CHALMERS
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Utilizing 3D Printing to Provide Customized Joysticks

Designed to function universally across Volvo's construction equipment set to be released in 2021

Bachelor thesis within the program Design and Product Development

Adis Imširović
Getoar Kumnova

Institution of Product- and Production Development
The Department of Design and Human Factors
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

BACHELOR THESIS YYYY:NN

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Cover:
The final concept, Smooth Mouse, presented in chapter 5.

Preface

This bachelor thesis of 15 credits has been conducted at the bachelor programme of Design and Product Development at Chalmers University of Technology, within the Department of Design and Human Factors at the Institution of Product- and Production development. This project has been assigned by the Engineering department for Volvo Construction Equipment, in Eskilstuna in collaboration with the Design department in Gothenburg.

Firstly, we would like to thank Sidney Levy, Roland Schling and especially Peter Jones from Volvo Construction Equipment who helped to initiate the thesis and provide us with a supervisor.

A big thank you to Mikael Lundaby and Magnus Andersson from CPAC for guiding us regarding operator safety and cognitive awareness. We would also like to thank Börje Larsson from Cascade for helping scanning our plasticine model that we later used as reference when 3D modeling.

We would like to thank Shastry Narasimha from Volvo Construction Equipment for spending a lot of time and energy answering our questions that appeared during the course of work. Shastry was involved from the early phase of the project and we considered him as being the secondary supervisor for all the help and support that he has provided us with. We would also like to thank Jari Devad, Robert Sundkvist and remaining Volvo Construction Equipment employees that helped us during our project.

We also would like to thank Håkan Almius, our supervisor at Chalmers University of Technology, for the support, help and guidance that was necessary in order to steer the project in the right direction. Håkans significant experience and knowledge of 3D printing and 3D modelling was invaluable when designing the final concept. We would also like to thank remaining employees from Chalmers who helped us during our project.

Finally, we would like to give special thanks to the Design Director, Chris Hillman, who was our official supervisor at Volvo Construction Equipment's design studio in Gothenburg. Chris has been involved in the project from the start to the end by mentoring us, guiding us to the right people and helping us resolve problems that emerged during the course of work. We would also like to thank Chris for helping us organise field trips and giving us a broader insight into the company and how they work with product development. Finally we would like to thank Chris for motivating us and giving us free reins to execute the thesis work within our framework.

Abstract

The work presented in this report was primarily done in Gothenburg but also in Eskilstuna on behalf of Volvo Construction Equipment. An investigation would be conducted based on proposing how 3D printing could be implemented to manufacture end use joysticks for their construction equipment. The goal was to find ways to exploit the benefits of 3D printing. In conjunction with this, a universal joystick would be developed with the assumption that a interface is implemented that allows the operator to easily connect the joystick across the excavator, wheel loader and articulated hauler set to be released in 2021. This means that the joystick needs to be portable, functional, ergonomic and applicable to the three construction equipment models. The bachelor thesis has been completed within the Bachelor's degree in the Design and Product Development program at Chalmers University of Technology.

The research resulted in a concept of a universal hand held joystick that is modularized and based on a business model that utilizes the advantages of 3D printing. The developed business model enables joystick customization for every customer. The final concept was designed with regard to ergonomic principles, market researches, user studies, a product specification, creative concept generation, evaluations and continuous discussions with competent employees from Chalmers, CPAC and Volvo Construction Equipment.

The business model which the final concept is based on, consists of a chronological ordering process with several phases that result in a joystick that is modularly built. The business model is proposed to be maintained by engineers from Volvo Construction Equipment and will be used by the customers that want to order a joystick that can be designed by their preferences. For Volvo Construction Equipment, the business model means a way to retain customers that currently chooses to install joystick from external companies, establish themselves in an unexplored market, attract new customers, increase freedom in design and give possibility to offer a better developed joystick customizability than the competitors do today.

The thesis is limited to only developing hand held joysticks. The interface that enables the operator to connect the joystick across the three construction equipment models is assumed to function and be designed by Volvo Construction Equipment. The electrical-, mechanical-, and hydraulic factors that enables the final concept to function are also assumed to function.

Sammanfattning

Det arbete som presenteras i denna rapport utfördes på uppdrag av Volvo Construction Equipments ingenjörsavdelning i Eskilstuna, i samarbete med deras designavdelning i Göteborg där majoriteten av arbetet utfördes. En undersökning skulle utföras som grundar sig på att ta fram ett förslag på hur 3D printing skulle kunna implementeras för att tillverka joysticks till deras konstruktionsfordon. Målet var att hitta ett sätt att utnyttja de fördelar som 3D printing medför. I samband med detta skulle en universell joystick tas fram med grund i att ett gränssnitt skulle finnas tillgängligt som möjliggör att operatören enkelt kan koppla joysticken mellan grävmaskinen, hjullastaren och dumpern som planeras att släppas år 2021. Detta medför att joysticken ska vara portabel, funktionell, ergonomisk och applicerbar för alla tre konstruktionsfordon. Examensarbetet har genomförts inom kandidatexamen för Design och Produktutveckling vid Chalmers tekniska högskola.

Resultatet blev en handhållen universaljoystick som är modulärt uppbyggd och grundar sig på en framtagen affärsmodell som drar nytta av de fördelar som 3D printing erbjuder. Affärsmodellen möjliggör kundanpassning för varje joystickbeställning. Joysticken är utformad utifrån ergonomiska principer, marknadsundersökningar, användarstudier, produktspecifikation, kreativt idégenererande, utvärderingar samt regelbundna diskussioner med kompetenta personer från Chalmers, CPAC och Volvo Construction Equipment.

Affärsmodellen vilket slutkonceptet är uppbyggd utifrån, består av en kronologisk beställningsprocess med flera faser som slutligen resulterar i sammanställning av en modulärt uppbyggd joystick. Affärsmodellen som utvecklats är tänkt att underhållas av ingenjörer från Volvo Construction equipment och är tänkt att nyttjas av kunder som vill beställa en joystick som kan kundanpassas. För Volvo Construction Equipment innebär affärsmodellen möjlighet att bevara och behålla de kunder som idag väljer att installera in externa joysticks i deras konstruktionsfordon, etablera sig i en outforskad marknad samt attrahera nya kunder, ökad frihet i design och möjlighet att erbjuda större anpassningsbarhet än vad konkurrenterna idag gör.

Examensarbetet är avgränsat till att bara utveckla handhållna joysticks. Gränssnittet som möjliggör användning av joystick mellan olika konstruktionsfordon antas kommer fungera samt designas av Volvo Construction Equipment. De elektroniska, mekaniska och hydrauliska faktorer som möjliggör att slutkonceptet och övriga joystickmoduler fungerar antas även vara uppfyllda.

Table of contents

1. Introduction

The following chapter presents the background of the work that is carried out in the report. Furthermore, the purpose, research questions and limitations of the project are presented.

1.1 Background

Additive manufacturing, also called 3D-printing, is a manufacturing technique that has developed rapidly for 5 years and is predicted to be a manufacturing method that can produce end products without the need of post processing (Zhou, 2017). How 3D printing works is that layers of desired material is sequentially placed in height until a defined solid product remains (Karlsson, 2014). Before 3D printing, surface modelling software is used to create computer-aided design (CAD) which is virtual products that later can be printed to physical products. 3D printing is mainly used for producing components which are manufactured in low volume since it is more profitable compared to usage of traditional manufacturing. However, with more efficient 3D printing machines it will be possible to produce components at a larger scale that is more profitable in the coming decade.

Volvo Construction Equipment (hereafter referred to as VCE) is a business area of Volvo Group. Volvo group is one of the world's leading manufacturers of buses, trucks, marine, construction equipment (hereafter referred to as CE) and industrial engines (Volvo Group, 2017b). VCE´s main business area is manufacturing, developing and selling equipment for construction applications (Volvo Group, 2017g). VCE are currently working on new concepts for their excavators, wheel loaders and articulated haulers set to be released year 2021 and one of their ambitions is to design cabins that share a larger interior commonality across the different models.

In conjunction with releasing new models of CEs, VCE wants to examine the possibilities in using 3D printing to manufacture end use handheld joysticks that can be customized and ordered in low volume by the customers. Using 3D printing as a manufacturing method will be optimal to minimize costs to produce low volume joysticks.

Using an e.g. traditional manufacturing mould for low volume components that are customized is not profitable since the moulds are very expensive and progressively more expensive depending on the complexity of the component. Therefore a larger series of the component has to be manufactured in order for the mould investment to be profitable. Therefore VCE issued an assignment to conduct a research on 3D printing in order to propose how it can be implemented profitably and efficiently within VCE’s operation to manufacture end use joysticks.

1.2 Purpose

The purpose of the bachelor thesis is to obtain more knowledge of 3D printing for VCE. This will be done in order to facilitate VCE to examine whether it is an attractive investment to implement the use of 3D printing to manufacture end use joysticks in their excavators, wheel loaders and articulated haulers set to be released year 2021. The thesis should ultimately result in a proposal on how 3D printing can be implemented within VCE to manufacture end use joysticks as it is currently only used for prototyping. This will be done in conjunction with designing a conceptual ergonomic universal handheld joystick that can be used across the three CE models.

1.3 Research questions

1. Can VCE utilize 3D printing to offer customers customized joysticks and how can this be done?
2. What are the advantages that that VCE can benefit from implementing 3D printing as a manufacturing method to offer end-use products?
3. Can an ergonomic handheld joystick be designed to enable full functionality across the new excavator, wheel loader and articulated hauler set to be released 2021?
4. Can the final concept of the handheld joystick be prepared for 3D printing in order to verify the technology as a manufacturing method for end use products?

1.4 Limitations

- The project work is based on circumstances of today and near future, approximately 10 years ahead. Examination of advantages/disadvantages further into the future will not be definitive since circumstances can only be estimated.
- The only construction equipment that are treated in this project is the excavator, wheel loader and articulated hauler from VCE.
- It is assumed that there will be an interface that enables the operator to attach and detach the handheld joystick and a UI display that are compatible in 2021 CEs. Both are assumed to function and be designed by VCE.
- Technical requirements that are assumed to be fulfilled by VCE are not included in the final product specification. (Material properties, mechanical properties and electrical wirings)
- The project will only regard the Swedish market and the regulations set.
- Specific numbers regarding VCE manufacturing costs, sales, profits and customers are not included.

2. Theoretical framework

The purpose with theoretical framework is to provide required knowledge to the reader to offer a better understanding of the project. The gathering of information was also done for the aspiration to gain insight in Volvo's Construction Equipment, 3D printing and ergonomics. The information is used as reference when argumenting for different claims consistently through the project. Information for the theoretical framework was accumulated from the internet, literature, study visits and input from VCE employees.

2.1 Glossary

The glossary consists of words that are considered complex and unfamiliar in an everyday language. Some words are presented with shortenings that are used throughout the report. Information about each word is presented in order to give the reader further understa-nding.

Name	**Shortening**	**Information**
Additive manufacturing	(AM)	The technical term for 3D printing.
Post processing		Work done after the main process to refine.
Tooling		Manufacturing tools such as moulds, jigs, mills.
Turning, CNC milling		Subtractive Manufacturing methods.
Excavator	(EXC)	Construction Equipment.
Wheel Loader	(WL)	Construction Equipment.
Articulated Hauler	(AH)	Construction Equipment.
Volvo Construction Equipment	(VCE)	Affiliated company that manufactures, develops and sells equipment for construction applications.
Resins		Natural or artificial organic substances of varying composition that mainly consists of resin acids.
User interface	(UI)	Referring to human-computer interaction. It is the space where the interaction between humans and machines happen.
Computer-aided design	(CAD)	Digitally based design and creation of technical drawings used in design and architecture.
Support material (3D Printing)		These are rigid pieces of base material created next to the object being printed. Support structures do a good job of holding everything in place.
Attachments		Attachments that can be added to the CEs such as bale grabs,

	brooms, mining shovels, couplers and water delivery systems

Table 1. Glossary

2.2 Volvo's Construction Equipment

VCE provides a broad range of construction equipment which their customers can purchase (Volvo Group, 2017d). The CEs are designed to withstand demanding industries like mining, construction and agriculture. The product range that is available by VCE consists of excavators, articulated haulers, wheel loaders, compactors, pavers, demolition equipment, asphalt pavers, pipe layers and forestry equipment. In addition to their product range, VCE also provides their customers with a wide range of services, attachments and parts tailored according to the customers' requirements.

2.2.1 Construction Equipment

This project will only focus on three CEs which are the excavator, wheel loader and articulated hauler due to project limitations (see 1.4).

Excavator

Excavators (hereafter referred to as EXC) are mainly used for digging trenches, holes and foundations (Volvo Group, 2017c). They can also be used for material handling, forestry work and river dredging. The EXC is available in two editions, the crawler EXC and the wheeled EXC. The crawler EXC is equipped with continuous tracks suited for worksites with tough terrain while the wheeled EXC which is equipped with wheels is more suited for urban worksites. There are various sizes of excavators and attachments available for the customer depending on what the customer needs. Depending on the size of the EXC, it is possible to operate a weight between 12 230kg - 91 840k with a bucket capacity that can handle 0,15m^3 - 6m^3.

Figure 1. Excavator in work (Volvo Group, 2017a). Reprinted with permission.

Wheel loaders

Wheel loaders (hereafter referred to as WL) are versatile machines that can be used for quarrying, aggregates, material handling, block handling, civil and building construction and recycling- respectively waste handling (Volvo Group, 2017f). Depending on which WL you are using, it is possible to carry between 11 000kg - 56 000kg. The bucket capacity for big WL's stretches between 1,6m^3 to 16m^3.

Figure 2. Wheel loader transporting material (Volvo Group, 2017c). Reprinted with permission.

Articulated Hauler

Articulated haulers (hereafter referred to as AH) are used for transportation on demanding conditions and terrain (Volvo Group, 2017e). AHs are used for quarrying, tunnelling, mining, earthmoving, material handling and waste handling. Depending on the size of the AH, an AH can maximally carry a payload between 24 000kg to 55 000kg.

