4 Curvature and Surface continuity

Curvature or tangency can easily be created using setting in the tool dialogue boxes (figure 4.11).

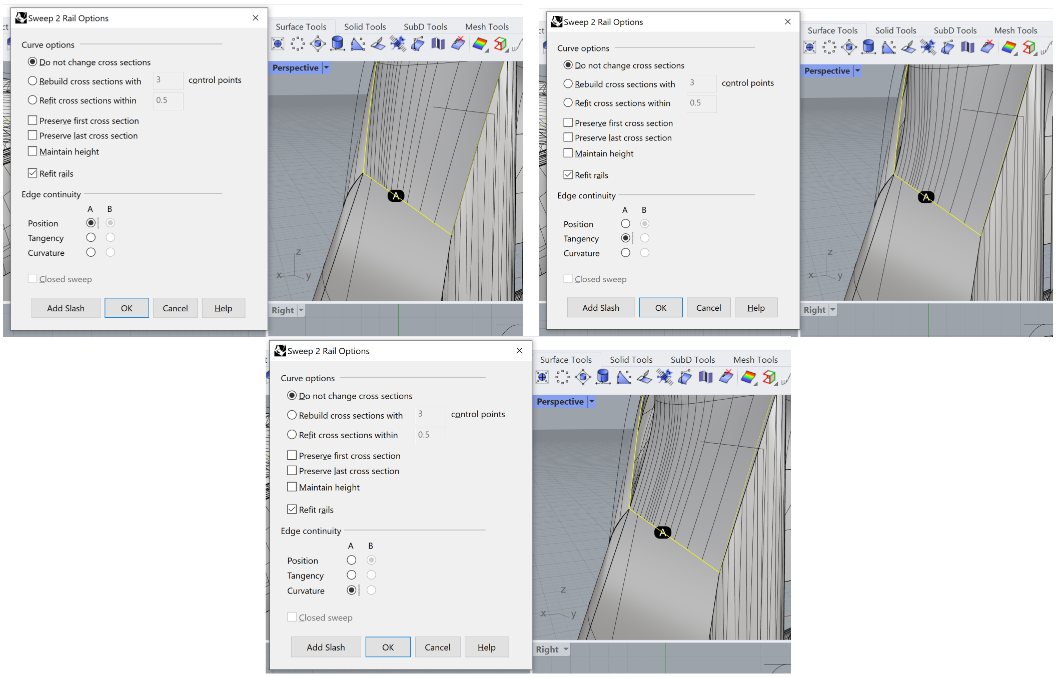

Figure 4.11: Example on how tangency or curvature can be chosen in tool settings.

Rhinoceros 3D has several different tools for analysing shape and continuity. The classic zebra pattern can be used to evaluate surface continuity (figure 4.12). The program also has tools for evaluating continuity, draft angles, and edges (figure 4.13).

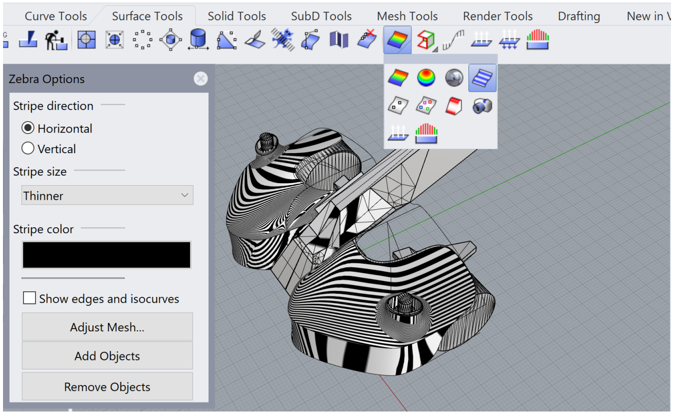

Figure 4.12: Zebra analysis tool.

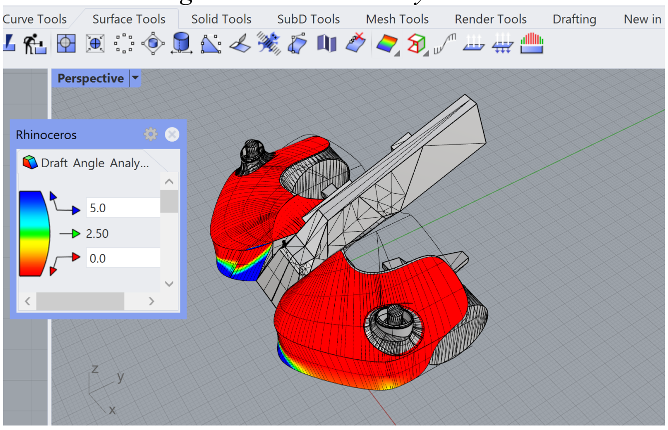

Figure 4.13: Draft angle analysis tool.

4.6.5 Create double curved surfaces

There are a few different tools that can be used to create double curved surfaces, depending on what kind on available in-data and desired result.

In the example below two, both double curved, surfaces are generated with surface continuity. Figure 4.14–4.18 illustrates the workflow.

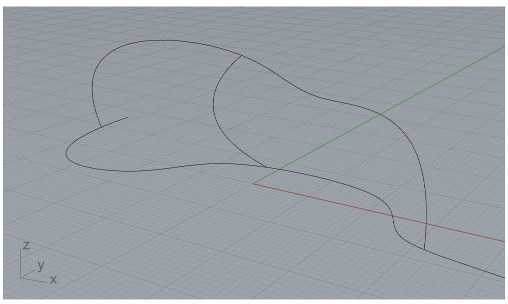

Figure 4.14: Three curves are generated.

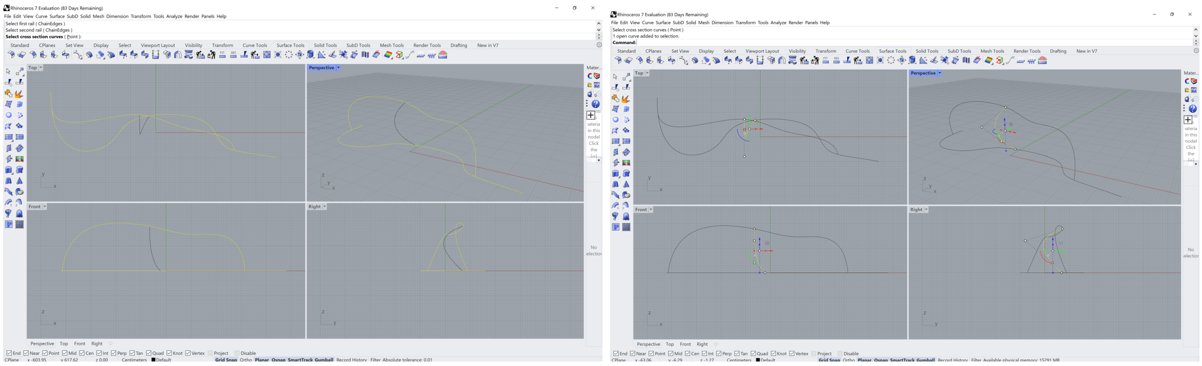

Figure 4.15: The tool Sweep 2 rails is chosen. The dialogue box instructs the user to select first, second and cross section rail.

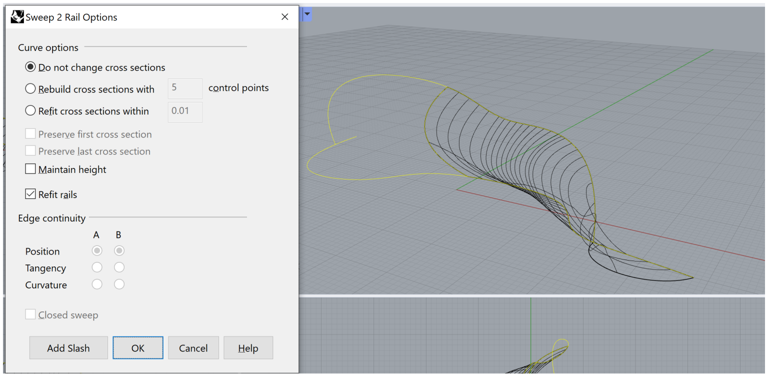

Figure 4.16: The first surface is generated. Surface settings can be made in the dialogue box before saving.

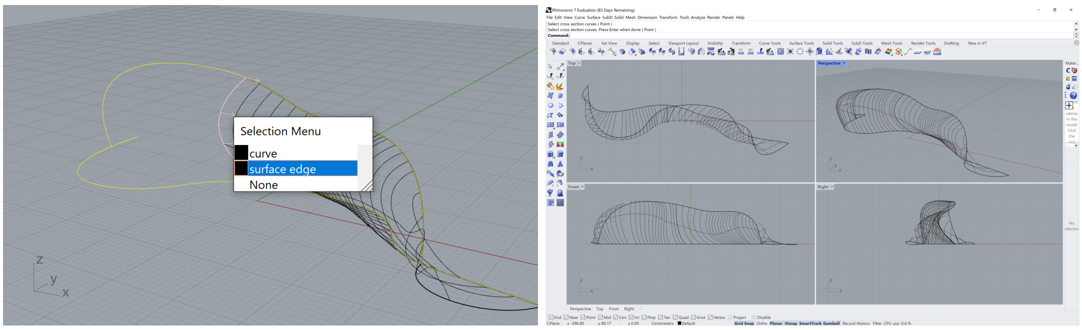

Figure 4.17: The second surface is made in the same way as the first, but this time the surface edge is chosen as interior section rail instead of the curve. In the setting dialogue box curvature is selected.