Figure 3. Articulated hauler in movement (Volvo Group, 2017b). Reprinted with permission.

2.2.2 Cabins

The cabin is the place where the operator sits to operate the CE. Today's cabin provide protection towards potential threats like stone chips, bad weather, falling objects. If the CE overturns, the cabin should be able to handle the weight without breaking and save the operators life.

The cabin is constructed with big and clear glasses that is placed around the operator to enable a good view of the workplace (Appendix 1, 2017). Each CE has its own primary controls. Wheels, joysticks, pedals and levers are described as primary controls. Primary controls are controls that are considered to be used very often during regular work conditions.

Cabin of Excavator

Figure 4. Cabin view from a crawler excavator (Volvo Group, 2017d). Reprinted with permission.

The cabin perspective shows the operator's view from an EXC on a work site (see figure 4). The machine interfaces are designed for optimal efficiency and control with ergonomics in mind (Volvo Group, 2017c).

The height of the seat and configuration of interior panels are made to optimize downward visibility (Appendix 1, 2017). The operator sits in an ergonomic position while their seat is placed towards the front in order to reach the steering levers. The primary controls for the wheeled EXC are pedals, steering wheel and joystick. The crawler EXC does not have a steering wheel, instead it has a lever control stick that enables steering and movement. The primary controls for the crawler EXC are steering control levers, pedals and joysticks for controlling the attachment bucket.

Cabin of Wheel loader

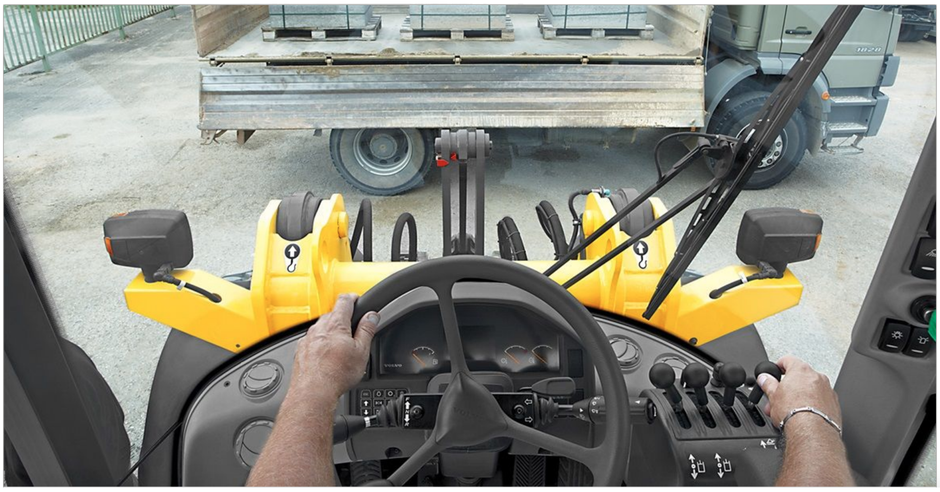


Figure 5. Cabin view from wheel loader (Volvo Group, 2017f). Reprinted with permission.

The cabin of the WL is designed with ergonomically placed controls, protection against vibration and insulation of external sounds (Volvo Group, 2017f). The WL is also designed to offer storage space and it has conscious design called ROPS (Roll Over Protection System) and FOPS (Falling Object Protective Structure) which are certified safety concepts created by VCE.

The operator needs to sit upright to allow constant visibility towards the bucket in order to see the ground in front during loading operations (Appendix 1, 2017). The primary controllers for the WL are accelerator and brake pedals, steering wheel, lever steering and hydraulic control joysticks.

Cabin of Articulated Hauler

Figure 6. Cabin view from Articulated Hauler (Volvo Group, 2017e). Reprinted with permission.

VCE puts emphasis on creating a comfortable cabin for the AH with good suspensions and good conditions for simple operation in tough conditions (Volvo Group, 2017e).

Driving a AH is similar to driving a truck where the operator sits in a relaxed seat that is moved backwards with all buttons close at hand (Appendix 1, 2017). The AH has the biggest cabin compared to standard size WL and EXC since it is necessary to give possibility for an instructor to accommodate the operator inside the cabin. The primary controls for the AH is the steering wheel, the joystick to control the dump bucket, accelerator pedals and brake pedals.

2.2.3 Joysticks

The purpose of the joystick is to control and manoeuvre an object. Joysticks are available in different configurations and serve different purposes depending on what it is used for (Appendix 1, 2017). The configuration of the different joysticks are market dependent and can be adjusted to a certain extent for customers, based on what is desired. The configuration of joysticks have some restrictions due to regulations by authorities, agreements between companies and culture within company. The joystick can be controlled hydraulically or electronically, there are also some joysticks that are hybrid of both. Using electrically controlled systems occupies less space, makes less noise, makes less heat inside the cabin and is more responsive.

Joystick in Excavator

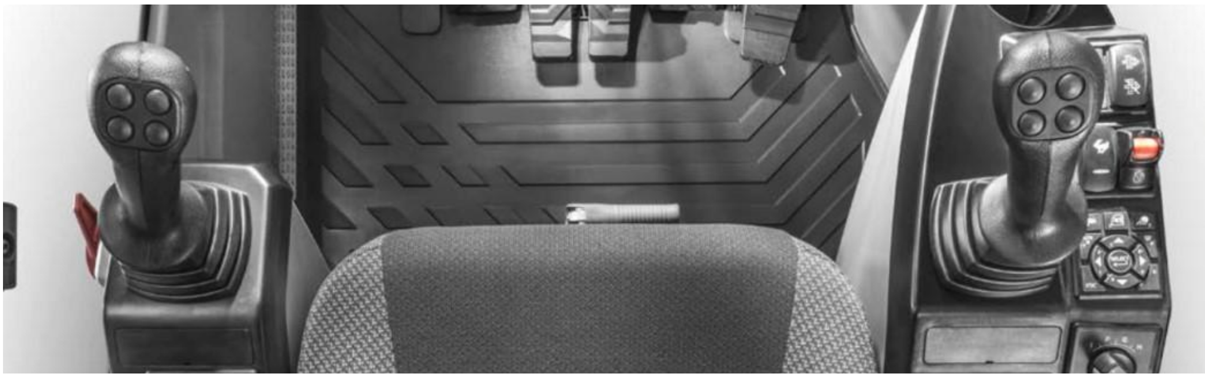


Figure 7. Remote control value used in excavators (Appendix 9, 2017). Reprinted with permission.

The excavator uses the same kind of hand held joysticks on both right- respectively left hand side (see figure 7), the only difference is that they are mirrored to provide same use for both hands (Appendix 1, 2017). The EXC joystick is called remote control valve and is used to manoeuvre the cabin and the bucket. The different buttons on the joysticks offer different functions as controlling optional attachments. The excavators have bigger joysticks compared to joysticks used by wheel loaders and artificial haulers which depends on the fact that functions like lights, display control and horn are integrated directly on the excavator joystick. The reason for the different button layouts on the joysticks depends in general on the requirements that the operators need in order to carry out their work.

Joystick in Wheel Loader

Figure 8. Electro-hydraulic 4 function linear control lever (Appendix 9, 2017). Reprinted with permission.

If the WL is constructed with a steering wheel or not determines if the WL has either one or two joysticks (Appendix 1, 2017). On the left hand side there is an optional steering system known as CDC lever which is used for steering the WL horizontally with your hand. CDC is used as a complement if there is no steering wheel available in the cabin.

On the right hand side there is two alternatives of joysticks, a multiple lever joystick configuration with two, three or four levers or a hand held joystick called electro-hydraulic 4 function multi control single lever (see figure 8) (Appendix 1, 2017).

Figure 9. Electro-hydraulic 4 function multi control single lever (Appendix 9, 2017). Reprinted with permission.

Joystick in Articulated Hauler

Figure 10. Control lever used in Articulated Hauler with basic movement (Appendix 9, 2017). Reprinted with permission.

The AH uses only one lever (see figure 10) that is known as a control lever (Appendix 1, 2017). The control lever is used for lowering and raising the dump bucket on the back of the AH. Pressing the lever forward raises the bucket while pressing the lever towards the operator lowers the bucket. The configuration with multiple levers that is used in the WLs right hand side, called electro-hydraulic 4 function linear control lever (see figure 8) uses the same kind of levers with small differences in shape.

VCE Joystick Regulations

According to engineers from VCE it is a standard work process to follow cognitive ergonomics principles and ISO regulations when developing new joysticks (Appendix 1, 2017). The regulations impact the joystick in such a way that certain buttons and joystick movements are locked to specific attachments in the CE. It also restricts the operator to map out certain functions on the joystick to a certain degree.

2.3 3D printing (Additive Manufacturing)

3D printing is an additive manufacturing process that creates a physical part from a digital design (3D HUBS, 2017). There are several 3D printing technologies available but they all share the same principle which is that a physical three-dimensional object is created layer by layer from a digital model.

Figure 11. Concept of 3D printing (3D HUBS, 2017f). Reprinted with permission.

Every object that is 3D printed is based on a digital 3D design file (CAD-file) similarly like a structured object is based on a blueprint (3D HUBS, 2017). The CAD file is created by 3D modelling software such as Alias Autostudio, Catia and Solidworks. A CAD file is always needed to 3D print a physical object exactly the same way that a traditional document printer needs a text file or a photo file to print the digital material on a sheet of paper. The conversion between a digital design file and a 3D printed object is explained simply as a digital file is "sliced up" into thin layers which is precedingly sent to the 3D printer (see figure 11). Exactly how the object is 3D printed depends on the specific technology and it varies from a desktop printer that melts a plastic material and lays it down layer by layer, to larger industrial level machines that uses a laser at high temperature to selectively melt metal powder.

2.3.1 History and the Development of 3D Printing

Upon inventing stereolithography in 1984, Charles Hull had had broken new ground (Goldberg, 2014). It was made possible to create physical 3D models by using digital data. What stereolithography did was to enable designers to use digital data to create digital 3D design files which later could be created as a physical product.

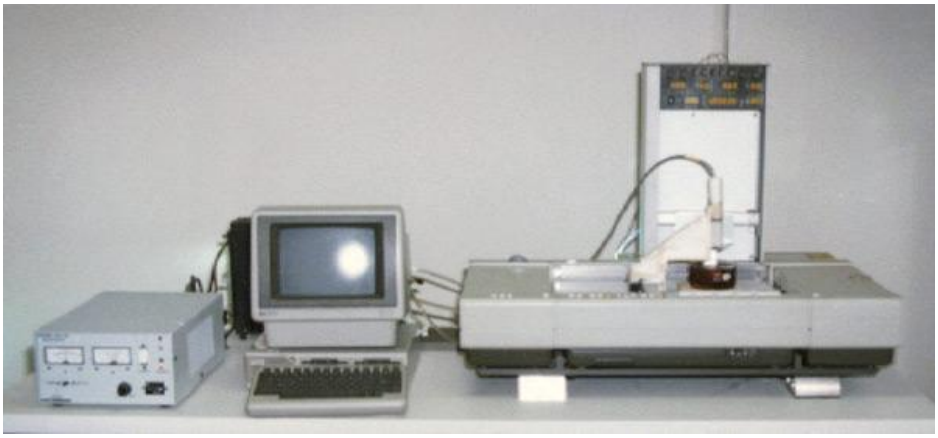


Figure 12. SLA-1, the first 3D printer invented by Chuck Hull in 1983 (3D HUBS, 2017g). Reprinted with permission.

3D systems which was Charlie Hull's company, later developed the world's first stereolithographic apparatus (SLA) machine which basically made it possible to fabricate complex parts, layer by layer (Goldberg, 2014). This enabled inventors and designers to verify their designs by producing a prototype in a fraction of the time it would normally take and to avoid the large upfront investment that traditional manufacturing would require and it ultimately paved the way for the new era of additive manufacturing and different 3D printing technologies.

2.3.2 3D Printing Technologies

A range of different 3D printing technologies are available as manufacturing methods (3D HUBS, 2017a). Cost, choice of material, post processing requirements and requirements of surface finish respectively dimensional accuracy is what generally determines which technology is best suited for a specific application.

The most usual printing methods will be presented along with the most common materials and applications for each technology. For more information about which 3D technologies are available, see appendix 2.

Stereolithography (SLA), Digital Light Processing (DLP) and Continuous Digital Light Processing (CDLP)

Stereolithography and Digital Light Processing works in such a way that liquid photopolymer are hit by a light source which then instantly turns the liquid photopolymer into solid plastic (3D HUBS, 2017). The build platform is submerged into a tank filled with liquid resin which is then a solidified by a light that is located inside the machine. When the layer has been solidified, the platform lifts up and gets a new layer of resin until the desired product has been completed (see figure 13). The difference between SLA and DLP is that SLA uses a laser while DLP employs a projector. The technologies is mainly used for highly detailed prototypes, jewellery and sculptures but is restricted to large objects because of the limited size of printers.

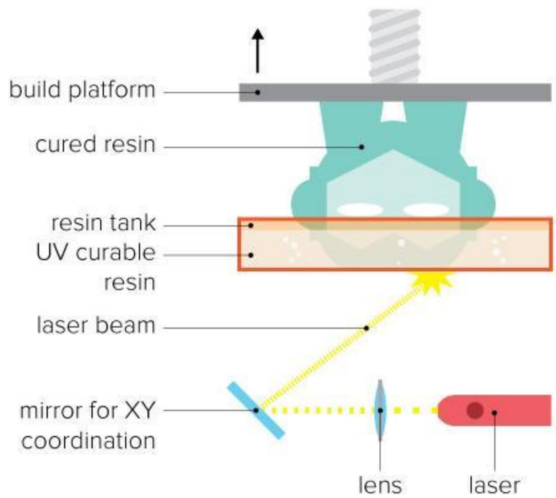


Figure 13. Schematic showing how SLA technology works (3D HUBS, 2017b). Reprinted with permission.

Continuous Direct Light Processing (CDLP) (also referred to as Continuous Liquid Interface Production or CLIP) is a photochemical process that balances oxygen and light to produce parts rapidly (Carbon3D, 2017b). The process is the same as DLP but the difference lies in the way that the light is projected. It is done through an oxygen-permeable window into a reservoir of UV-curable resin. As a continuous stream of UV images are projected, the part starts to solidify continuously as the build platform rises. This allows for a process that provides faster build time since the printer does not need to stop and separate the part from the build platform after each layer.

Selective Laser Sintering (SLS)

The way that the SLS machine works is that the machine does not shoot a laser on a liquid, instead it shoots a laser on a powder (see figure 14) which hardens selectively (3D HUBS, 2017). When the layer has been solidified, the powder bed moves down and gets filled with a new layer of powder from the roller. The process is repeated until the desired object has successively been created. The technology is mainly used for industrial 3D printing applications but the market is expected to expand to the mainstream user. SLS is widely used for functional prototypes and some end products. SLS offers almost complete design freedom with no additional support needed thanks to the unmelted powder. A weakness with SLS is the lead times due to finished parts require time to cool. Polyamides (nylon), thermoplastic elastomers and polystyrenes are the material that is mainly used.

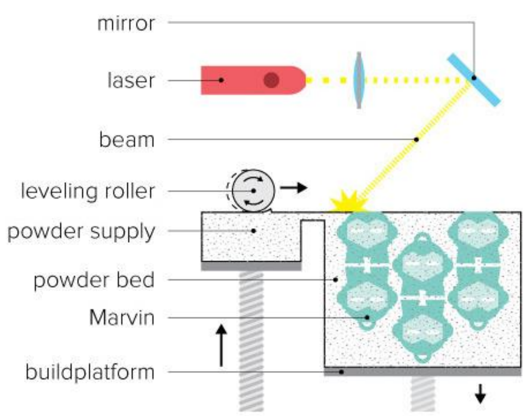


Figure 14. Schematic showing how SLS technology works (3D HUBS, 2017c). Reprinted with permission.

Fused Deposition Modelling (FDM)

FDM is the cheapest and most common technology for desktop 3D printing because of low-cost and quick prototyping (3D HUBS, 2017). A broad variety of plastic-based materials like PLA, nylon and ABS are available in different colours. Exotic material blends like wood, carbon and bronze can be used in some machines. The filament, a solid material, is guided from a reel that has a heated nozzle that melts the material (see figure 15). The material is extruded layer on layer on a predetermined path until the entire object is manufactured. FDM can be used for a variety of applications often for easy prototypes and not intricate designs because of its limitations in design and material. Furthermore, recent innovations has given the possibility to manufacture end products with embedded mechanical parts and electronics like drones.

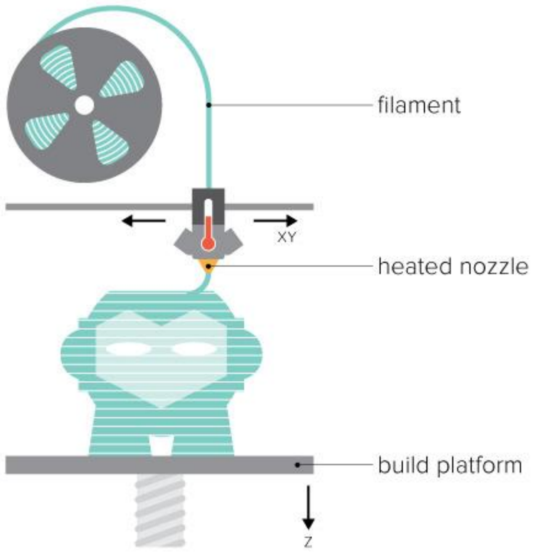


Figure 15. Schematic showing how FDM technology works (3D HUBS, 2017d). Reprinted with permission.

Material Jetting

Material jetting is based on jetting layers of liquid photopolymer on a build tray and then harden directly by using UV light (3D HUBS, 2017). The process (see figure 16) is repeated until a precise object is created. For prints that are complex and require support material, a temporary removable gel-like support material is created that can be removed when the print is complete. The technology is used for creating prototypes that are realistic and functional that could be used for end products. Material jetting is the most precise 3D printing technology that currently exists with the possibility to print 16-micron layers. It also provides a variety in properties among toughness, flexibility and transparency. The most advanced systems can offer multiple usage of jets simultaneously which allows combination of different colours and materials.

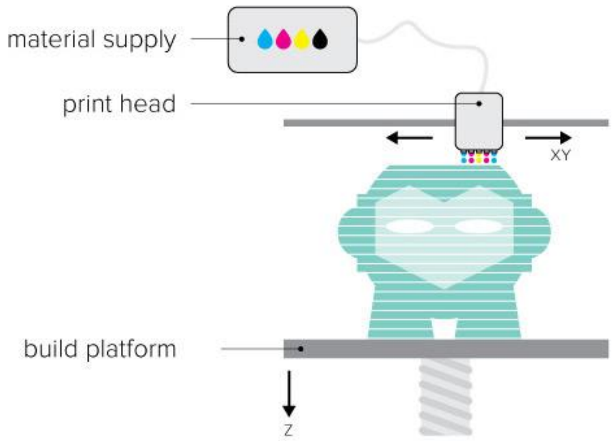


Figure 16. Schematic showing how material jetting technology works (3D HUBS, 2017d). Reprinted with permission.

Binder Jetting

Binder jetting is similar to SLS regarding usage of thin layers of powdered material to build up an object (3D HUBS, 2017). The difference is usage of a binding agent extruded from a nozzle to bind the powder together instead of a laser that sinters the layers. A nozzle spreads the binding agent across the first layer and then binding the powder together (see figure 17). When the first layer has been fully fused together with the binding agent, the printing bed moves down and gives space for new powder across the surface. The process is repeated until the entire object is formed. In order to give further strength and make it resistant to discoloration, an adhesive glue is coated on the object. Binder jetting is used for industrial applications and is cheaper than SLS technology because the process requires less energy. Full colour sandstone is the most common material that is used for the printing.

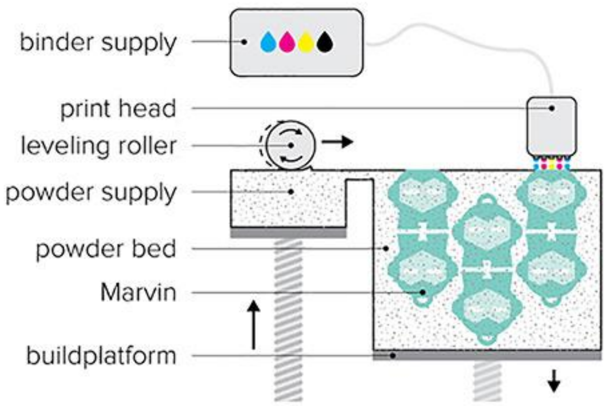


Figure 17. Schematic showing how binder jetting technology works (3D HUBS, 2017e). Reprinted with permission.

Metal Printing (Selective Laser Melting (SLM) and Electron Beam melting (EBM))

SLM and EBM are the most common metal 3D printing technologies currently available (3D HUBS, 2017). Similar to SLS technology the processes build objects from thin layers of powdered material by melting from a heating source. Because of the material properties that metal has compared to plastic, the process requires more energy to work. SLM uses a laser while EBM uses an electron beam. A layer of metal powder is disturbed across a build platform, which is then melted by either an electron beam (see figure 18) or a laser beam (see figure 19). The build platform is gradually lowered and coated with new layers of metal powder until a final object is constructed. EBM and SLM require support structures that enables transfer of heat the melted powder. The SLM needs to operate in a low oxygen environment and EBM in vacuum in order prevent warping and reduce thermal stresses.

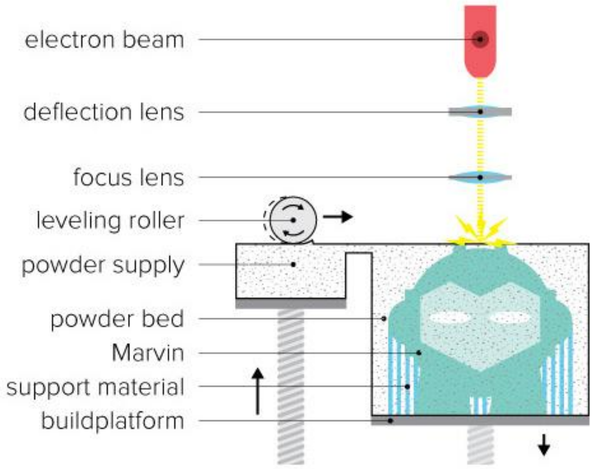


Figure 18. Schematic showing how EBM technology works (3D HUBS, 2017g). Reprinted with permission.

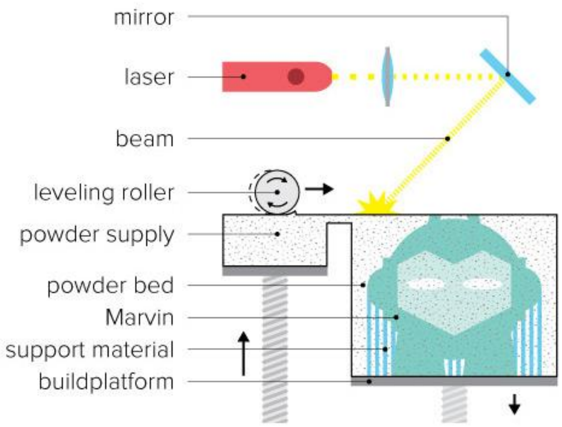


Figure 19. Schematic showing how SLM technology works (3D HUBS, 2017f). Reprinted with permission.

Aircraft, aerospace, healthcare and automotive use a range of high-tech applications that directly go from prototyping to final production (3D HUBS, 2017). SLM and EBM use alloys and metals among steel, aluminium, titanium and nickel.

2.3.3 The Advantages that 3D Printing Enables in an Industrial Company

Using 3D printing as a manufacturing method results in many advantages over the traditional manufacturing techniques (Redwood, 2017). As mentioned before, there are a large range of different 3D printing technologies but the advantages mentioned hereafter are generally applied to the industry as a whole.

The probability of 3D printing completely replacing traditional manufacturing is rather small by today's standards but there are still several applications where the technology currently excels over the traditional methods (Redwood, 2017). By using additive manufacturing, it enables the possibility to deliver a design rapidly by using functional materials with the end result showing high accuracy. By understanding the technology and in which areas it outperforms other methods, it will help designers make better choices regarding the manufacturing methods with the ambition to obtain the optimal product.

Verification Speed

By using additive manufacturing to produce a part, the time for verifying and developing a design idea is significantly reduced (lead time) compared to the traditional manufacturing methods (Redwood, 2017). An intricate and complex design can be modelled in a CAD program and the conversion from a digital design file and a physical object is only a few hours. What this allows is for the designer to hold the physical product in their hand a few hour after finishing the design, where the traditional methods would have taken days or in some cases weeks to produce a prototype, e.g. by using an injection mould die cast, the resulting lead time could be weeks.

Even though the larger industrial types of 3D printers needs a longer time for printing and post processing, the possibility to produce low to mid volumes of functional end parts results in a significant time efficiency compared to how it was in the past before the additive technology was available (Redwood, 2017). The exact printing time is of course dependent on size of part, complexity and 3D printing technology but the technology as a whole is by far the most effective for evaluating a design's potential.

Design Freedom and Single Step Manufacturing

To clarify how the lead time can be reduced, it is explained as the following: When designing a part, one of the biggest concerns is how the part is going to be manufactured as efficiently as possible, it is also known as design for manufacturing (Redwood, 2017). What this means is that different manufacturing methods require a large number of manufacturing steps before the final part is produced. The order in which these steps are executed also have an impact on the manufacturability and quality of the design.

The single step manufacturing becomes obvious when e.g. designing a steel bracket prior to 3D printing (Redwood, 2017). A CAD model is needed for both but when the design for traditional manufacturing is complete, the first step of the fabrication begins with the steel being cut to the correct length and many several steps thereafter. Which is a long process before it is ready for post processing and until finally complete. What 3D printing does is to eliminate the large number of steps during the fabrication phase which would have been needed without it and no further interaction is necessary during this time (see figure 20). The conversion from a digital design file to a physical object occurs only in one step and this provides the possibility for a designer to exclude the traditional manufacturing constraints when designing and direct focus to the final product.

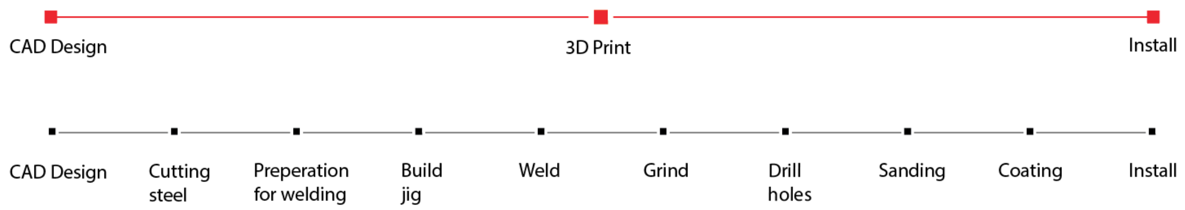


Figure 20. 3D printing process compared to ordinary manufacturing method (3D HUBS, 2017h). Reprinted with permission.

Since parts are produced layer by layer, the traditional requirements such as undercuts, draft angles and tool access do not apply (Redwood, 2017). Restrictions on minimum size features are current with 3D printing since the printing is accurate to a certain size. Other than that, the restrictions are basically regarding how to optimize the orientation of the print to reduce the support dependency and the probability of print failure. An advantage is also that some parts that are designed with traditional manufacturing in mind might have to be manufactured in several smaller components that has to be assembled if the design is too complex. This is what allows the designer work more freely and design complex parts that can easily be manufactured with 3D printing (3D HUBS, 2017).

Customer Customization

Figure 21. Customizable 3dprinted headphones designed by Print+ (3D HUBS, 2017h). Reprinted with permission.