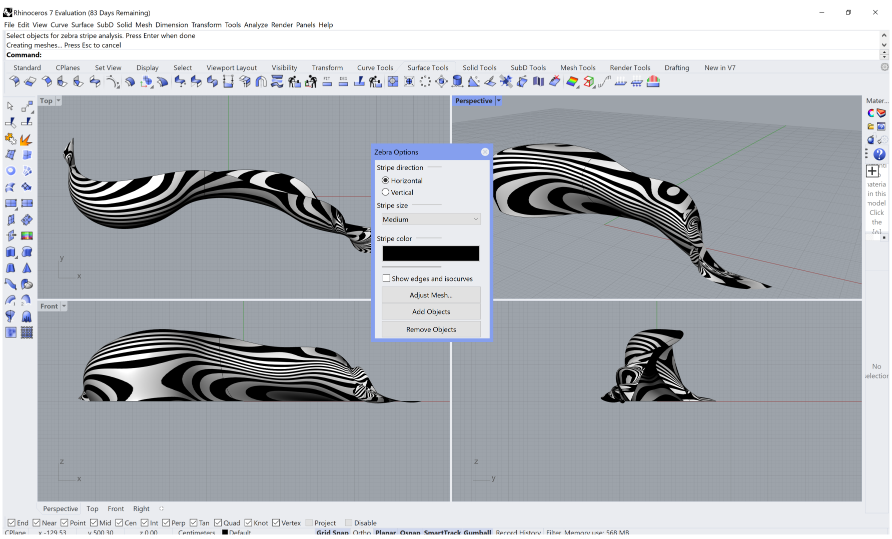

Figure 4.18: The surface continuity is then examined by using the zebra analysing tool.

4.6.6 Rendering studio

Rhinoceros 3D includes a rendering studio where material can be applied and light, background, and perspective can be set. The rendering studio comes with a default environment with standard background and lights. The user also chooses image size, format, and resolution after their preferences. In general, Rhinoceros 3D rendering studio is easy and effective to use and creates high-quality pictures. In the studio, the user can create their materials by using a few selected settings (figure 4.19). The materials are then easily applied to the model through drag and drop.

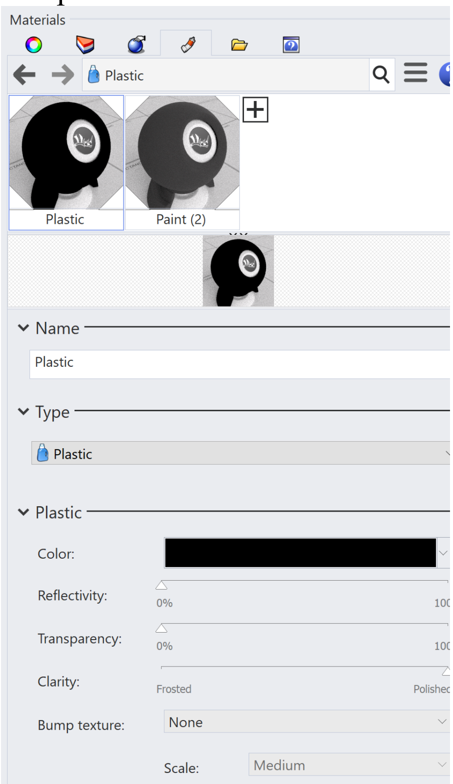

Figure 4.19: Tool for creating material appearance for plastic.

4.6.7 Program weaknesses

The program is not natively 3D parametric. It is possible to create some parts that are 3D parametric, but that require expert modelling skills. The program does not have the ability for creating generative design. To do so, the add on program Grasshopper needs to be used.

Require some basic experience in surface modelling to achieve highly accurate and complex models.

4.6.8 Usability in Rhinoceros 3D - Creating models

The surfaces are built by curves, which are built with CVs. The modelling process starts with creating a sketch using the workbench called "Curve tool".

Main category for tools that creates surface from sketch/curve: Revolve, rail, patch, extrude and loft. Additionally, there is tools for editing curves such as: extend, cut, divide existing surfaces and tools that creates blending's between curves.

Effectiveness
Rhinoceros 3D has over 10 ways to create surfaces. But the user has to know some background information about how to create surfaces out of curves, to generate the right in-data to the right tool. The SMS can be used for creating simple solid models without further solid model experience, but if more complex geometries are the goal, the SMS can create that accuracy as well. Accuracy requires proper knowledge from the user, otherwise, it will not help you.

Efficiency
Curves can easily be drawn in several dimensions. Various snapping tools are available to make it easier for the user to find already known points, curves, or other objects.

When you click on a tool, instructions for that specific tool appears in a dialogue box. This dialogue box tells the user exactly what input data that I required to perform the edit and in the right order. This makes it easy to avoid incorrect input data, which easily could lead to that the program does not perform what the user wants. It also leads to quickly learning and understanding the program.

There are snapping tools available that facilitate the creation of precise sketches or transform. This is easily activated through a toolbar at the bottom of the interface (figure 4.20).

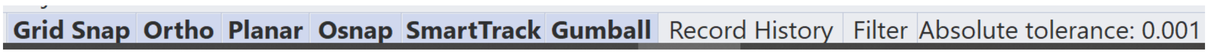

Figure 4.20: Available snapping tools in Rhinoceros 3D.

Ease of Learning
The dialogue box does not only facilitate efficiency, but it does speed up the process of learning how the program works. A small amount of knowledge or experience in surface modelling should help the user navigate the interface. Every tool has a symbol that vaguely shows its function. The name of the tool shows when hovering above the symbol.
If the user cannot find the wanted tool there is a search function available.

Error tolerance
Rhinoceros 3D requires precision using to work properly. If not, then it will create surfaces that are not as intended. Complex implementations such as trimming surfaces are based on that several previous steps in the modelling have being done correctly. The error tolerance, therefore, depends both on the type of tool and on how many possible mistakes the user might have made in previous steps.

Another example is if the user may have succeeded in creating two surfaces and think that these are joined and continuous. The user then wants to create a rounding that extends over both surfaces but fails. The program does not do as the user expects, nor is any helpful information given in the dialogue box as the program did not assume that something is wrong. Cases like this are due to the user's shortcomings but the tolerance of a tool could have been higher. The dialogue box should ensure that the user provides the correct input, but sometimes its description is not detailed enough to be interpreted correctly.

Engagement
Rhinoceros 3D is well suited for both digital prototyping and generation of production data. Complex surface models can be created with, and accuracy then converted to a solid model

and prepared for the next production step. These features facilitate for a user who works with example prototype production. For a less complex model the SMS may be too complicated.

4.6.9 Usability in Rhinoceros 3D – Editing models

Effectiveness
Surfaces are modified by editing the input data, the curve or sketch. There is no way to open the tool settings for a previously created surfaced. If history recording was activated when starting modelling, edits in the sketch will automatically follow to the surface, if it is still possible to create this surface based on the new curve.

Efficiency
A simple model with history between curves and surfaces is effectively manipulated. If history is created consists of several surfaces or if there is no history, the most flexible way is to remove the surface that needs to be changed. Sometimes the user may need to generate new curves or use a completely different tool to achieve the desired result.

Ease of Learning
Since edits in the model are made in the same way as the model was created, no additional learning process is required.

Error tolerance
Building surfaces is relatively a quick task, compared to editing surfaces. If a bigger change is to be made it will not be enough to edit the curve that the surface is based on. Due to the low error tolerance and require for accurate in-data of the tools, changes often require rework (deleting surfaces and generating new ones).

Engagement
Deleting and re-building surfaces can sometimes seem unnecessary, and the user does not understand why the program cannot implement a change. The rework can take time and be perceived as very cumbersome.

4.7 Alias Surface

The first reference program is Alias Surface. It comes in different variations from simple to more advanced: Concept, Surface and Autostudio. Surface is the middle variant, and it offers most of the functions to a smaller price than Autostudio. The three programs are otherwise similar, and anyone experienced in one of the programs, will know the other two well.

The result of the gokart body made in Alias Surface is shown in figure 4.21. The shape was meant to tightly encapsulate the components. There's space near the pedals for the feet. The centre-console is wrapped on the sides and meets the front continuously. Body panels would be separated with panel gaps later.

The model was made to have a front fender that would wrap around the lidar sensors, continue the front, leave space for the pedals, and then meet the centre console. This would then be mirrored on the other side and then the gap between the front fenders would be filled. This model would use Alias's common surfacing tools to make the front and centre and test the basics. The meeting between them would be a more complex part and would test how well Alias handles continuity.