The design freedom that additive manufacturing enables also allows design of complete customizable parts (3D HUBS, 2017). Since the concept of 3D printing is to produce one part at a time it is suited perfectly for producing one-off parts that differs from the normal production. Custom made prosthetics, implants and dental aids are examples on how the technology has been embraced in different industries. What additive manufacturing does is to allow cost effective single run production of custom parts.

Reduced Risks

The consequences of finding flaws in a prototype can result in huge losses when using traditional manufacturing. (Redwood, 2017) Seeing that applying changes to a designed prototype later in the process results in having to make changes to a mould or to the production. The moulds and the changing of processes are very expensive and it is a situation that would want to be avoided.

By using additive manufacturing it is possible to verify a production-ready prototype before making the investment in expensive manufacturing equipment such as tooling, moulds or jigs (3D HUBS, 2017). This eliminates the risk of making a wrong decision when investing in manufacturing equipment that are based on a faulty prototype.

Economic Benefits

The implementation of additive manufacturing on an industrial operation result in different economic benefits which becomes apparent in specific ways (Redwood, 2017). These advantages can generally be divided into three following main categories according to Redwood:

Machine Operation Costs

Desktop sized 3D printers uses approximately the same amount of energy as a laptop. There is large difference in consumption of energy compared to industrial sized technologies which uses a large amount of energy whilst producing a single part however the turnaround and efficiency is higher since complex geometries can be produced in one step. The cost of machine operation usually has the lowest impact on manufacturing costs.

Material Costs

The cost for the material needed varies drastically depending on the specific technology. FDM printers that are desktop sized uses filament coils cost around 25$/kg compared to SLA printers which requires resin that costs around 150$/litre. The variety of materials available for additive manufacturing makes it difficult to make an extensive quantifying comparison to traditional manufacturing. Nylon pellets that are used for injection moulding cost only $2 - $5 per kg, which is very cheap compared to the nylon powder that costs around $70 per kg when printing with the SLS technology. The cost of the material needed for a 3D printer is the largest contributor to the cost of printing a part.

The cost advantage of additive manufacturing printing however becomes apparent when comparing it with traditional manufacturing regarding low volume production. In regards to prototyping and producing one off functional parts, additive manufacturing provides a huge cost efficiency. If the objective however is to produce a large number of parts, traditional manufacturing is the optimal method as of today since the large production volume compensates the expensive upfront tool investment.

Labour Costs

The reduced necessity for labour is a main cost advantage with additive manufacturing. If the eventual need for post processing is disregarded, the only labour needed for 3D printing is a technical operator that is required to push a button. With traditional manufacturing, highly skilled operators and machinists are usually necessary, compared to 3D printing where the machine's automated process begins by the push of a button which effectively lowers the cost of labour to almost zero.

Environmental impact

Using traditional manufacturing methods such as turning and CNC drilling result in huge material losses (3D HUBS, 2017). Both methods are what is called subtractive manufacturing and they initiate the manufacturing with a block of material which is machined until it is processed down to the intended design. It is considered normal in some cases to lose up to 90% of the raw material during the process. On the other hand, additive manufacturing generally only uses the amount of material that is needed since the part is produced layer by layer. Combined with the reusability of the material that most 3D printing technologies offer, the material waste is minimal compared to other manufacturing methods. This does not only provide environmental benefits but it also provides benefits in regard to cost savings in material.

The increasing number of 3D printing machines around the world has also impacted the shipping distance of prototypes (Redwood, 2017). Since only a basic understanding is required to operate a 3D printer it is no longer needed for designs to be sent to prepared for manufacturing by an expert. This results in reduction of shipping and in turn a reduction of environmental impact. Combined with the aerospace industry beginning to take advantage of 3D-printing's benefits by producing lighter components with the same performance of products created by traditional manufacturing methods (Karlsson, 2014). The weight savings enables big reduction on fuel consumption which contributes to lower carbon emissions and fuel costs. The possibility to also produce necessary spare parts on site reduces the need of shipping and if shipping is inevitable, additive manufacturing enables more fuel efficient transport.

2.4 Ergonomics

Ergonomics is the science of human in work (Edström & Malmquist, 2017). In other words, the interaction between human and working equipment. Characteristic of ergonomics is the mixed knowledge of technology, psychology and biology. The basic idea is to use the different knowledges in order to adapt the working environment to human limitations and capabilities.

2.4.1 Hand ergonomics

There are several factors that should be taken into consideration when designing a hand operated tool with ergonomics adjusted to all users (Bohgard et al., 2010, p. 179-180). It is a given standard in today's products compared to how tools were designed in the past. In other words the hand has a central importance for the human since it is used for a lot of everyday activities. Therefore it is essential to care for the hands and enable them to be used in the most natural way as possible, both in the workplace and at home.

Natural position

The hand should work as close as possible to its natural functional starting position

(Bohgard et al., 2010, p. 182). That is why it is optimal for the tool to be designed in such a way that it can be used in the most natural manner as possible. Tools that are going to be used in the arms longitudinal direction should have a grip that has angle of 70 degrees relative to the tool itself (see figure 22).

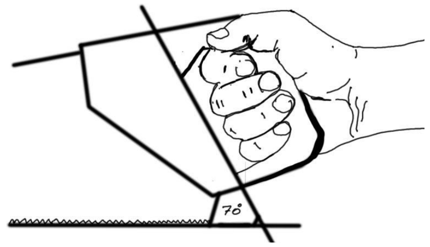


Figure 22. The recommended angle between the tools horizontal line and the grip is 70 degrees. Author's own Copyright.

Grip size

Since hand dimensions varies significantly between different individuals where women e.g. often has smaller hands than men, therefore grip size has to be taken into consideration when designing a hand operated tool (Bohgard et al., 2010, p. 180-181). However the measurements for men and women can overlap in various degrees regarding different grip dimensions. To exemplify this the comparison can be made for gloves used at home where it is obvious for the user to have the right sized gloves compared to gloves available at work where it is not as expected to have the right size available. This has resulted in size adjustments to hand operated tools at work where the sizes are adjusted with respect to the specific profession and if it is dominated by either men or women. In a profession dominated by men, women usually has to adjust to tools designed for men.

Figure 23. Recommended enfolding of grip. Author's own Copyright.

A rule of thumb is that the girth of the tool should (see figure 23) enable the hand's contact surface to enfold more than half of the grip's circumference (Bohgard et al., 2010, p. 183). However the hand should not either completely enfold the grip (see figure 24).

Figure 24. Not recommended grip. Author's own Copyright.

Grip shape

If the grip shape is adjusted to a specific hand, it does not mean that it is suited for every user (Bohgard et al., 2010, p. 183). This implies that the grip must be designed in such a way that it can suit every type of user and not have e.g. to defined predetermined finger placements (see figure 25).

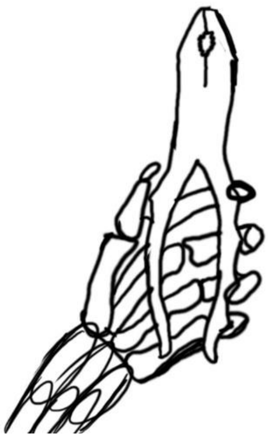


Figure 25. Grip shape. Author's own Copyright.

Grip variation

Risk factors with hand operated tools can be split into 3 dimensions which are force, precision and repetition (Bohgard et al., 2010, p. 172 & 181). While for e.g using a knife which does not require much force it may however result in strain injury due to the large amount of repetitions at a high precision which knife work can require. Therefore it is important to design the tool in such a way that it offers grip variation (see figure 26) to reduce monotonic repetitive movements since it can lead to strain injury.

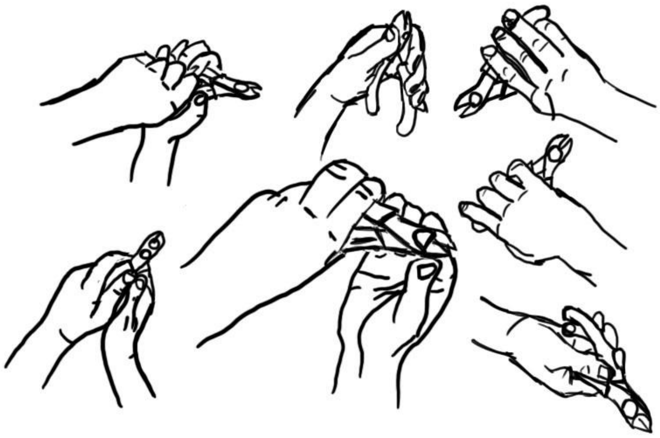


Figure 26. Varied grip. Author's own Copyright.

Decreasing static strain

There are also several other factors that must be taken into consideration when designing a tool which concerns how the hand is strained statically, which refers to how the user's body is strained when the tool is only enfolded and not actively used (Bohgard et al., 2010, p. 178).

2.4.2 Legal Requirements for Joystick Ergonomics

Arbetsmiljöverket is a Swedish authority that has the task to ensure that laws on working environment are followed by companies and organisations (Arbetmiljöverket, 2015). Arbetsmiljöverket has compiled several reports of rules and recommendations to prevent illness and accidents at work and what can be done to improve the working environment.

Arbetsmiljöverket has compiled a report called Maskiner which deals with regulations and recommendations about machines, including actuators (Arbetsmiljöverket, AFS 2008:3).

The requirements which were most relevant to joysticks was be found in the report Maskiner (Arbetsmiljöverket, AFS 2008:3). Chapter 1.2.2, describes that an actuator needs to be:

- Clearly visible and identifiable,
- Positioned for safe handling without hesitation,
- Designed so that movement of actuator is in accordance with its action,
- Designed to withstand foreseeable stresses,
- Designed with regard to ergonomic principles

3. Methods

During the project work, a variety of methods were used for progressing the work forward to a conclusive result. The methods used in this project are divided in following categories: pre study, concept generation, evaluation of concepts and analyses of results.

3.1 Pre study

The purpose a pre study is to gather information about a product, competitive products and market in order to identify the expectations for the project (Johannesson, Persson and Pettersson, 2004, p. 577-579). A pre study usually result in a product specification which lays the foundation for further work. Material for the study was obtained from ackknowledged websites, research articles, literature, user studies and field trips.

3.1.1 Problem Definition

It is essential to determine the source of the problem in order to target the work process in the right procedure (Johannesson, et al., 2004, p. 403). Using problem definition as a method gives opportunity to determine the present situation, what the desired status is and what obstacles exist on the path to the desired situation. Activities must be sequentially arranged in order to lay out the right approach to desired situation. Following questions need to be answered:

1. *What is the current situation today?*
2. *What is the desired situation?*
3. *What are the divergence between the two situations?*

In order to define the problem, it is valuable to meet and get input from competent employees that have good understanding about construction equipment and their product development. To accomplish this, a field trip to VCE in Eskilstuna was made to provide as a project brief to define the problem and the purpose of the project. It was important to ensure that the work was set on the right path and that relevant tasks were performed. With the information gathered from the project brief in VCE Eskilstuna, the problem could be defined.

3.1.2 Market Research

The purpose of the market research was to identify who the customers and end users are. The market research also investigated the construction equipment joystick market that consists of VCE´s operation and a competitor research. 3D printing developments and trends were also researched.

Identifying the Customer and End User

The purpose of identifying the customer and end user was done in order to clarify what needs exist from each part and how they are intertwine with each other. The information for the research was gathered from discussions and meetings with VCE employees.

VCE´s Operation

A research about why VCE needs to implement 3D printed joysticks and take advantage of the manufacturing. An ambition was to also get an understanding of the joystick operation within VCE. The information for the research was gathered from discussions and meetings with VCE employees.

Competitor Research

A competitor research was also made in order to gather information regarding current market situation and what the competitors offer. The competitor research were based on discussions with VCE employees and literature studies.

3D Printing Developments and Trends

A research on different developments and trends within 3D printing was made in order to create a basis for how VCE can surpass their competitors by utilizing the upcoming advantages that additive manufacturing will provide in the near future and how it can impact the implementation of 3D printing on end use joysticks. The gathered information would also serve as support to strengthen arguments for the different design choices in the concept generation phase. The information of 3D printing developments and trends is based on articles found from the internet.

3.1.3 User Studies

A successful design process has the user in focus, in this case the operators are the end user (Stiftelsen Svensk Industridesign, 2017). The opinions and reflections acclaimed from the studies can later be used as inspiration for the concept generation. The user studies are used to get a better understanding of the user. The methods used for the user studies in this project are: interviews, participant observations and a scenario.

Interviews

Interviews are performed in order to obtain input from the operators (Trost, 2017). The interviews can be done by meeting, phone call or post. Each participant gets the same questions that are semi structured, this provides space for new ideas to be brought up as a result of what the interviewee replied.

The interviews were done on different work sites with operators that currently uses or has had experience with using VCE´s CE. The questions from the interviews were primarily oriented around the current joystick with regards to function, ergonomics, design and future development but also questions about what they think is lacking in the current version of joysticks.

Participant Observations

Participant observations are primarily used in cultural- and social anthropology, ethnology and sociology (Nationalencyklopedin, 2017a). What characteristics participant observations is that the researcher personally lives in the cultural and social situation that is studied. By being a part of the research the researcher gets an opportunity to obtain knowledge of the studied group or situation.

In order to get a insight on the operator's perspective, participating observations was made on EXC-, WL- and AH simulators. The participant observation was done in VCE Lindholmen and CPAC Mölndal which is a subsidiary of VCE that works with integrating electronic control systems for commercial vehicles (CPAK, 2017). There were two simulators placed in VCE Lindholmen which were a WL with a four lever configuration and a AH. The EXC simulator was placed at CPAK. The simulators' purpose is to give the user a sense of how it is to control a real CE. The simulators are used in various trade fairs in order to create interest and involve the visitors. All functions that are available in the real corresponding CEs are also available in the simulators.

Scenario

A scenario is a systematic description of a possible future situation that could occur from a development of the current situation towards the described situation (Nationalencyklopedin, 2017b). The scenario is made to give a simplified picture of the situation with links to different contributions of sectors in the society. To illustrate the scenario, obtained knowledge from the user studies is used to show the most correct picture as possible.

The scenario is based on the information that were gathered during the pre-study regarding operators choosing to install external joysticks. It also facilitates to further investigate what needs that are lacking for some customers in VCE's current EXC joysticks. The scenario would also serve as a foundation for the concept generation to identify which aspects of the current EXC joystick could be improved for the future CEs and how the scenario could be avoided.

3.1.4 Product Specification

To accomplish a good result from the project work it is important to fully understand the product (Johannesson, Persson and Pettersson, 2013, p. 150). The specifications gives an understanding regarding which requirements must be realized. A product specification was made in order to compile the requirements obtained from the pre study.

3.2 Concept Generation

The purpose of the concept development is creating a space of solutions that will lead to a final concept (Johannesson, et al., 2013, p. 161-162). It is desirable to try to think outside the box and avoid critic of solutions during the concept generation. A lot of iterating and evaluation of concepts is topical to enable further development of concepts. Additionally, a product specification is executed before concept generation to identify elements that needs concept generation.

The concept generation was initiated by choosing the EXC's joystick (see 2.2.3) as a reference joystick for the concept generation. The principle was that if a joystick design covered all the functions of a fully equipped EXC then the number functionalities would be sufficient enough to cover the required functions in the WL and AH. This is assumed to be true since the handheld EXC joystick was the biggest and most functional joystick compared to the joystick configurations that are available in the WL and AH.

3.2.1 Pugh's Matrix of Alternative Solutions

The research of alternative solutions is done in order to see if there are any features from existing products that can be combined or used as inspiration, before initialling further concept generation (SCIENCE BUDDIES, 2017).

The Pugh´s Matrix is done in order to make a selection between different concepts (Johannesson, et al., 2013, p. 183-186). The criteria used must be based on the product specification. A reference solution should be implemented in order to be compared with each concept. Each criteria is valued different depending on how big impact it has on the final concept

For this method, the Pugh`s Matrix was used to compare alternative solutions that have the same or similar solution on the main function, manoeuvring an object. The product that was used as a reference solution was the EXC joystick. Gaming joysticks, RC controllers and ergonomic mouse are products that have been studied. The Pugh's Matrix is made to compare the different products based on the most vital requirements from the product specification. All products from the matrix that identified were found from the internet.

Importance of each requirement is weighed in numbers between 1-3, where 3 is the most important criteria. If the product meets a requirement better than reference joystick a "(+)" is awarded worth 1 point, if worse a "(-)" worth -1 points is awarded and if there is no difference a "S" is awarded worth 0 points. Each point is then multiplied with the weighting ratio. The score is then summed up in total better points and total worse points. The difference between the total better points and total worse points is presented in the total score. The product which has the highest value in total, has most optimally met the given requirements.

3.2.2 Brainstorm

A creative method to produce many ideas is brainstorming (Johannesson, et al., 2013, p. 166-168). The aim is to produce as many ideas as possible. One person is appointed leader in order to make sure all ideas are saved and further encourages the participants to perform. The rules for brainstorming are:

1. *Critique is not allowed*
2. *Quantity is prioritized over quality*
3. *Go outside the box*
4. *Combine ideas*

The brainstorming was divided in two stages where the first stage lays focus on producing as many concepts as possible without taking consideration any restrictions. The second stage lays focus on producing applicable concepts that utilize the benefits of 3D printing in order to offer customizability that exceeds what the competitors offer.

3.2.3 Rapid Prototyping

Rapid prototyping is used in order to work with a living model that easy can be modified based on impressions from the design process (Lyndon, 2010). The ability to show ideas and thoughts through a physical model in addition to the sketches gives further value for usage of this method. Rapid prototyping consist of numerous iterations which consists of 3 elements:

1. *Prototype*
   Take into consideration the given requirements from the product specification (see section 3.1.4) and create prototypes.

2. *Review*
   Take help from users in order to get input for further development.

3. *Refine*
   Based on the gathered comments and reflections, identify elements that can be furthered developed and improved.

Rapid prototyping was done with plasticine in order to quickly verify the large number of concepts which emerged from the second phase of brainstorming. An important aspect of the rapid prototyping was to find the correct dimensions and verify the different concepts from an ergonomic perspective. The process was iterative, using plasticine enabled the possibility to make easy and quick changes in design.

3.2.4 Morphological Analysis

A morphological analysis is used in order to create alternative part solutions from different sub functions that exist from current products (Johannesson, et al., 2013, p. 174-175). Combining the various part solutions, provides several concepts that could be inspiration or solutions for the final concept.

In this case was the morphological analysis used in order to create different concept combinations which was developed from the rapid prototyping. The morphological analysis was also used for narrowing down the number of combinations that could be solve the problem of a universal handheld joystick.

3.3 Evaluation of Concepts

The purpose of doing an evaluation is to evaluate and assess different solutions in order to find the best concept (Johannesson, et al., 2013, p. 179). The concept which has the highest value/quality with the given requirements and wishes in mind is the best choice.

Evaluation of concept was done on the results from the morphological analysis. The Pugh`s matrix of concepts served as the internal evaluation and the external evaluation with experts from engineering- ergonomics- and design departments. The purpose of dividing the evaluation into an internal and external phase was due to intention of evaluating the concepts by the given requirements from the product specification as well as acquiring an objective point of view from experts that have knowledge and experience from engineering, ergonomics and design.

3.3.1 Pugh's Matrix of Concepts

A Pugh´s Matrix is done in order to make a selection between different concepts (Johannesson, et al., 2013, p. 183-186). The criteria used must be based on the product specification. A reference solution should be implemented in order to be compared with each concept. Each criteria is valued different depending on how big impact it has on the final concept.

Importance of each requirement is weighed between 1-3, where 3 is the most important criteria. If the product meets a requirement better than reference joystick a "(+)" is awarded worth 1 point, if worse a "(-)" worth -1 points is awarded and if there is no difference a "S" is awarded worth 0 points. Each point is then multiplied with the weighting ratio. The score is then summed up in total better points and total worse points. The difference between the total better points and total worse points is presented in the total score. The product which has the highest value in total, has most optimally met the given requirements.

The Pugh´s Matrix in this method is used to compare the module concepts that was made in the morphological analysis. The criteria were divided into four categories: general, operating in the EXC, operating in the WL and operating in the AH. This was done in order to value how well concepts worked in each CE.

3.3.2 Evaluation Meetings with Engineering-, Ergonomics- and Design Departments

Evaluation meetings with knowledgeable and experienced employees from CPAC, VCE and Chalmers were organised in order to evaluate the concepts which were developed from the Morphological analysis (see 4.2.4). Engineers from CPAC evaluated the concepts with focus on functionality, industrial designers from VCE design studio evaluated the concepts with focus on design and ergonomic experts from VCE and Chalmers evaluated the concepts with regard to ergonomic principles.

In total were four meetings done with participants from each department. Five concepts made of plasticine were brought to each meeting in order to evaluate the concepts and create further discussion how they potentially could improve. The participants were asked to choose which concept they liked the most and then give feedback on how the concepts could be further developed.

3.4 Analysis of Results

In order to define how VCE will benefit from implementing the 3D printing business model in their operation, analyses were made. Based on the current 3D printing advantages and the identified developments, further arguments were made about how they become apparent for VCE in terms of cost, environmental impact and customer value.

Furthermore, a final SWOT analysis was made in order to define how the proposed business model will impact VCE.

3.4.1 SWOT Analysis

The SWOT analysis is a method that is used in order to create a quick and foreseeable picture over the business goals that can be achieved by selecting an appropriate strategy (Stiftelsen Svensk Industridesign, 2017c). Strengths and weaknesses are internal factors that is affected by the external factors opportunities and threats. By identifying the different factors and analysing them, it is then possible to invest in the strengths and opportunities while eliminating weaknesses and solve threats.

The SWOT analysis was applied on VCE as a business with 3D printing implemented in their operation. This was made in order to get a better understanding of what needs to be focused and improved on. The method was also used in order to conclude the project and verify all the ideas that project has resulted in.

4. Results

The results that the methods resulted in are presented in the following chapter and they are divided in the same categories as in the methods: pre study, concept generation, evaluation of concepts and analysis of results.

4.1 Pre study

This section presents the results from the problem definition, market research, user studies and product specification.

4.1.1 Problem Definition

The pre study was initiated by traveling to VCE in Eskilstuna with the intention to meet the engineers and designers that work closely with developing the construction equipment. Information was also gathered regarding the basics of the different construction equipment by getting a guided tour and observing different CE cabins and joysticks.

The trip ultimately served as a brief in such a way that the expectations from the project work was presented and what general activities had to be made in order to reach the end result. The goal set from the brief in Eskilstuna was to design a handheld joystick that is 3D printed and can be used across the future EXC, WL and AH. Since the future construction equipment will share more commonality between the interior in the cabins, it is supposed that the same joystick will be able to be connected in all three models since there will be an interface connectability that enables this. This in turn paves the way for providing customers with customized joysticks since 3D printing is recognized as being optimal for producing one off products. With the information gathered from the Eskilstuna trip, it was now possible to define the problem at hand and determine what activities had to be made to solve the task.

Defining the problem

The brief that was presented by VCE contained information on how the current situation within the company was and where they wished to be in the near future. The method of problem definition was used to interpret and analyse what the specific assignment was and what areas needed to be examined for the execution of this project. Three questions were answered in order to define the project:

1. *What is the current status?*
   VCE provides a broad range of products and traditional manufacturing methods are exclusively used for producing end use parts and components for the different cabins. While there currently are research projects on increasing the implementation of 3D printing within their operation, it is currently only used for prototyping.

2. *What is the desired status?*
   The new EXC, WL and AH are in VCE's catalogue of construction vehicles that are in development with plans to be launched in 2021. The three types of CEs will share a larger commonality in their cabin interiors with the ambition to integrate a UI display and connection interface that enables the operator to easily connect the joystick across the three CEs. This in turn opens up for the possibility to implement a universal handheld joystick.

   The desired situation is implementing 3D printing technology on a larger scale by offering the customers the possibility to customize their joysticks combined with the ability to switch them easily depending on what joystick is needed. Effectively what is desired is the increase of customer value and implement production of one off joysticks that are ergonomic and suited for the users by exploiting the advantages that 3D printing enables in an industrial company.

3. *How do we achieve the desired status?*
   Milestones had to be set in order to structure the project and also to define what activities were needed to reach every milestone (see table 2).

Milestones	*Activities*
Understand Volvo's CEs and how the joysticks are designed.	Literature study, meetings and interviews.
Understand how 3D printing works, its' advantages and examine the developments of the technology.	Literature study, market research and meetings.
Develop concepts of an ergonomic universal handheld joystick that offers customizability.	Ergonomic studies, market research, user studies, product specification and concept generation.
Develop the final concept. Propose how 3D printing can be implemented in VCE and analyse its' impact.	Concept evaluations, 3D modeling and analyzes.

Table 2. A table that consist of milestones and activities

4.1.2 Market research

The market research resulted firstly in identifying who the customers and end users are. Secondly, it resulted in identifying opportunities to keep customers within VCE operation so that they will not refer to external companies. These external companies were also identified and viewed as competitors. The market research was limited to the Swedish market due to project limitations (see 1.4).

Identifying Customer and End User

The customers were identified as being either construction companies that buy products from VCE's product catalogue directly and hire their own operators or rental equipment companies that buy and rents out CEs to construction companies (see Appendix 3). The rental equipment companies can also provide the service of their in-house employees to operate the CEs at the construction companies' work sites. The purchase of CEs and other products from VCE are done through different dealers.

The end user of VCE's products which in this case was specifically the joystick, were identified as being the person who operates the CE which is considered to primarily be a professional operator (hänvisa till bilaga). The secondary users are different persons who either use CE simulators for educational- or marketing purposes. However since the operators are the main users of the joystick, they are the specified target group when developing a joystick. By focusing on the operator's needs, the needs of the secondary users are considered to be fulfilled.

Defining who the customers and end users are resulted in the conclusion that the needs of the customers and the needs of the end users are intertwined. This depends on the fact that the customer who employ their operators is the buyer of VCE's products. What this means is that the operators needs are also in extension the customers needs due to the fact that the customer wants to provide their employed operators with the right conditions to work efficiently, comfortably and safely. Good working conditions for employees leads to a prosperous working environment that translates to more profitability. This concludes in referring to both the customer and operator when argumenting for customer value since their needs are dependent on each other.

VCE's Operation

The outcome of the meetings were that there is a current problem of a small percentage of customers choosing to instruct VCE's dealers to remove the factory assembled joysticks in the EXCs (hänvisa till bilaga). This is in order to install external joysticks from other companies which are viewed as competitors. This is on the account of either two things:

1. *Preference*
   Operators which are the end users of the joystick do not prefer the current joysticks that VCE offer based on design, ergonomics, button layout and functionality. Since the preference of hand tools is very individual, the current joysticks might not fulfill the specific needs for a small percentage operators. It can also be as simple as operators having a habit of using an old joystick that does not have optimal design and ergonomics compared to today's standards.

2. *Post production attachments*
   Customers has to install an external joystick in the EXC based on optional hydraulics

that are added post production externally. These are the customers that will use the EXC for specific tasks and can change throughout its lifetime depending on which attachments are added or removed. Changing the joystick to one that is designed with additional buttons and functions, is more suited for doing those specialized tasks and becomes a natural outcome to enable the operator to work.

This proves that a small percentage of VCE's customers are not satisfied with the standard joystick or that the limited choice of configurations which is offered is not enough. The limited choice can sometimes restrict the operator to work effectively with additional hydraulics. This in turn forces them to reach out to external companies and this indicates that there is room for improvement to keep all of the customers within VCE's operation.

Competitor Research

There are two external companies which are viewed as competitors on the market which provides external joysticks for the EXC. These competitors are:

SVAB

SVAB Provides customers with ergonomic joysticks that the customer can customize to a certain extent. The customizability is limited to choosing between five joystick handles for which the customer has the possibility to choose what type of buttons they desire on the predetermined slots on the handle. The types of buttons can be chosen from a small set of list and the principal is that every button takes up x number of slots on the handle depending on what type of button it is. The number of buttons that can be added then depends on how many slots are available on the joystick handle which leads to the delivered joysticks differentiating from one another due to the different desires of the customers.