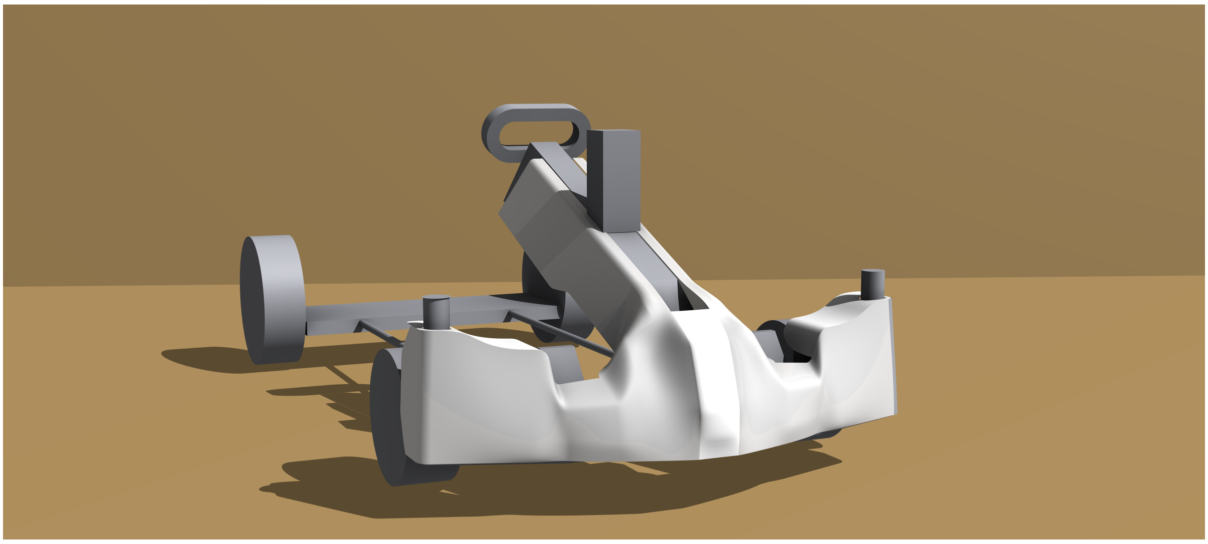

Figure 4.21: Gokart body made in Alias Surface.

Alias Surface does from version 2019 include generative design (Autodesk, 2021). It is called *Computational design* in Alias Surface's version of generative design. According to Design-engine (n.d.) Alias Surface is not parametric but has a more direct approach in designing.

Alias Surface is solely a surface modelling software and has no solid modelling capabilities. It does, however, offer a high compatibility with a lot of file formats and other common CAD programs (for example Catia V5). The surfaces are built with curves, which are built with points (CVs). Figure 4.22 shows curves with their CVs. The rail tool is an example of a common way to create a surface. Figure 4.23 shows how to build a surface with rails. In this case, the generation curves have run along the rail curve to create a two-dimensional surface.

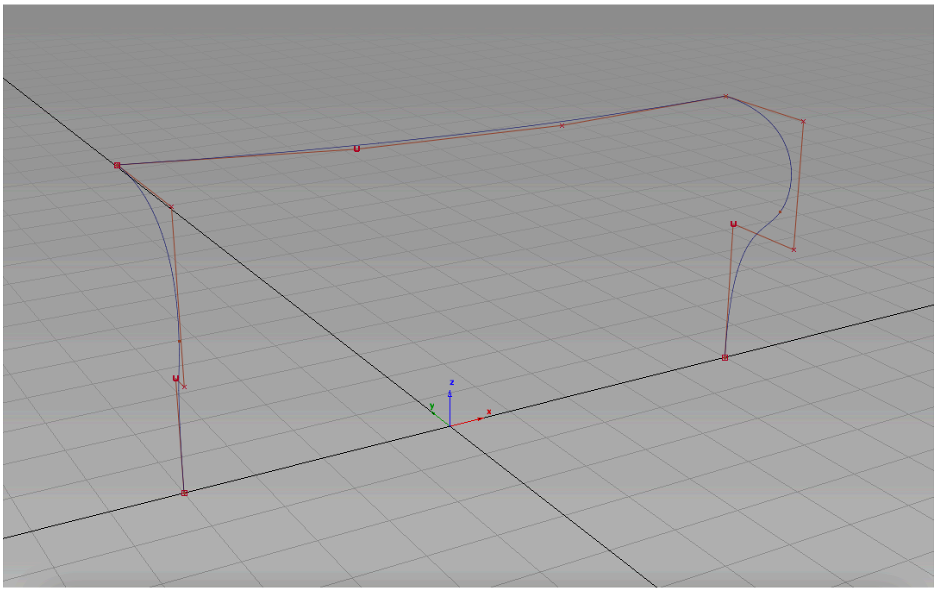

Figure 4.22: Curves in Alias Surface with CVs.

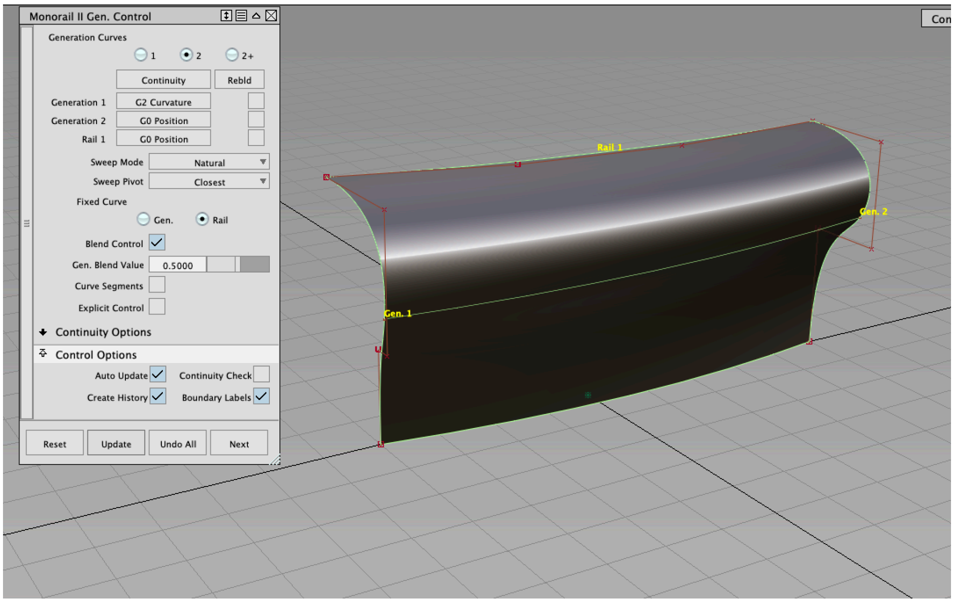

Figure 4.23: Building a surface with the rail tool in Alias Surface.

4.7.1 Creation of History in Alias Surface

Alias Surface does not have a traditional history tree like other programs where each action is showed in a specific order. Instead, each object is infused with its history. In figure 4.24 another surface has been made based on the previous surface.

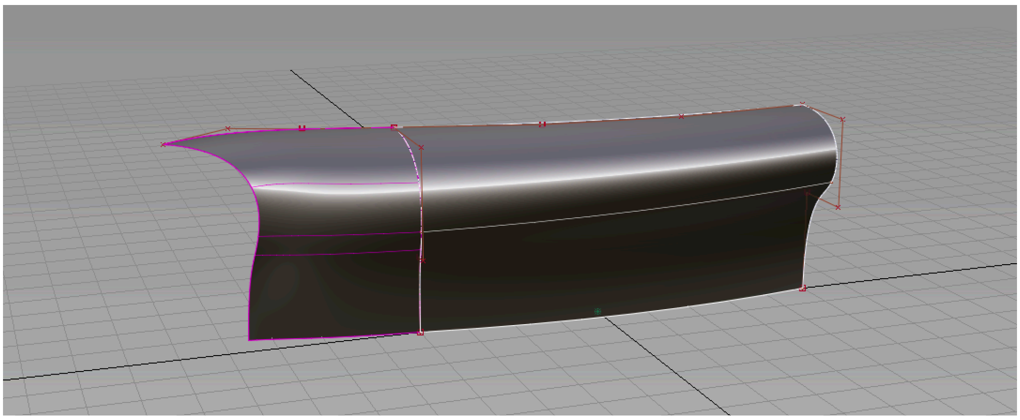

Figure 4.24. Surface in white is the original surface and surface in purple is dependent on the original surface.

The first surface (to the right, which is marked with white lines) is now selected. The new surface to the left is not selected but it is marked with purple to show that it has history with the original surface. Changing the original surface will also change the new surface. This is shown in figure 4.25.

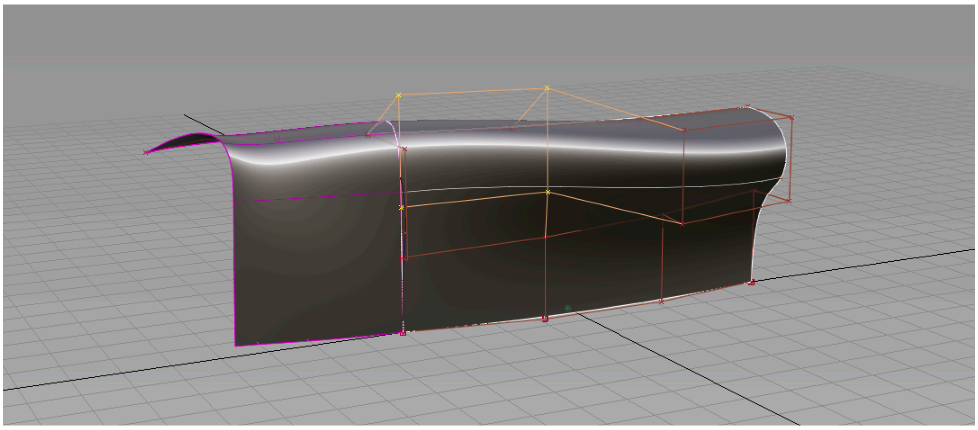

Figure 4.25. The original (white) surface has been modified and the new (purple) surface has changed with it.

The history can be removed if the new surface is moved. This (figure 4.26) will then warn you and confirm your action.

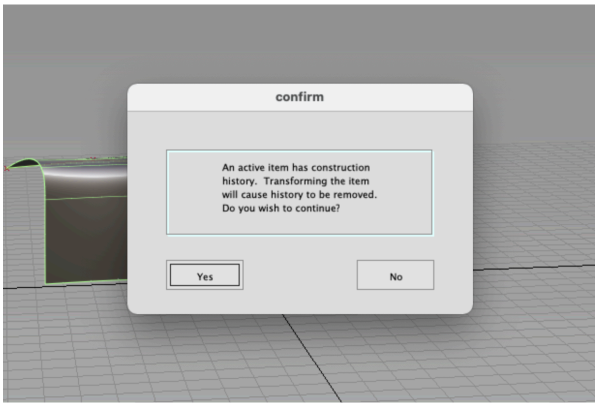

Figure 4.26. The warning dialog when history is about to be removed.

4.7.2 Program Weaknesses

Alias Surface is a highly advanced SMS. This means that it is capable of the most sophisticated models, but it also requires a lot of knowledge to achieve the desired outcome. This is noticeable in the rendering studio. Alias Surface's rendering is made of shaders that the user configures themselves. This means that the user must adjust many settings to get a shader correct instead of other SMSs like fusion where there are preselected shaders for metals, plastics etc.

4.7.3 Usability in Alias Surface – Creating

As previously mentioned, Alias Surface is an advanced SMS for skilled users. For new users this program will seem confusing and not let the beginner do what they want. This SMS will demand precise modelling to complete the model and will also offer the necessary tools to do so.

Effectiveness

Alias Surface has over 15 ways to create surfaces, many unique and some that does the same thing differently. If the user should complete something accurately, the user must know what tool to use. In other words, Alias Surface is a fully accurate SMS but without proper knowledge it will not help you.

Efficiency
Building a surface is a quick task since it mostly requires selecting a few objects and a minor adjustment. There is a click wheel with access to shortcuts when picking objects and transforming objects (figure 4.27) which allows for fast modelling. But what does take time is the preparatory work when building the curves. It is the curves that define most of the model so those must be good for a good model. So, the curves must be carefully built and then analyzed, so the final model is well built. This means that it takes a long time to complete the tasks.

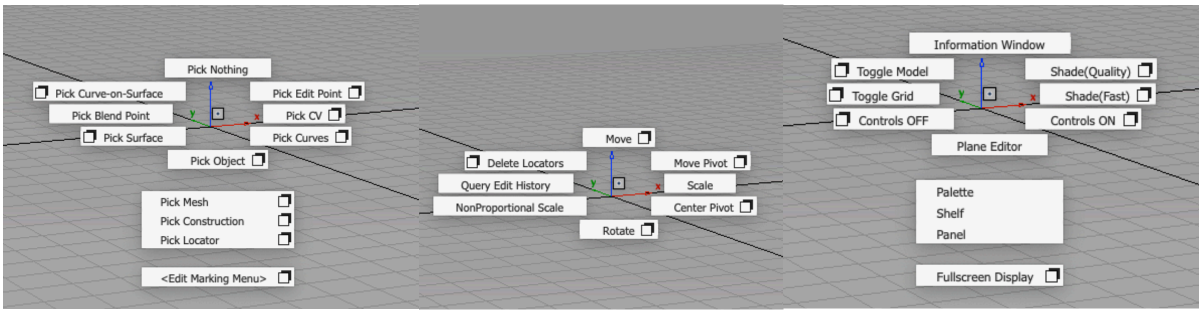

Figure 4.27. The click wheel shortcuts in Alias Surface.

Engagement
Alias Surface is well suited for the industry. The program is for example used by Volvo for creating both car design and visualisation material (Business Wire, 2012). If the user is doing a complex model, Alias Surface will be pleasant to use since it can offer many advanced tools but for a simple model it may be too complicated.

Error Tolerance
Alias Surface requires precision using to work properly. If not, then it will create bad surfaces that are disformed and not as intended. For example, when curves are not aligned properly or are too advanced the surfaces will be bad. There is a dialogue window at the top which tells the user what is needed or what is wrong. A problem with this dialogue, is that the text is only there for a period and then disappears. This makes finding out what went wrong difficult and requires more time to read and understand the error.

Ease of Learning
Users experienced in, or with knowledge of surface modelling would be able to navigate the interface. Every tool has a symbol that vaguely shows its function along with a descriptive text. This text shows when hovering above the tool for a short time then disappears. For a user to read and understand the text, they will need to make the text reappear.

4.7.4 Usability in Alias Surface – Editing
Changing a surface in Alias Surface can be done by changing the curve that created it. This, of course, means that the history still needs to be active. Another way is to use the tool Query edit. This lets the user select a surface and then the dialogue window from when it was created reappears. The user can now change settings and in some cases reverse the action.

Effectiveness
Thanks to the Query edit, surfaces can be changed accurately to a certain degree. Settings when the surface was made can be changed but often this is not enough, and the surface need to be deleted and remade.

Efficiency
Query edit can be found in the click wheel which allows for extremely fast editing. If Query edit does not work, it takes more time to edit and often the surface needs to be remade.

Engagement
When Query edit is not enough, manual editing is required which is not as precise and can be more time consuming. It means deleting surfaces and curves and building new ones which makes the experience tedious.

Error Tolerance
Manual editing is often required when Alias Surface does not keep the history on objects. Manual editing means deleting existing objects and starting over which is time consuming.

Ease of Learning
New users may find the history difficult to understand. Alias Surface does sometimes warn the user when history is about to be removed. The Query edit tool is not obvious as it is hidden with the other tools which will make it hard for a new user.

4.8 Catia V5

Catia V5 is a CAD program that is mainly for solid modelling with many add-on configurations. One of which is the Generative shape design (GSD), which is what is used here. GSD contains surface modelling capabilities. Catia V5 requires detailed modelling meaning that it needs a lot of groundwork to eventually build surfaces. Otherwise, GSD offers many powerful tools for surface building and editing.

The gokart body made in Catia V5 is seen in figure 4.28. This model was made to have the front fender run along the front with panels on the centre console meeting the front continuously. Catia V5 was a time-consuming program which limited the design which is why the front is made from one part and the centre as well. The design is therefore a simple one with few details since it was hard to implement details in such a complex SMS.

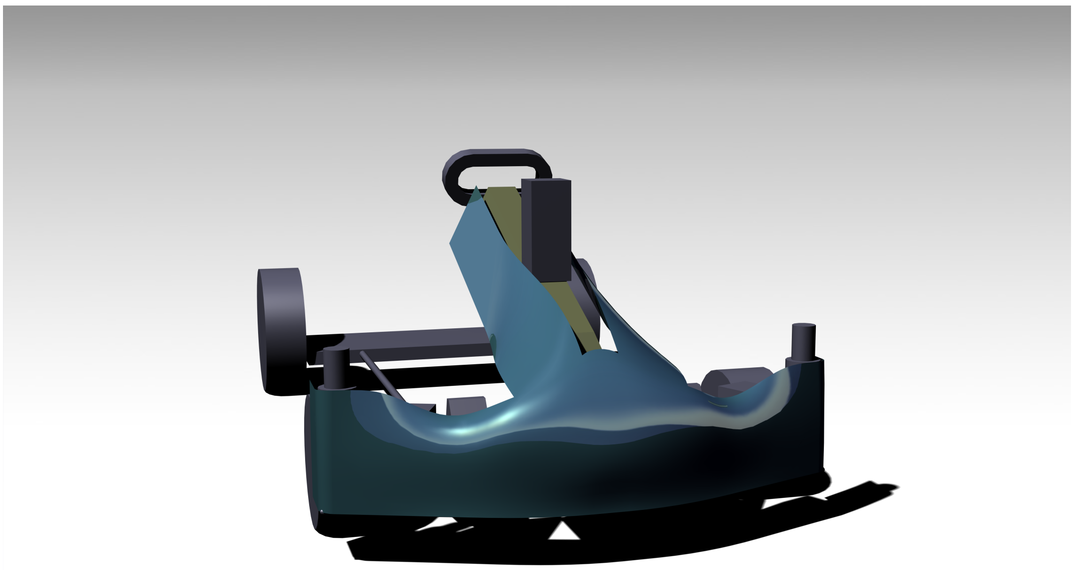

Figure 4.28: Gokart body made in Catia V5

Catia V5 does have generative design in the form of Function driven generative design (Inflow, n.d.). The program is also parametric since it is using a history tree.

4.8.1 History in Catia V5

Catia V5 automatically creates a *history tree*, which shows the entire history of the model. Nothing disappears from this tree, so everything is always editable. This is helpful if you need to change something from the beginning. Catia V5 will then recalculate with the latest data to update the model.

4.8.2 Surface Continuity

There are different ways to create surface continuity in Catia V5. Most of the times it requires support surfaces. For example, when using the Blend tool select two edges with respective support surfaces (figure 4.29). In this example to create the red surface, the edge on the blue and yellow are selected with the respective surface as a support to create surface continuity.

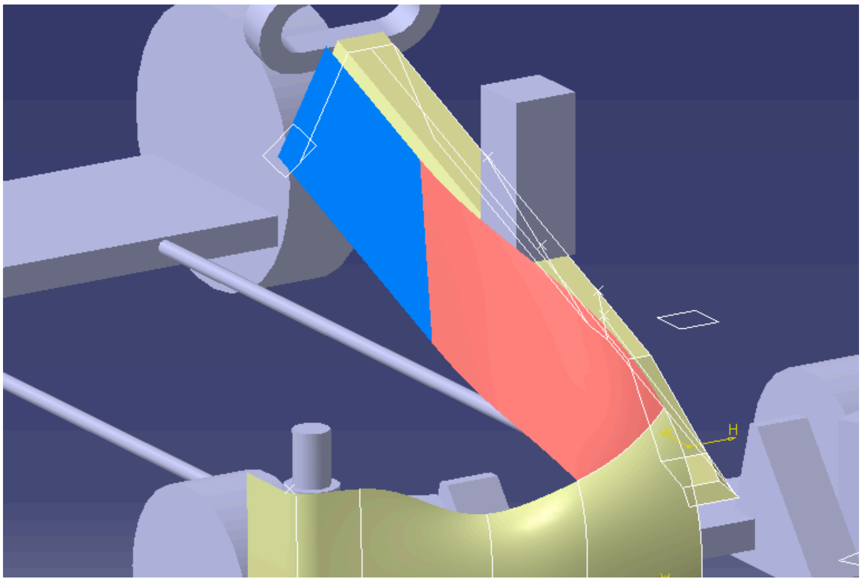

Figure 4.29: Example of surface continuity in Catia V5.