For SVABS' latest handle model, the L8 which is their most popular one, they have also integrated a web configurator which they call *Mongoose.* This enables the customers to create their customized joystick directly on the website, it also provides a live update of how the joystick looks with everything attached. The L8 model has 9 predetermined slots that the customer can fill with the desired number of buttons and there are six types of buttons to choose from. There is also the possibility for the customer to order a hand support add-on for the joystick which helps to relieve the hand and wrist from strain.

Steelwrist

Steelwrist and SVAB are affiliated companies thereof Steelwrist also offering SVAB's L8 joystick with the same level of customizability in their catalogue. They do however also offer their own ergonomic joystick handle that is customizable, the *XControl.* The principle of customizability is the same as in the L8, however the number of slots is limited to only seven but the types of buttons available are the same.

Other external suppliers that provide additional hydraulics for EXC's have together with Svab and Steelwrist signed a contract stating that everyone must follow standards regarding the placements of certain functions in the EXC and functions on the joysticks (Maskinleveatnörerna, 2017b). The contract, "Funktioner i förarreglage för grävmaskiner", is an industry agreement that is owned and managed by the Swedish trade association, Maskinleverantörerna. The reason for the contract is to heighten security since there have been casualties involving operators making mistakes due to the change of function layout in the EXC and joysticks.

The agreement describes how the coupling of different functions should be made when external hydraulics are added after the delivery from the CEs` manufacturers factory (Maskinleverantörerna, 2017a). There are however some exceptions and it depends on some functions already being locked to the factory built CEs`, (see 2.2.3).

3D Printing Developments and Trends

Additive manufacturing has been around for more than 30 years but the majority of growth has been made during the last 5 years (3D HUBS, 2017). The result has been a large increase of 3D printers that has entered industry which has led to ease access for designers (see figure 27). 3D printing has developed from being considered a niche technology that was available to a small segment of the manufacturing industry to being a cost competitive manufacturing method that is utilised in many industries. With different developments being made constantly in additive manufacturing, we are closing in on the day when traditional manufacturing is going to be played out 3D printing technology.

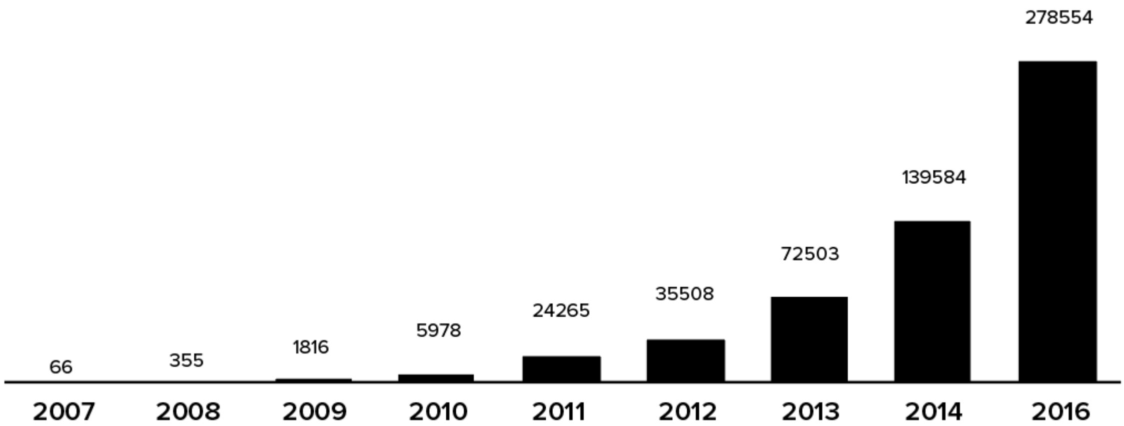


Figure 27. Number of printers under $5000 sold globally per year (3D HUBS, 2017). Reprinted with permission.

Better Efficiency for Larger Production Runs

The advantages that comes with 3D printing are many but compared to traditional manufacturing, it is still not competitive when it comes to a larger production run (3D HUBS, 2017). The turning point is around 1000 to 10000 in most cases and the number is dependent on the design and material used. But as developments are being made regarding lowering the cost of both the 3D printers and materials used, the efficiency for larger scale production runs is expected to increase in the near future.

The improvement on printing time has also been significant and the prediction is that instead of only doubling in printing speed every couple of years, the speed is probably going to go 10x, 50x, 100x in the next five years (Diamandis, 2016). There are already examples of companies such as Carbon3D that are showcasing that they can develop to a convincing scale with 3D-printing that compared to today's printing standard can be up to 100 times faster.

More material choices and different materials in a single print

There are currently more than six-hundred materials available for 3D printing today which is quite many and most are plastics and metals but the alternatives are still limited compared to conventional colours, finishes and product materials (3D HUBS, 2017). Developments are however being made and the range of materials is catching up rapidly with new materials such as woods, new metals, composites, ceramics and even chocolates are examples of development in material alternatives.

A development that is estimated to be reached in the near future is the ability to print finished mixed-material devices (rubber, structure, wiring) — e.g., electronics, cars, houses (Diamandis, 2016). Today it is already possible to 3D print a toy truck with metal chassis, clear plastic or glass windshield and rubber tires in one single print. The next aspiration is the ability to print devices with circuits, sensors and logic that are fully functional.

Increased strength and endurance

Due to the layer by layer manufacturing with 3D printing, it can lead to a part strength that is not uniform (3D HUBS, 2017). This results in parts that are often weaker compared to their counterpart that is manufactured traditionally. The strength and durability of the part is also dependent on which direction they are printed, in other words in which orientation the part is produce layer by layer. A problem regarding repeatability is also a current issue where respective 3D printing machine can have a slight impact on the properties. Technical improvements are however being made where 3D printing processes are being developed and the limitations will ultimately be removed.

Carbon3D is a company that has already started to make breakthroughs in this area besides increasing the printing speed whereas they have successfully developed the 3D printing technology (see 2.3.2) named Continuous Liquid Interface Production (CLIP) (Carbon, 2017a). This method removes the flaws that are present with current layer based 3D printing technologies.

The trade-off between mechanical properties and surface finish is no longer forced whereas the parts are not repositioned harshly with every layer and makes it possible to offer surface finishes and details needed for end-use parts from a large range of materials with engineering grade mechanical properties (Carbon, 2017b). Another benefit is that the 3D printed parts are not dependent on which orientation they are printed because CLIP printed part are consistent and behave the same in every direction.

4.1.3 User Studies

This section presents the results of the interviews, participant observations and the scenario.

Interviews

The participating interviewee were operators who use EXC, WL and AH from VCE. All the interviews were done at the operator's work site. The questions were compiled in a semi-structured order with opportunity for open questions. Some probing occurred during the interviews which gave interesting input that were not addressed from the initial questions. In total were five interviews was made in two different work sites, both placed in Gothenburg or close by. All interviewees were working fulltime as operators of CEs. The average age of the interviewee was 51 years with average work experience 20 years. All interviewees were men.

The first two interviews was made possible thanks to PEAB. The worksite was located in the city close to Götaälvbron where they are building an underground passage. The second visit at a work site, where three interviews were made, belonged to Skanska. The work site was located in Ale were they extract sand, gravel, shingle and rubble. PEAB and Skanska are construction companies which are customers to VCE.

Following is a concluded text with comments and reflections from the interviews. For the complete list of interview questions, see appendix 4.

Design

All operators expressed that they think the current joystick configuration has room for improvement. However the operators found Volvo´s CE´s to be among the best in the industry, mainly because the CEs are experienced to be comfortable to operate and easy to manoeuvre.

Ergonomics

The operators expressed that it was not necessary to have a hand moulded grip for a joystick to be ergonomic. It was considered to be sufficient to just have a universal ergonomic grip that could be made available with different sizes to accommodate hand sizes. Something they expressed was missing was the ability to variate their grip ergonomically. It was put forward that they themselves and colleagues sometimes placed their hand on top of the joystick to force a varied grip which was not optimal since the joysticks was not designed to be used in such way. Some operators apparently gripped the joystick in bizarre ways in order to variate their grip which from an ergonomically point of view were not comfortable and ideal.

One operator with over 20 years of experience who had used multiple CEs expressed that each generation of CE had small development of the joystick and each update is perceived as bothersome but eventually one prefers and get used to the current configuration. Among all the different joystick configurations that operator had used, he felt that the SVAB joystick which is one of the companies that sells customized joysticks that enables user adjustment was worth mentioning because of the design that offered good grip.

Functionality

Commonly among many operators is that they preferred configuration with the various short levers instead of the handheld joystick because they prefer working with small movements in the WL. They described it as a “piano-playing” control scheme which was considered seamless. Furthermore, several operators expressed that they had used the same configuration of joystick for many years and even if they initially felt it was a hassle to learn to use it, they had adjusted to the design and it was now preferable.

Future Development

The operators expressed some desirable functions that they felt were missing from the current configuration of joysticks. The possibility of regulating movement sensitivity by yourself is desirable since it is only possible for service technicians to change the settings of the joystick today. The operators found the change of settings to be bothersome. For it to even be possible of regulating the sensitivity of the joystick it is required to be electrically controlled which was preferred by all operators. Furthermore, it was desirable to directly run the wipers from the lever, access to weighting system and comradio was desirable.

The operators were finally asked to explain what they think the future joystick would look like. Some interesting comments were that ergonomics is the most important aspect especially the possibility to variate grip was considered most important which is not currently offered. Function and ergonomics were considered to be more important than aesthetic appeal.

The single lever that is available currently in the AH was not seen as problematic from the operators since an entire workday consisted of approximately only transporting material while the bucket was used approximately only 10% of the time during a work day. While the EXC and WL joysticks was continuously used actively during a work day, they were considered to be in greater need of development.

Participant Observations

Usage of the simulators gave an insight on how the operator's workplace is designed and it also provided a better understanding of how it feels to operate them.

Excavator Simulator

Sitting in the EXC simulator (see figure 28) was perceived as comfortable and the placement of the joysticks felt very natural as well. The design of the joysticks was perceived as very neutral which by some is considered a good thing, but showed a lot of room for improvement since it did not feel ergonomically optimal for long term use even though the EXC joystick is used almost constantly during a work day as expressed from the operator interviews. Adding some kind of texture to increase friction would benefit the joystick very well and compensate for the neutral grip. The buttons felt responsive and were easy to press. The synergy between buttons and hydraulics felt natural as expressed from the interviewed operators.

Figure 28. EXC simulator (Appendix 9, 2017). Reprinted with permission.

Wheel Loader Simulator

The WL simulator (see figure 29) was constructed with a four lever configuration. The levers were close to reach from the fingertips and felt very responsive when used. As an operator it felt desirable to be able to use the different levers without having to move the palm to much since the spacing between the levers was not ergonomically optimal for finger use or as the operators referred to as “piano playing” control scheme.

Figure 29. WL Simulator (Appendix 9, 2017). Reprinted with permission.

Articulated Hauler Simulator
The AH simulator (see figure 30) shared the same comfortable design and placements of joystick as in the other 2 CEs. Using the AH single lever felt very natural as well and provided the same feel as using the joysticks in the other two simulators.

Similar to the levers in WL, the lever felt very responsive and intuitive to use. Since there was only one lever and the hydraulic buttons where close to reach, the control board used in AH was perceived as optimal for the amount of time it is used during a workday.

Figure 30. AH Simulator (Appendix 9, 2017). Reprinted with permission.

Scenario

Sven is currently a CE operator and has worked as one for a total of 25 years whereas he has operated an EXC for 15 years and a WL during the last 10 years. The majority of work sites that Sven has worked on during his years as an operator used CEs from Volvo. The switch to operating a WL happened because Sven volunteered to take the internal course when the manager at his work site needed an extra WL operator and could not find someone to hire. Sven ended up really enjoying to operate the WL and he found that the working method suited him better, he has worked as a full time WL operator ever since. His favourite joystick configuration to use is the 4 lever configuration as he thinks it feels very natural and seamless to operate.

However for the last three weeks at his current work site, Sven has been forced to replace a co-worker that operates an EXC and is on sick leave. He has not been put in this position yet where he had to switch operating a CE ever since he made the switch to a WL ten years ago. He does however recognize the situation because he has had operator friends working on different worksites that has to frequently switch between an EXC and WL, and in some cases even to a AH.

The new work situation seems to be problematic for Sven because the joystick in the EXC was not the same as the one he had used during his 15 years as an EXC operator. He did not feel confident at all during the first days of the replacement and it took him a full week to get used to the button functions. He also felt that the joystick did not suit him ergonomically whatsoever.

Sven tells a operator friend about his new problematic working situation and his friend refers him to a company called SVAB that offer customized joysticks for EXCs. This was something Sven was unaware of, that there is a possibility to install external joysticks. This led to him telling his manager to order one the following day. The motivation was that Sven felt unable to work effectively and safely with the joystick that was currently installed which results in him having his own customized joystick by the end of the week.

4.1.4 Product Specification

The final product specification was categorized in five categories: technical & dimensions, ergonomics, design, functionality and joystick connection interface. Content for the product specification was concluded from the pre study. The gathering of information resulted in requirements.

Due to the project limitations (see 1.4) technical requirements such as electrical wiring within the joystick and also requirements regarding joystick properties has been disregarded. The properties that has been has been disregarded are mechanical- and material properties. Furthermore, the requirements regarding regulations and recommendations of the machines according to Arbetsmiljöverket (see 2.4.2) are assumed to be fulfilled.

The focus of the project is to design a handheld joystick that at least enables the operator to use the base attachments across the EXC, WL and AH. The joystick should however be designed in such a way that it offers functionality for a CE that has added attachments.

Focus lays on the design, ergonomics, functionality and the interface connection for the future 3D printed joysticks. The requirements for the joystick connection interface in the future CE's is assumed to be fulfilled due to the project limitations. However, the requirements for the interface is still included to define what is possible for the future concept.