4.8.3 Usability in Catia V5 – Creating

Effectiveness

Catia V5's tools are very precise in that they offer (and sometimes demand) specific settings. For a user who understands these settings it will let the user create a very precise model, otherwise it will hinder the user.

Efficiency

Creating a surface in Catia V5 takes some time. For a multi-section surface, it takes several steps before the surface can be made. First, the guide curve is made (figure 4.30). Secondly, points are placed on the curve (figure 4.31) to create a plane on which to sketch the sections. Then the section-curves are made, and the surface can be made (figure 4.32-4.33). All in all, this is a lot of steps to create a single surface which can be time consuming. But arguably, this type of precision can be helpful later in the process.

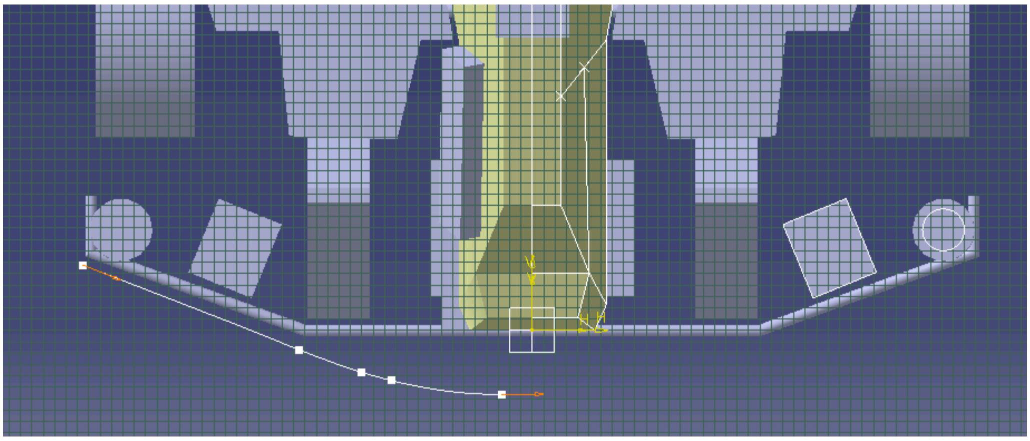

Figure 4.30. Creating a guide curve in Catia V5.

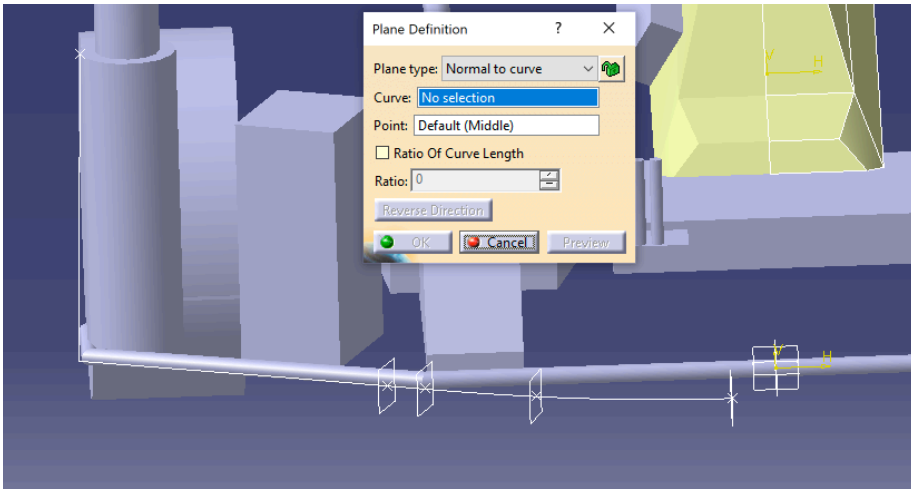

Figure 4.31. Creating points and planes on the guide curve in Catia V5.

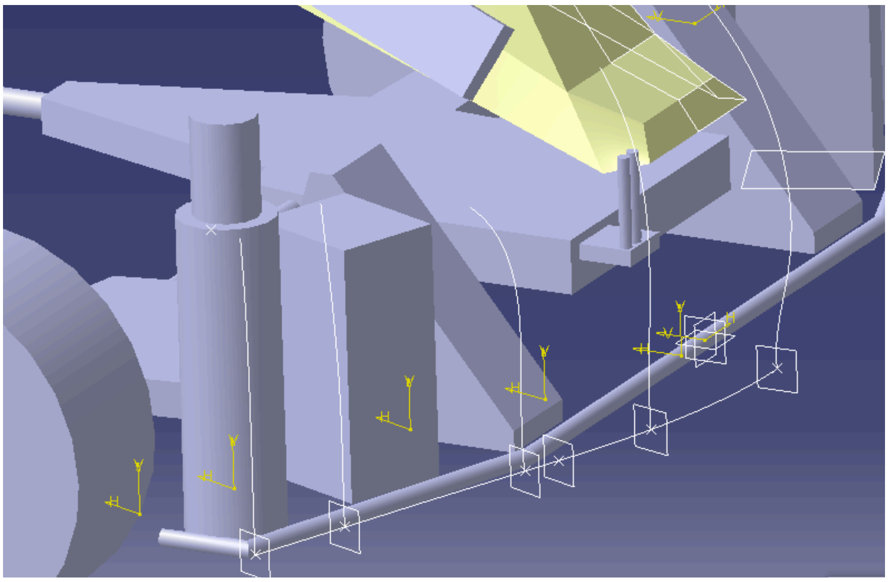

Figure 4.32. Creating section curves in Catia V5.

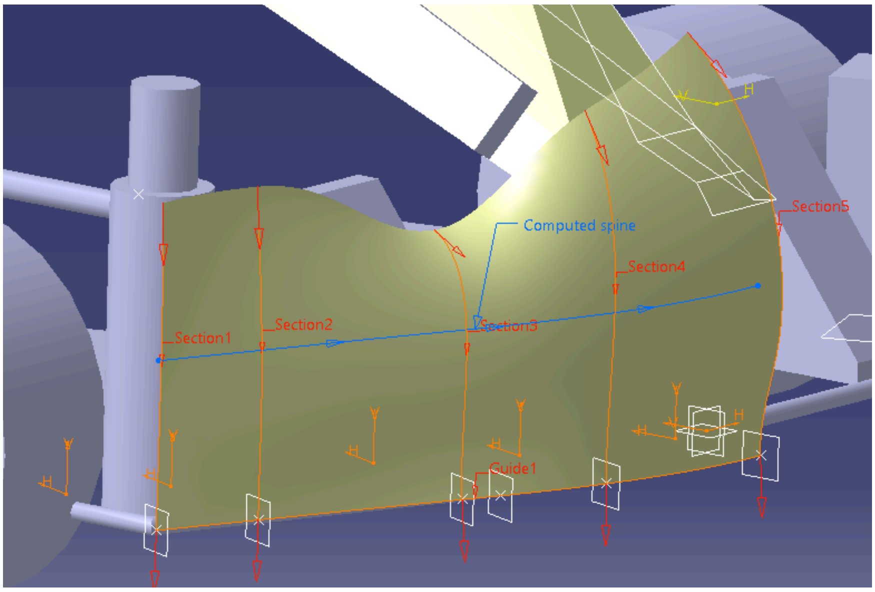

Figure 4.33: Creating the multi-section surface in Catia V5.

Engagement
Catia V5 does make smooth surfaces when they are properly done. When the preporatory is done, Catia V5 will do the rest of the job and create good surfaces.

Error Tolerance
As previously mentioned, Catia V5 requires precise modelling and many times advanced settings to create surfaces. This means that it does not tolerate much error from the user.

Ease of Learning
New users will find it hard to use Catia V5. There are multiple reasons, for example, the interface is old which doesn't appeal to new users but are better for experienced users. Tools are not named like in other SMSs (Pad instead of Extrude). Another reason is that every tool needs precise settings to function properly. A new user will not know the exact settings.

4.8.4 Usability in Catia V5 – Editing
Thanks to Catia V5's history tree, editing is easy. It works like a programming code: It reads the first command and continues to the end. If an edit does not interfere with later commands, Catia V5 will simply update the model.

Effectiveness
Catia V5 lets the user edit everything accurately. The user can enter a previous command and change the settings and the model will then be updated.

Efficiency
Editing a model is as quick and easy since the user only must find the command in the history tree or double-clicking on it in the model. What can be difficult is that sometimes commands are imbedded in other commands in the history tree.

Engagement
Catia V5's editing style is suitable for precise modelers who work with parametric design. It is also good for users who just want to manually adjust a curve.

Error Tolerance
When editing a surface, the user must not interfere with later commands. Catia V5 shows a dialogue-window with the error(s) and an Edit-button to automatically go to where the error appears.

4.9 Summary of the SMS analysis

In this chapter, the results from evaluating the four SMSs are presented. The result is presented in form of two matrices, including technical specification about the programs and a usability summary.

4.9.1 Technical specification

In table 4.4 an overview of the technical specification in the program is presented. The details about each program can be read under the program evaluation.

The creation of history and program structure is included in the matrix since this is where the biggest differences between the programs are. Other technical aspects such as creation of surface continuity, snapping tools and shortcuts are included in the matrix because this is commonly performed actions and wanted tools.

Table 4.4: Chart over technical features.

		Alias	CATIA	Rhinoceros 3D	Fusion360
General Informaion	Intended for	Advanced surface modeling	Advanced surface and solid modeling (manufacturing, analysis etc)	Advanced surface modeling, as well as basic solid modeling	Rapid modeling, both surface and solid.
	Solid modeling possible	No	Yes	Yes	Yes
	Manufacturing preparation possible	Yes	Yes	Yes	No
	Rendering studio	Yes	Yes	Yes	Yes
	General comment	Suitable for advanced surface modelling of complex geometries and products (for example, cars). Products with high demands on surfaces and models for further production/manufacturing.	Suitable option if there is a need to implement both high-level surface and solid modelling.	Suitable for surface modelling of less-middle complex geometries and products (for example, electrical kitchen tools). Less complex industrial design, models for visualisation and 3D sketching.	Mainly suitable for solid modelling with the ability to create/edit single surfaces as a surface object. Possible (but not optimal) to create surface models.
Technical modeling specefication	History	History is infused in objects which may be removed	Complete editable history tree	User can choose to enable history saving.	All edits in the model are shown in chronological order on display. The program creates historical connections automatically between most events.
	Structure	Open structure	Tree strucutre	Open structure	Tree structure, all parts of the model appears on the display on display
	Surface cotinuity and Curvature	Curves and surfaces can be modified to create curvature	Easliy created with support surfaces	Can easily be created by setting up surface-creating tools.	Possible but difficoult do create, due to the lack of tool settings.
	Double-curved surfaces	Easy to create.	Possible to create	Easy to create.	Possible to create
	Tools for evaluating surface continuity	Yes	Yes	Yes	Yes
	Sketch snapping tools	Yes	Yes, but requires more input	Yes	No
	Shortcuts	Click wheel	No	Yes	No
	Generative Design	Yes	Yes	No. Possible with the add on programe Rhinoceroes Grashopper.	No
	Parametric	Partly	Yes	The program is not natively 3D parametric.	No

4.9.2 Usability

The usability of the SMSs has previously in this study been examined on a basic level by doing the MC-tank. After modelling the gokart, an additive usability grading was done, performed in the same way, based on the five criteria for usability. This time there was more information and experience to base the decision on and set the assessments in the form of numbers, which explains the minor differences between the results of the two times, see table 4.5.

Table 4.5: Summary over Usability evaluation

	Alias	CATIA	Rhinoceros 3D	Fusion360			
Effectiveness	5	5	4	1		very low	1
Efficiency	2	1	4	2			2
Ease of Learning	2	1	3	5			3
Error Tolerance	3	3	3	1			4
Engagement	5	5	2	1		very high	5
	17	15	16	10			

Alias Surface and Rhinoceros 3D scores the highest number, the best result, in usability. There is, however, a difference between the distribution of the score. Alias Surface scores high when it comes to *Effectiveness* and *Engagement* but lower when it comes to ease of learning. A high score in *Effectiveness* means that the SMS supports users in completing actions accurately. A high score in *Engagement* means that the user finds it pleasant to use. This applies to more experienced modellers or users with experience in the program since Alias Surface is a complex program that takes time to learn. Thereof the low scores for *Ease of learning*.

Rhinoceros 3D scores quite high on *Effectiveness* as well, but exceptionally low on *Engagement*. Furthermore, the *Efficiency* is relatively high. The *Ease of learning* is slightly higher in Rhinoceros 3D than in Alias Surface. This means that the program is easier to learn, compared to Alias Surface.

The SMS supports users in completing actions accurately at a high level, but not as good as Alias Surface. The high score for *Efficiency* means that the user can perform tasks quickly through the easiest process, this applies to more modelling of more simple geometries. The low score in *Engagement* is based on the difficulty of creating complex models. Compared to Alias Surface where the program sets no limits for what is possible by having a variety of special tools, Rhinoceros 3D has fewer tools and settings available. This makes it more complicated to modelling specific complex geometries and the user must think of a plan to be able to create their desired result if it is even possible. The lack of specified tools makes the modelling process time-consuming and sometimes unnecessarily difficult. In turn, the smaller number of settings and tools makes the process of learning the program much easier and is a contributing factor to *Efficiency* having a high score.

5. Discussion

This chapter discusses the author's bias, the impact of the case application, the sustainability aspects on the thesis, ethical perspective of the thesis.

5.1 Formulation of the problem statement

The problem statement has been altered during the project, partly due to the project itself changing but also to fit the result more appropriately. Therefore, the formulation is suitable since it follows the result of the project and not the other way around.
The problem statements are formulated in an open but at the same time limited way. This is necessary to be able to answer it.

5.2 The impact of the exercises

The MC-tank (figure 4.1) exercise was used to evaluate the ability of creating surfaces out of curves in the SMSs. The geometry of the tank is so simple that the influence of the product becomes non-existent on the result.

The citrus press (figure 4.2) is a slightly more complex product. The use of this exercise might have influenced the result but since the exercise is developed for a course in surface modeling at Chalmers University of Technology, a surface modeling software should be able to perform it.

5.3 The authors skills and Authors' bias

One factor that most possibly influence the evaluation result is the authors own modelling ability and previous experience in solid modelling programs. Experience in any SMS may subconsciously have influenced that program's rating in the evaluation. To avoid this, clear structures throughout the work process and not setting grades based on pure intuition was implemented.

5.4 The impact of the company

The company has not contributed with any extensive list of requirements connected the thesis. The company's biggest impact on the project is the case application they provide, the gokart. Since the company only had a few design requirements connected to the gokart, the impact of the company relatively the thesis is exceptionally low.

5.5 Different application instead of the gokart

The impact of the gokart case application cannot be ruled out. Neither the exercises used in the early stages of the study. If another product or if several products of different nature had been used, other geometries might have had to be created. This might have turned out to be beneficial for other programs which might have given a different result.

Cars are one complex product that is modelled using surface modelling. That made the gokart case relevant in some way to evaluate the programs from an industrial viewpoint.

5.6 Sustainability

Since this thesis is about digital programs for surface modelling it is not relevant to investigate sustainability in the same terms as a physical product. Instead of investigating the effects of material use and disposition, it is in this thesis more relevant to evaluate the economical sustainability aspect and the possible energy consumption caused by the computers that are used when modelling and the energy needed for the storage of digital files.

The sustainable contribution of this thesis includes knowledge and guidance that helps modelers', product developers or designers to find the SMS that is best suitable for their specific situation. This includes the users' financial conditions, the wish of integration with other programs and the requirements set by the task itself. Working with the right modelling program is not only decisive for obtaining the desired result. It is also important for creating as good working conditions for the user as possible.

5.6.1 More sustainable iterative product developing process

Using digital prototyping instead of physical contributes to a more sustainable product development process in many ways. Without any physical model, there is no use of any kind of material, which reduces environmental impact. The digital model is also easier to manipulate, and changes do not require as much time as if they were to be made in a physical model. Cutting time in a project often leads to reduced costs. The cost for the model itself is eliminated. Making the digital model or prototype requires a program that often is accessed by a costly license. This cost might be higher than the price of developing a physical model but are in most cases split over many projects. In that case, a physical model is used, the model, later, needs to be converted to a digital model in order to create manufacturing data.

The use of digital models contributes to more effective collaboration between modelers and companies. Effective workflows are created by the ease of sharing information (models) which in turn saves both time and money.

Digital testing and simulations using 3D models are not only effective in terms of saving time and money. The technology also makes it possible to simulate material properties and manufacturing processes, that can be used when developing environmentally sustainable products.

5.6.2 Cloud based computing

Fusion 360 is a program that offers cloud-based rendering, meaning that the calculations are done by servers somewhere else. According to Molitch-Hou (2019), cloud-based computing can be more efficient than local based, primarily for large companies. He also states that by relying on cloud computing, a business could improve its energy efficiency by 22 to 93%. There are other services that offer cloud computing as an independent service. Chaos is a company that offers a service called Chaos Cloud (Chaos, 2021) that Rhinoceros 3D users can utilize.

An increase in cloud computing could therefore result in more efficient energy consumption, but there is a thing called Jevons Paradox which means "Efficiency gains contribute to increasing production and consumption which increases the extraction of resources and the generation of wastes" (Uneven Earth, 2020). Greenpeace (2017) showed an example in a report about streaming services, that when cloud computing costs next to nothing, consumption increased significantly. So, cloud computing can be more efficient for CAD, but it should not be used in abundance.

5.6.3 Usability and social sustainability

This thesis evaluates usability in SMSs. A better usability will help the user in their work by making it easier and better. This means that better usability will make life easier for the users, and inherently more sustainable.

5.6.4 Economical sustainability

Many licenses on today's market are purchased monthly. The user usually gets a more favourable price per month if signed up to buy for a longer period. Some licenses are linked to personal user accounts, but there are several different business solutions where the company can share licenses and get discounted prices if several different software licenses are purchased. This business model and cost structure that the supplying software company has helps companies tailoring a solution that matches their needs and avoids unnecessarily huge licensing costs. Compare with expensive one-time purchases that require a lot of usages to be profitable, this is a much more economically sustainable solution.