For the complete list of requirements see appendix 6.

4.2 Concept Generation

This section presents the results from the Pugh´s Matrix of alternative solutions, brainstorming, rapid prototyping and morphological analysis.

4.2.1 Pugh's Matrix of Alternative Solutions

The result of the matrix showed that the gaming joysticks Sven and Xbox one controller fulfilled the requirements from product specification most optimally. Both products had six criterias that were better compared to the current configuration of EXC joystick. The ergonomic mouse and airplane joystick received total points that were better than the reference joystick which indicates that they have elements that could be taken into consideration at further concept generation. The worst result was obtained by the RC controller, which according to the matrix is the worse product to meet the requirements compared to the other products. To see how each product performed with regards to the criterias and weighting ratio, see figure 31.

For more information regarding each product from in the Pugh's matrix, see appendix 5.

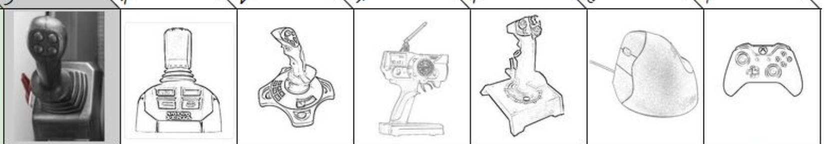
Pughsmatris								
Concept Comparison Better (+) The same S Worse (-)	Alternative joysticks							
Criteria	Weighting ratio	Reference Joystick (EXC)	Volvo penta joystick	Gaming joystick - SVEN	RC controller	Airplane joystick	Ergonomic mouse	Gaming Joystick - Xbox
								
Enable varied grip	3		(-)	(+)	(+)	S	(-)	S
Provide precision in movement	3		S	S	(-)	(+)	(+)	(+)
Give opportunity for customization of design	2		S	(+)	(+)	S	S	(+)
Capacitate space for functions	3		S	(+)	S	S	S	(+)
Portable for transportation	1		(+)	(+)	(+)	(+)	(+)	(+)
Reduce risk for pinching	3		S	S	(-)	S	S	S
Aesthetic appeal	3		(+)	(+)	(-)	S	S	(+)
Intuitive usage	2		S	(-)	(-)	(-)	(+)	(-)
Ergonomicly designed for long usage	3		(-)	(+)	(-)	(+)	(+)	(+)
The number of criteras that were better			2	6	3	3	4	6
The number of criteras that were worse			2	1	5	1	1	1
The number of criteras that were the same			5	2	1	5	4	2
Total better (+) points			4	15	6	7	9	16
Total worse (-) points			6	2	15	2	3	2
TOTAL			−2	13	−9	5	6	14

Figure 31. Comparing products that have the same main function, maneuvering an object. Author's own copyright.

4.2.2 Brainstorming

Since the purpose of the project was to implement 3D printing to manufacture end use joysticks, it resulted in free reigns when generating concepts. This is due to the additive manufacturing process which enables complex designs to be created without having to take account to the restrictions that are current with traditional manufacturing (see 2.3.2).

The brainstorming resulted in two phases of concept generation. The first stage resulted in thumbnail sketches that were made without taking regards of any limitations.

The second stage resulted in creating realistic sketches with the intention to propose how 3D printing can be utilized in order to offer customers customizability. In addition to creating applicable sketches, the second phase brainstorming resulted in forming an innovative business model that offers modularized joysticks with variation and customization.

First stage ideas

Combining the extensive pre study and final product specification with the analysis of alternative solutions, the concept generation resulted in a few start thumbnail sketches. The sketches were presented and discussed between the group members and then compared with VCE's current joysticks, the competitor's joysticks and also the alternative solutions.

Each project member sketched individually and focused on the aesthetics, base design and base functionality for the future 3D printed joysticks.

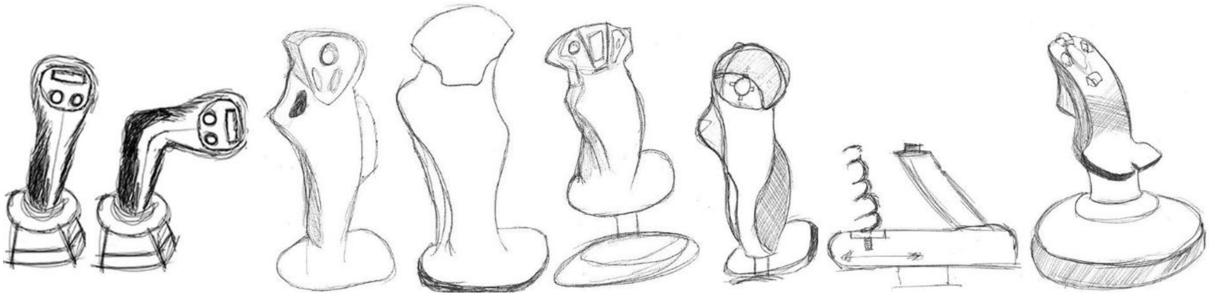


Figure 32. Results from the first stage of brainstorming. Author's own copyright.

The result of the first stage sketching gave a space of solutions with many interesting ideas but the problem was that none of the sketches was experienced to really utilize the benefits of 3D printing to the desired extent. It was considered that a system or some kind of business model is necessary in order to utilize the benefits of 3D printing in the most optimal way to provide customers with customizable joysticks.

Second stage - Forming a Business Model

After reviewing the sketches a conclusion was drawn that a business model that utilizes the benefits of 3D printing is necessary in order to offer effective customizability for the customer and fulfil the needs they have better than VCE's current joystick competitors.

An important aspect of the discussion was that every operator has different needs that needs to be fulfilled. Even if the review of the alternative solutions resulted in the gaming joysticks and ergonomic mouse being the products that meet the criteria optimally (see 4.2.1), shows that it is all based on specific criteria. Since every operator has their own criteria which they value differently depending on needs and preferences, it results in every operator desiring different joysticks.

VCE's competitors SVAB and Steelwrist offer customization of joystick for operators, but only to a certain extent. Their assembly will not be optimal for Volvos future CE's where it will be possible for the operator to connect their customized joystick across the EXC, WL and AH. If a joystick is going to be designed in such a way that it can be used in all three models, the joystick design has to be redesigned since requirements for all three types of joysticks has to be fulfilled in one universal design. The new interface and connectability in the future joysticks will also open up for new preferences and criteria from the operators. Just offering up to five different joystick handles and a limited set of button layouts and button types will not be able to fulfil all the new requirements from the product specification efficiently.

By further brainstorming and conducting discussions, a new business model was created for how VCE can exploit the advantages of 3D printing and offer customers value and a efficient customizability that is simple and user friendly. The principle of the new business model was to modularize the joystick design in which the customer has extended influence of the entire joystick design based on what requirements needs to be fulfilled. Modularizing the joystick to defined modules gives the customer a catalogue of solutions to choose from. The design of the joystick was divided into 4 modules:

Grip template

Grip templates (see figure 33) will be available in the business model and designed differently depending on the given requirements and specific tasks it must perform. Each grip template is designed with a predetermined number of slots for which the customer can choose to add buttons that are ergonomically and strategically placed. The predetermined slots will be placed specifically on each grip, depending on the design of the grip. The grip templates will be available in three standardized sizes: small, neutral and large in order to accommodate individual preferences and hand dimensions. The size of buttons and amount of slots does not change between each standardized size.

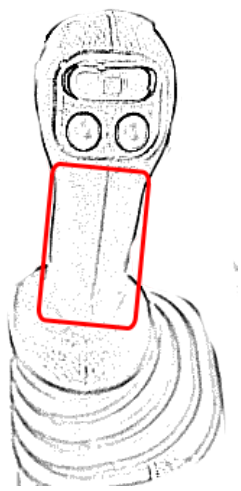


Figure 33. Illustration of grip template. Author's own copyright.

Some grip templates are equipped with an unloading surface referred to as power grip. The power grip refers to a grip that is designed to provide more precision and control without any buttons interfering while gripping the grip template on a determined location. The power grip enables the operator to grip the joystick with the hand positioned in a natural manner. This minimizes the required force while also increasing precision which in turn reduces the strain load. The power grip is formed by the ergonomic principles that was derived from the theoretical framework (see 2.4).

Following figures shows sketches of grip templates and examples how they can be designed.

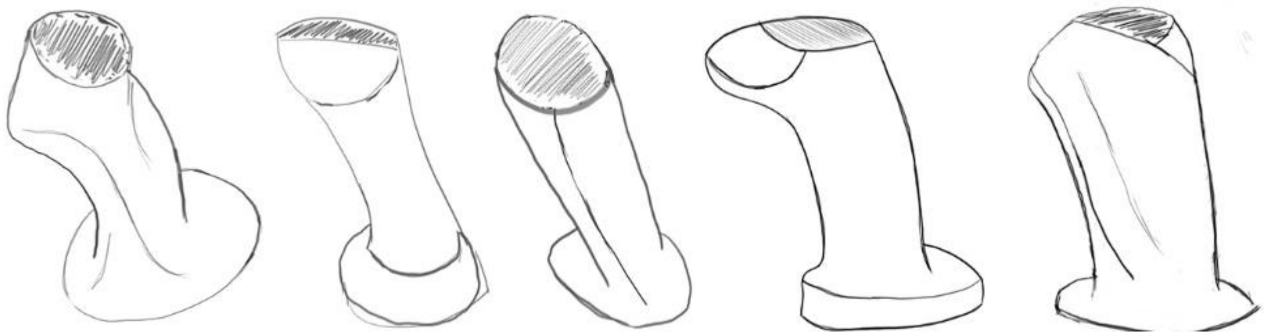


Figure 34. Results from the second stage of brainstorming. Author's own copyright.

Joystick head

The concept of a universal handheld joystick that will have the functionality of three CEs will lead to new requirements that was not present when a joystick is only designed to be accessible in one CE. That is why it is important to think about all needs that exist for each CE since a universal joystick needs to provide full functionality for all three CEs. Something that was very inspirational finding a solution for the new needs was reviewing alternative solutions such as the Xbox controller, Sven joystick and the ergonomic mouse. Reviewing these alternate solutions on how a joystick can be designed with regard to many functions combined with good ergonomics which resulted in the module joystick head.

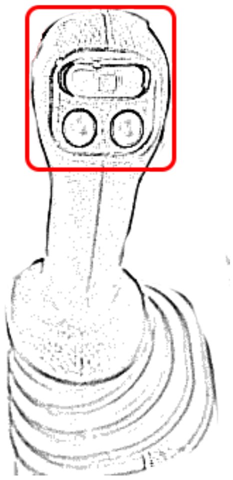


Figure 35. Illustration of joystick head. Author's own copyright

The joystick head is the part of business model which revolutio- naries and changes how a handheld joystick can provide more than one way of usage. Some joystick head modules provide the ergonomic need of varied grip and the functional need of additional functions since the joystick can function across the EXC, WL and AH. The operators have different preferences regarding the way of working with their joystick as evidenced by the interviews (see 4.1.3).

The joystick head (see figure 35) is complementary to the grip template even if some joystick heads may enable varied grip and offer a secondary use in addition to the grip, it shall never affect the already selected buttons and base functionality of the grip template.

The joystick heads will also have predetermined number of slots for which the operators can choose to place buttons on. Since some joystick heads will be designed to be enfolded and enable varied grip, they will also be available in three standardized sizes to accommodate individual preferences and hand dimensions. Like the grip template, the enfolding joystick heads will be available in small, neutral and large when customizing the joystick. The size of buttons and amount of slots does not change between each standardized size.

Following figures shows sketches of joysticks head and examples how they can be designed.

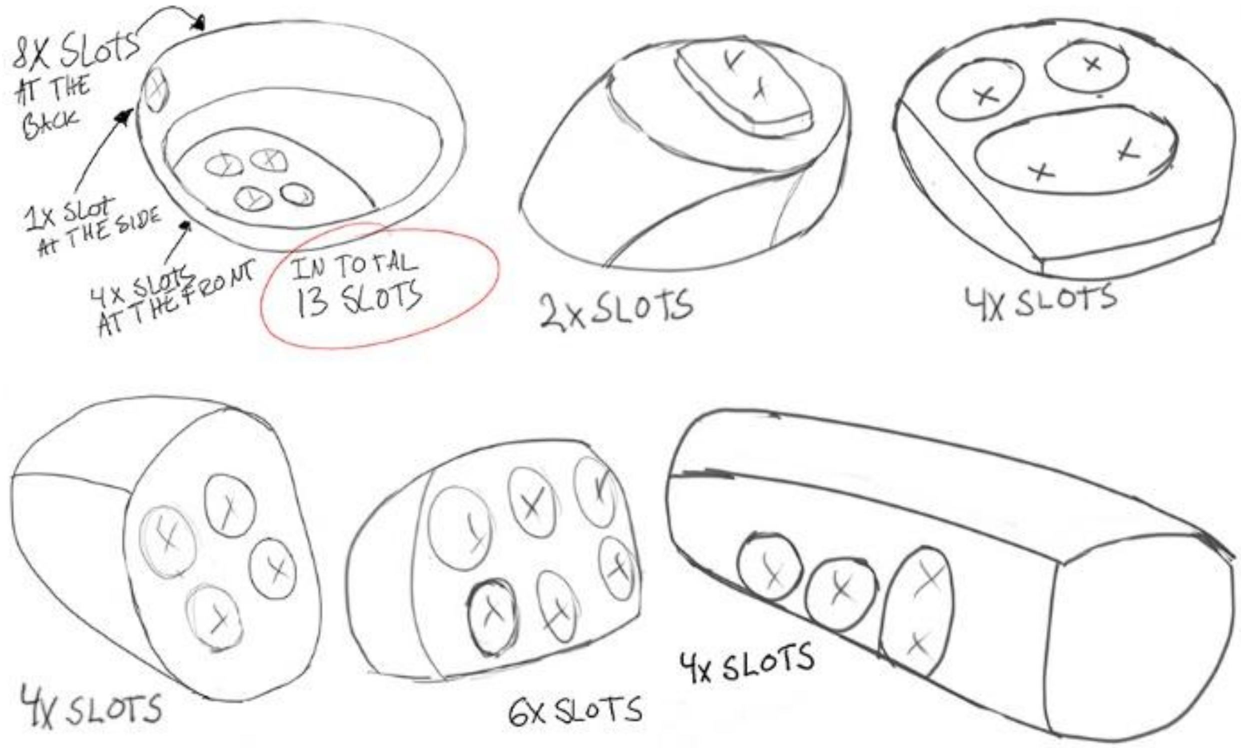


Figure 36. Results from the second stage of brainstorming. Author's own copyright.