Offering a trial period is common in software industries. It lets the user try the program before purchasing. This means that a company does not have to spend money on a large investment, just to realize the program does not suit them.

5.7 Ethics

There are four questions one can ask themselves to explore the ethical impact a project has (Chalmers, 2021).

- *What ethical aspects are relevant for the project? How can we implement our project to avoid ethical problems with our method?*
- *What could be of use or cause ethical problems with the expected result which should be considered?*
- *Who is affected by the implementation or result of the project? How are they affected? Are there ethical problems connected to this that should be considered?*

In the end, one could either decide to terminate the project, continue because the pros outweigh the cons or change the project (De Fine Licht, 2019).

This project does not develop a product or service, it is a research project which seeks to find a suitable SMS for a small to medium-sized company. The project itself does not raise ethical questions, but there are known ethical issues in software. Lawton (2020) lists five common ethical issues in software as:

- *Addictive design*
- *Personal data storage*
- *Algorithmic bias*
- *Vulnerable personal information*
- *Overemphasis on features*

Most of these are not relevant to CAD industries, except perhaps the last one. For example, according to Lawton, if development is measured by the number of features it produces, ethical issues of those features are not likely to be prioritized. But then again, it is hard to imagine this being relevant in the result of the project.

This project could consider ethical factors when evaluating and eliminating SMSs, like how their business model is designed. Unfortunately, it is not something companies show.

The result that will likely be a chosen SMS, could have bad or good ethical attributes. Since it is hard to determine, it cannot be part of this project.

The most affected is the case company since they will use the research directly. The most affected partner is the case company since they will use the research directly and eventually base their decisions on this study. It is unlikely that overemphasis on features will be relevant. This research project will be used to choose SMSs based on technological features and well-defined usability factors. Ethical attributes are not considered since they are too difficult to find.

5.8 Actuality of thesis

The thesis is based on current information about the SMSs on today's market. The market variety can change a lot in a short period, since the supplying companies constantly work on developing their products. This is exceedingly difficult to avoid since it is impossible to predict how the market supply will develop over time.

5.9 Would the result be affected if the same geometry were created in the different SMS?

The purpose of using the case application was to simulate how the SMS could be used in a real industrial project. The goal was not to achieve the best possible design. Rather on creating shapes as flexible as possible, using the program. It is not possible to rule out that there would be a different result if the same form had been sought for all models. The risk, on the other hand, could be that the authors' bias had played a greater role. This since they inevitably could be more familiar with an SMS and in advance know how to create a specific form.

6. Conclusion

Today's market of surface modelling software's (SMS) is vast and offers a wide variety in price, capability, and usability. This thesis has done a market research to examine what differs in what the market offers. Following are the problem statements.

- *What does the range of SMS on today's market look like? And what differs between the software's on a more comprehensive level (example license cost, hardware requirements)?*

The overviewing matrices facilitate for the reader to create an understanding of the current market supply of SMSs. This overview includes information about basic functions, price, type of licenses and summarizes the biggest similarities and differences between the SMS on an informational level.

- *How can a usability evaluation be structured to evaluate SMS?*

To evaluate usability, a case project was used to test a few selected SMSs. The SMS were rated on how well they performed in the five different criteria of usability: *effectiveness, efficiency, engagement, error tolerance and ease of learning*.

- *What distinguishes programs in terms of how well they meet different parts of the usability criteria?*

The summary over how well usability criteria fulfils and technical differences between SMS provides the reader with further information about a smaller amount of SMS. The associated evaluation offers a more analytic investigation in usability, both for creating and editing models in Rhinoceros 3D, Catia V5, Alias Surface and Fusion 360.

The compilation provides the reader with an idea of the program's technical weaknesses/strengths and how well they meet the usability criteria and can under the right circumstances act as a tool when choosing software.

It should be emphasized that only SMSs that are free of charge or offers free trials have been evaluated in the in-depth evaluation and that this limits the use of the results. A program recommendation must always be adapted to the situation based on several different aspects and circumstances. The work is therefore not able to unequivocally recommend any SMS. The reader is left to decide for themselves which program is the best option for their current situation.

7. Future work

This chapter presents example what could be studied further on.

7.1 Is there a program that manages to perform both solid and surface modelling at a basic level?

This study evaluated some SMSs that was workbenches for both solid and surface modelling. Most of the programs were eliminated in the early stages of the study since the workbench for surface modelling appeared to be too simple and have too few tools to be able to create complete surface models. A further recommendation is to test solid modelling in order to evaluate at what level the SMS can create solid models. This may be interesting information for companies that need software for both solid and surface modelling.

7.2 Free SMS at the market that is good enough for industrial usage?

The only free SMS who underwent the evaluation study was Blender. The SMS were discarded in the Evaluation matrix (table 4.3) since the program made it past the first elimination matrix (table 4.2) is possible to create surfaces out of curves in Blender. This makes it possible to use the program for less complex surface modelling. This study did not examine the limitations specifically in Blender, so the exact limits for what the program can handle is unknown. This is a recommendation for further studies to evaluate. Since it might be interesting to know if there is any free tool on today's market that can be used for industrial use.

7.3 Evaluation of programs without free trial version

Since only those SMSs with a trial version of student-license could be evaluated, a lot of SMSs were not tested. For a more complete evaluation of today's SMSs, those without a trial period should be evaluated as well.

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Appendix

Appendix A – Selection Matrix

Tool	Main area of work	Cost				Usability					Support		System requirements					Functions	
		Demo-version available	License cost	One-time purchase	License structure	Effectiveness*	Efficiency *	Engagement *	Error Tolerance *	Ease of Learning *	Tutorials availability	Certificate	OS	CPU	GPU	RAM	Disk space	Rendering studio	3D-printing
Alias Autostudio	Surface modeling	Unavailable	$1195-1291/month	-	Stand-alone single-user license	4	2	4	2	3	Tutorials available from Autodesk	Available	Windows 10 & 8.1 (ej Windows 7)	2 GHz	8 - 16 GB	min 256 MB	10 GB	Available	Requires additional program
Alias Surface	Ytmodellering: industrial design software	Available	$695-1160/month	-	Stand-alone single-user license	4	2	4	2	3	Tutorials available from Autodesk. Autodesk community, support.	Available	Windows 10 & 8.1 (ej Windows 7)	2 GHz	9 - 16 GB	min 256 MB	5 GB	Unavailable	Requires additional program
Alias Concept	Product design software for sketching, concept modeling, surfacing, visualization	Available	$334-555/month	-	Stand-alone single-user license	4	2	4	2	3	Tutorials available from Autodesk. Autodesk community, support.	Available	Windows 10 & 8.1 (ej Windows 7)	2 GHz	10 - 16 GB	min 256 MB	7 GB	Available	Requires additional program
Blender	Surface modeling, animation, rendering	N/A	Free	N/A	-	2	2	1	3	2	Tutorials, community support	N/A	Windows 10, 8, 7 Linux macOS 10.13+	2 GHz	4 - 32 GB	1 GB	165 MB	Available	Possible with additional program
Catia V5	Solid modeling, calculations, surface modeling	N/A	-	-	Shared license, single user	2	2	3	1	2	Support forum, tutorials, training, e-learning	Available	Windows 10, 7	2.7 GHz	4 - 8 GB	Dedicated graphics	10 GB	Available	Requires additional program
Cobalt	Solid modeling, surface modeling	On request	$ 60 /month	$ 1495	Single user			not been able to evaluate			Tutorials, forums	N/A	Windows 10, 8, 7 macOS	-	512 MB - 2 GB	32 MB	1 GB	Available	Requires additional program
Form-Z	Solid modeling, surface modeling	Available	$ 439-739/year	$ 995-1690	Single user	2	3	2	2	3	Training, tutorials, Youtube	N/A	Windows 10, 8, 7 macOS 10	-	1 - 4 GB	-	-	Available (V-ray integration)	Requires additional program
Fusion 360	Solid modeling, surface modeling, sheet materials	Available (30 day trial)	650 kr/month	-	Stand-alone single-user license (Licensen connected to user account)	2	4	3	2	3	Tutorials available from Autodesk. Autodesk community, support.	Available	Windows 10, 8 macOS	1.7 GHz	4 - 6 GB	1 GB	3 GB	Available	Able to print directly from program with few adjustments
ICEM Surf	Surface modeling	N/A	-	-	Shared license, single user			not been able to evaluate			Support forum, tutorials, training, e-learning	Available	Windows 10, 7	3.6 GHz	8 GB	16 GB	–	Available	Requires additional program
KeyCreator	Solid modeling, surface modeling, CAM, calculations	Available	-	$ 3495	Single user	2	3	3	2	2	Tutorials, tutoring sessions	N/A	Windows 10	Intel, Core i7 (quad-core) or dual quad-core Xeons	1 GB	8 GB	3 GB	Available	Requires additional program
Onshape	Solid modeling, surface modeling	Available (Trial, free version)	$1500-2100/year	N/A	Single user	3	2	3	4	4	Online guides with videos, forum with tech tips	Available	Browsers: Google Chrome, Mozilla Firefox, Safari, Opera, Microsoft Edge	–	–	–	–	Available with additional app	Available with additional app
NX	Solid modeling, calculations, surface modeling	N/A	50 000 kr/year	120 000 kr + 20 000 kr/year	Single user			not been able to evaluate			Tutorials, training	Available	Windows 10, 7	-	-	4 - 16 GB	–	Available	Requires additional program
Rhinoceros 3D	surface modeling	Available	N/A	€ 995	All licenses are permanent and associated with a user's account. The price includes support for the current version. No maintenance costs.	3	2	3	2	3	Videos, community and tutorials/excercises	N/A	Windows 10 or 8.1, Mac OS 11, 10.15.7, 10.14.6	No more than 63 CPU	8 GB	8 GB or more	600 MB (Windows), 5GB (Mac)	Available	Requires additional program
Solid Edge	Solid modeling, surface modeling	Available	$ 185/month	-	Screen reader support is enabled.	1	1	2	1	1	Support center; comunity forums with discussion, articles and learning Services;	Available	Windows 10 Enterprise or Professional (64-bit only) version 1809 or later	-	-	16 GB RAM for commercial users and 8 GB RAM for academic users	8.5 GB of disk space required for installation	Available	3D print preparation and service
SolidWorks	Solid modeling, surface modeling, CAM, calculations	N/A	Standard with 1-year 16 000kr	N/A	Stand-alone single-user license (Licensen connected to user account)	1	2	2	2	2	Support forum, tutorials, training, e-learning	Available	Windows 10, 64-bit	3.3 GHz or higher	-	16 GB or more, PDM Contributor/Viewer or Electrical Schematic: 8 GB or more	-	Available	Can print directly from program but aditional software are recomended

Alias

Filformat	Import	Export
CATIA V5	R6 to V5-6R2020	R10 to V5-6R2020
CATIA V5	R6 to V5-6R2019	R10 to V5-6R2019
CATIA V4	All versions	Not supported
DES	All versions	All versions
DWG/DXF	All versions	All versions
EDF	All versions	All versions
FBX	All version	Up to FBX 2016
IGES	All versions	5.3
Inventor	Up to Inventor 2020	Not supported
JAMAIS (flavor of IGES)	All versions	All versions
JT	Up to 10.5	8.1
NX	Unigraphics V13 to NX 11, 12, NX 1847, 1872 Series, 1899 Series	V15, NX 1.0, 3.0, 5.0, 7.0, 8.0, 10,12
NX	Unigraphics V13 to NX 11, 12, NX 1847, 1872 Series	V15, NX 1.0, 3.0, 5.0, 7.0, 8.0, 10,12
OBJ	All versions	All versions
Pro/E	Wildfire 5.0	Up to Granite 9.0
	Creo Parametric 1.0 - 5.0	
	Granite 9.0, 10, 11, 12	
SAT	SAT: up to 7	SAT 7
SolidWorks	2001 Plus to 2020	Not supported
STEP	AP214, AP203E2, AP242	AP214, AP203E2, AP242
STL	All versions	All versions
VDAIS (flavor of IGES)	All versions	All versions
VDAFS	All versions	All versions

Blender

Import	Export
.dae	.dae
.abc	.abc
.bvh	.usd
.svg	.bvh
.ply	.ply
.stl	.stl
.fbx	.fbx
.glb	.glb
.obj	.obj
.x3d	

Catia

Import	Export
All CATIA V5 files	.stl
All CATIA V4 files	.igs
All Vector files (*.cgm, *.gl, *.hpgl)	.model
All Bitmap files	.stp
3 dxml	.stpx
act	.stpZ
asm	.stpxZ
bdf	.3dmap
brd	.3dxml
Catalogs	.3mf
Analysis (*CATANalysis)	.amf
Drawings (*CATDrawing)	.cgr
CATfct (*:CATfct)	.hcg
CATKnowledge (*.CATKnowledge)	.icem
Materials (*.CATMaterials)	.NavRep
Parts (*.CATPart)	.vps
Process (*.CATProcess)	.wrl
Products (*.CATProduct)	
CATResource (*.CATRecource)	
Shape (*.CATShape)	
CATSwl	
Functional System (*CATSystem)	
cdd	
cgm	
CGMReplay	
dwg	
emn	
gl	

Cobalt

Supports
.BVH
.SAT
.C6
.CO

Form-Z

Open	Save	Edit	Create	Export	Other
fan	fan	fan	fan	dwg	fsb
fmz	fmz	fmz	fmz	dxf	fza
fsb	fsl	fsl	fsb	iges	fzh
fsl			fsl	igs	spd
fza			fza	stepstp	zsr
fzb			fzb		
			spd		

Fusion 360

Supports
Auotdesk Alias (*.wire)
AutoCAD DWG Files (*.dwg)
Autodesk Fusion 360 Archive Files (*.f3d)
Autodesk Fusion 360 Toolpath Archive Files (*.cam360)
Autodesk Sim360 Archive Files (*.sim360)
Autodesk Inventor Files (*.ipt, *.iam)
CATIA V5 Files (*.CATProduct, *.CATPart)
DXF Files (*.dxf)
FBX (*.fbx)
IGES (*ige, *iges, *igs)
NX (*prt)
OBJ (*.obj)
Parasolid Binary Files (*.x_b)
Parasolid Text Files (*.x_t)
Pro/ENGINEER and Creo Parametric Files (*.asm, *.prt)
Pro/ENGINEER Granite Files (*.g)
Pro/ENGINEER Neutral Files(*.neu)
Rhino Files (*.3dm)
SAT/SMT Files (*.sab, *.sat, *.smb, *.smt)
SolidWorks Files (*.prt, *.asm, *.sldprt, *.sldasm)
STEP Files (*.ste, *.step, *.step
STL Files (*.stl)

ICEM Surf

Import	Export
All CATIA V5 files	.stl
All CATIA V4 files	.igs
All Vector files (*.cgm, *.gl, *.hpgl)	.model
All Bitmap files	.stp
3 dxml	.stpx
act	.stpZ
asm	.stpxZ
bdf	.3dmap
brd	.3dxml
Catalogs	.3mf
Analysis (*CATANalysis)	.amf
Drawings (*CATDrawing)	.cgr
CATfct (*:CATfct)	.hcg
CATKnowledge (*.CATKnowledge)	.icem
Materials (*.CATMaterials)	.NavRep
Parts (*.CATPart)	.vps
Process (*.CATProcess)	.wrl
Products (*.CATProduct)	
CATResource (*.CATRecource)	
Shape (*.CATShape)	
CATSwl	
Functional System (*CATSystem)	
cdd	
cgm	
CGMReplay	
dwg	
emn	
gl	

KeyCreator

Supports
AutoCAD .dwg, .dxf
Autodesk Inventor .ipt, .iam
CADKEY .prt, .cdl
Catia .mod, .model, .catproduct, .catpart
SolidWorks .sldprt, .sldasm
Pro/Engineer .prt, .asm
PTC Creo .prt
Siemens NX .prt
Unigraphics .prt
Neutral formats such as STEP .stp, IGES .igs, Parasolid .x_t, and ACIS .sat
Stereolithography (for 3D printing) .

Onshape

Supports
.shp
.shx
.bdf
Parasolid
Acis
STEP
IGES
Solidworks
Collada
Rhino
GLTF
OBJ
STL

NX

Supports
.nwd
.nwf
.nwc

Rhinoceros 3D

Import	Export
.3dm	.3dm
.3dmbak	.3dmbak
.rws	.rws
.3mf	.3mf
.3ds	.3ds
.amf	.amf
.ai	.sat
.dwg	.ai
.dxf	.dwg
.x	.dxf
.e57	.dae
.dst, .exp	.cd
.dst, .exp	.x
.off	.emf, .wemf
.gf, .gft	.gf, .gft
.gts	.pm
.igs, .iges	.kmz
.lwo	.gts
.dgn	.igs, .iges
.fbx	.lwo
.scn	.udo
.obj	.fbx
.pdf	.obj
.PLY	.csv
.asc, .csv, .xyz, .pts	.x_t
.cgo_ascii, .cgo_asci	.pdf
.txt	.PLY
.raw	.txt
.m, .pts	.pov
.svg	.raw
.skp	.rib
.slc	.svg
.sldprt	.skp
.sldasm	.slc
.stp, .step	.stp, .step
.stl	.stl
.vda	.vda
.wrl, .vrml, .iv	wrl, .vrml, .iv
.gdf	.gdf
.zpr	.wmf
	.x3dv
	.xaml
	.xgl
	.zpr

Solid Edge

Supports
STL
IGES
DXF
DWG
STEP
Microstation
Parasolid
ACIS
PLMXML
NX

SolidWorks

Application	Parts Import	Parts Export	Assemblies Import	Assemblies Export	Drawings Import	Drawings Export
3D XML		X		X		
ACIS	X	X	X	X		
Adobe Illustrator	X	X		X	X	
Adobe Photoshop	X	X	X	X	X	X
Adobe Portable Document Format		X		X		X
Autodesk Inventor	X		X			
CADKEY	X		X			
CATIA Graphics	X	X	X	X		
CATIA V5	X		X			
DXF/DWG files	X				X	X
DXF 3D	X					
eDrawings		X		X		X
Highly Compressed Graphics		X		X		
HOOPS		X		X		
IDF 2.0, 3.0 (CircuitWorks Lite)	X					
IDF 2.0, 3.0, 4.0 (CircuitWorks)		X	X	X		
IFC	X	X	X	X		
IGES	X	X	X	X		
JPEG		X		X		X
Mechanical Desktop	X		X			
PADS (*.asc) (CircuitWorks)		X	X	X		
Parasolid	X	X	X	X		
PDF		X		X		X
Pro/ENGINEER	X	X	X	X		
ProStep EDMD (*.idx) (CircuitWorks)		X	X	X		
Rhino	X					
ScanTo3D	X	X				
Solid Edge	X		X			
STEP	X	X	X	X		
STL	X	X	X	X		
TIFF	X	X	X	X		X
Unigraphics	X		X			
VDAFS	X	X				
Viewpoint		X		X		
VRML	X	X	X	X		
XPS		X		X		X

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