Button types

The choice of button types depends on the design of grip template and joystick head. The buttons can only be placed on the predetermined slots that are available on the grip template and joystick head. Each button type determines how many slots are filled up. The amount of slots that are available on each grip template and joystick head decides how many functions that can be added on each module combinations. The buttons are designed to be functional and in some cases more optimal for specific grip templates and joystick heads.

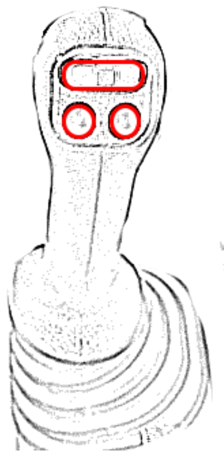


Figure 37. Illustration of button types. Author's own copyright

In order to heighten cognition senses when using the joystick, LED-lights that show which buttons are activated will be available for all buttons. Since the universal joystick will be available to connect across the three CE models, it is important to show e.g. which buttons are activated when connected to a specific CE and which buttons are not connected to any functions.

Following figures shows sketches of button types and examples how they can be designed.

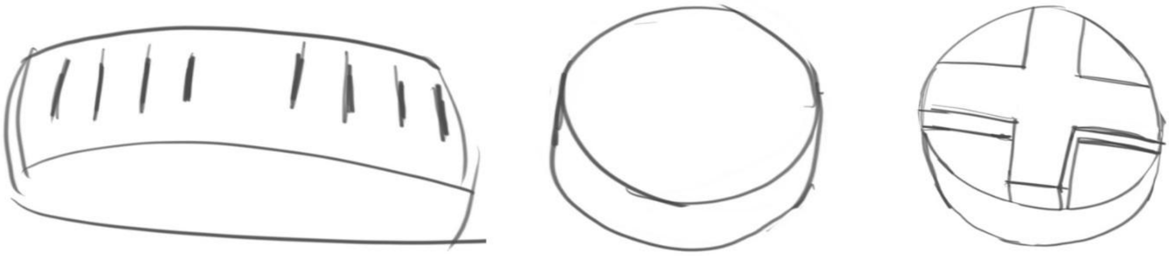


Figure 38. Results from the second stage of brainstorming. Author's own copyright.

Add-ons

The add-ons module gives the customer possibility to add hand support for decreased strain, grip texture for better grip and comfort and inscription. The add-ons are made to increase customer value by offering more control of form and affect appearance and personation. The add-ons are optional and not mandatory in order to produce a fully functional joystick. The add-ons are applicable only on grip templates and joystick heads. Exception is applied to the hand support add-on, since the add-on can only be applied on the grip template.

Following figures shows sketches of add-ons and examples how they can be designed.

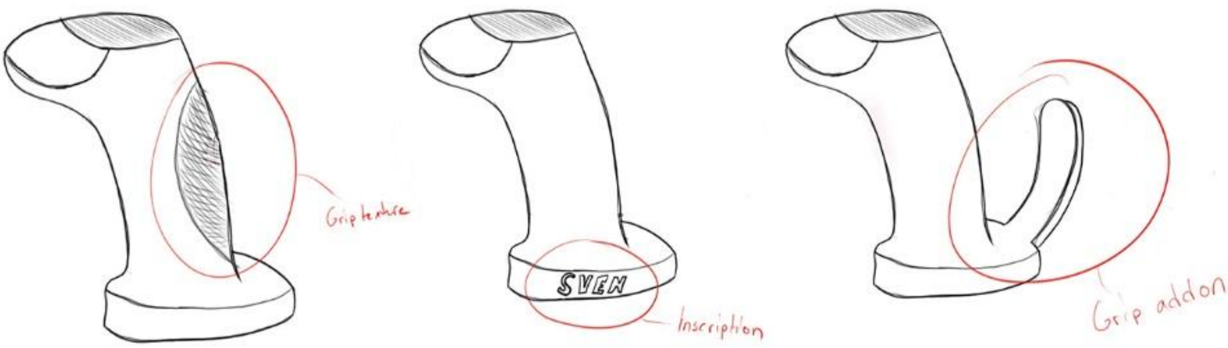


Figure 39. Results from the second stage of brainstorming. Author's own copyright.

The hand support add-on is made to give the user hand support in order to decrease strain when operating the joystick by the grip template. The hand support gives support to the back of the hand palm. The hand support is also made to work like an unloading surface when not operating the joystick. The creation and configuration of the hand support is based on decreasing static strain which is ergonomically optimal for joysticks (see 2.4.1).

The grip texture add-on gives possibility to offer better grip and comfort by enabling additional material to be placed on the surface where the operator grips. Implementing a grip texture increases friction which requires less force when operating a joystick according to ergonomic principles (see 2.4.1). The 3D printing technologies that are currently available, do not enable printing different grip textures consisting of different materials e.g. rubber directly on the joystick which implies it needs to be done post production. Based on development and trends of 3D printing (see 4.1.2) it is assumed that future 3D printers will be able to print with multiple materials which would enable grip textures directly on the joystick without the need of doing it post production. Participating in the EXC simulator revealed that adding texture to the EXC joystick currently used would increase friction and compensate for the neutral grip which emphasizes the value of the grip texture add-on.

The inscription add-on gives possibility to in script letters, numbers and figures on the modules. The add-on allows the customer to in script name, figures and logo of the operator name, company name or whatever the customer desires to have in scripted. Inscriptions are limited to words, numbers and logos that are not considered controversial.

4.2.3 Rapid Prototyping

All of the joystick modules were made with made in a neutral size for both grip template and joystick grip, which is fully described in the brainstorming section (see 4.2.2). The purple spots in the figures represent the slots that could be used for the button layout. For more information about each module from every category, see appendix 7.

Rapid prototyping resulted in a matrix containing three categories: grip template, joystick head and button types. Since the add-ons are optional in order to produce a complete functional joystick, they were not taken into consideration when doing the rapid prototyping. Focus of the rapid prototyping was creation of complete joysticks with regard to design, functionality and ergonomics.

Table 3 shows the results of rapid prototyping. In total were five grip templates, six joystick heads and three button types created.

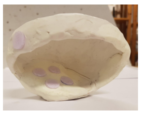
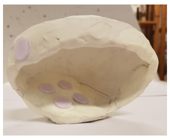
Grip Template	Airplane Grip	Smooth Grip	Charge Grip	Edgy Grip	Stick Grip	
						
Joystick Head	Four Slot Head	Roller Head	Mouse Head	Gear Shift Head	Six Slot Head	Handlebar Head
						
Button Types	Push Button	Roll Button	4Axis Button			
						

Table 3. The different modules that were produced from the rapid prototyping. Author's own copyright.

4.2.4 Morphological Analysis

The morphological analysis resulted in a matrix consisting of different joystick modules that were created from the rapid prototyping (see 4.2.3). None of the add-on modules were integrated in the morphological analysis since focus lied in design, functionality and ergonomics. For a description of each module from the different concepts see appendix 7.

The morphological analysis resulted in a total of five module combinations which were regarded to solve the problem of designing a universal handheld joystick that functions across the EXC, WL and AH.

<table>
<tr><td colspan="2">Smooth Mouse</td><td>Buttons
Push button & Roll button</td><td rowspan="3">=</td><td rowspan="3"></td></tr>
<tr><td>Joystick head
Mouse head</td><td></td><td>4x Back

1x Side

4x Front
</td></tr>
<tr><td>Grip template
Smooth grip</td><td></td><td>1x Back
</td></tr>
</table>

Table 4. Smooth mouse. Authors`s own copyright.

This combination is called smooth mouse and was chosen because it provided a good grip with the possibility for a power grip. The combination gave opportunity for varied grip by taking advantage of the mouse head which is designed to optimize a similar method of use that a WL with multiple levers provide. The combination of smooth grip and mouse head was interesting since the both modules have a round and curvy design that together creates a combination that is perceived to complement each other. The smooth mouse offers space for 14 slots in total, 9 slots at back, 1 slot at the side and 4 slots at the front of the joystick.

<table>
<tr><td colspan="2">Charge Mouse</td><td>Buttons
Push button & Roll button</td><td rowspan="3">=</td><td rowspan="3"></td></tr>
<tr><td>Joystick head
Mouse head</td><td></td><td>4x Back

1x Side

4x Front
</td></tr>
<tr><td>Grip templat e
Charge Grip</td><td></td><td>1x Back
</td></tr>
</table>

Table 5. Charge mouse. Authors`s own copyright.

The charge mouse consists of the mouse head and charge grip that like the smooth mouse has a round and curvy design that creates a combination that is perceived to be naturally assembled thanks to the clear lines and curvy charge grip that fit well with the mouse head. It also provides the ergonomic power grip Furthermore, the mouse head gives opportunity for a similar method of use that a WL with multiple levers provide (see 2.2.3). The Charge mouse offers space for 14 slots in total, 9 slots at back, 1 slot at the side and 4 slots at the front of the joystick.

Gear Plane		Buttons Push button		
Joystick head Gear Shift Head		2x Back  4x Front 	=	
Grip template Airplane Grip		1x Back 		

Table 6. Gear Plane. Authors`s own copyright.

The gear plane consists of the gear shift head and airplane grip that together creates a combination that reminiscent of a typical airplane joystick (see appendix 5). The combination of gear shift head and airplane grip provides varied use since the grip template and joystick head are designed to be gripped and operated from. The airplane grip is designed with a power grip in order to provide higher precision in movement. The joystick has seven slots available, six slots on the joystick head and one slot available on the grip template.

Six Slot Stick		Buttons Push button & Roll button	=	
Joystick head Six Slot Head		1x front  4x Front 		
Grip template Stick Grip				

Table 7. Six Slot Stick. Authors`s own copyright.

The six slot stick has is similar in design compared to the EXC joysticks that VCE currently offers. The design of the six slot stick is neutral and clean without a power grip or a joystick head that is comfortable to grip and operate from. The big difference is in the design of joystick head, were the six slot stick is rectangular and has place for six slots while the EXC joystick head used in current EXC has a square layout with place for maximally four slots.

Handlebar lever		Buttons Push button & Roll button		
Joystick head Handlebar Head		1x front  1x Side  2x Front 	=	
Grip template Edgy Grip		1x Back 		

Table 8. Handlebar lever. Authors`s own copyright.

The handlebar lever has a simple design with no advanced or complicated curves. The Edgy grip has a sharp surface which offers a power grip. The handlebar head formed like a bike grip which in combination with the edgy grip gives the handlebar lever a special design that differs from the other combinations. The handlebar lever gives possibility to be operated by the edgy grip aswell by the grip friendly handlebar head which can provide an alternate way of the "piano playing" control scheme that operator expressed as desirable. In total there are six slots available, five slots on the handlebar head and one slot available on the edgy grip.

4.3 Evaluation of concepts

The following section presents the results from the Pugh´s matrix of concepts and evaluation with engineering- ergonomics- and design departments.

4.3.1 Pugh's Matrix of Concepts

The Morphological analysis resulted in five different combinations of modules that was considered to solve the problem definition (see 4.1.1) and was evaluated in regard to how well they fulfilled the requirements from the product specification (see 4.1.4). The reference solution for the matrix was the EXC joystick (see 2.2.3). For a description of each module from the different concepts see appendix 7

The outcome of the matrix showed that all concepts received total points than were better compared to the reference joystick. Smooth Mouse, Charge Mouse and Gear Plane received the best total points since they functioned well in each CE`. The Mouse Head and the Gear Shift head gave opportunity to operate their joysticks in a way that differs from traditional usage while also enabling varied grip in combination with their grip template.

The Six sot stick was similar to the reference joystick, only better in two criterias compared to the reference solution. The result that the Six Slot Stick received was due to the big similarity in design and function compared to the original EXC joystick. It did not perform better regarding the different criterias of the CE except in two criterias of the general category.

The Handlebar lever performed good in the WL and AH since it offered functionality that was more suited for the CEs` which depended much on the configuration of joystick head called Handlebar head. Similar to the Smooth mouse, Charge mouse and Gear plane, the Handlebar head was created to give opportunity for varied grip.

To see how each product performed with regards to the criterias and weighting ratio, see figure 40.

Concept Comparison Better (+) The same S Worse (-)		Weighting ratio	Reference joystick (EXC)	Smooth Mouse	Charge Mouse	Gear Plane	Six Slot Stick	Handlebar Lever
			Concepts					
	Criteria							
General	Enable varied grip	3		(+)	(+)	(+)	S	(+)
	Provide precision in movement	3		S	S	S	S	S
	Give opportunity for customization of design	2		(+)	(+)	(+)	(+)	(+)
	Capacitate space for functions	3		(+)	(+)	(+)	(+)	S
	Portable for transportation	1		S	S	S	S	S
	Reduce risk for pinching	3		S	S	S	S	S
	Aesthetic appeal	3		(+)	(+)	(-)	(-)	(-)
Operating in the EXC	Intuitive use	2		(-)	(-)	S	S	(-)
	Ergonomicly designed for long use	3		(+)	(+)	(+)	S	(+)
	Joystick grip is adjusted for the majority of users	3		(+)	(+)	(+)	S	(+)
	Offer functionality	3		(+)	(+)	(+)	S	(-)
Operating in the WL	Intuitive use	2		(+)	(+)	(+)	S	S
	Ergonomicly designed for long use	3		(+)	(+)	(+)	S	(+)
	Joystick grip is adjusted for the majority of users	3		(+)	(+)	(+)	S	(+)
	Offer functionality	3		(+)	(+)	(+)	S	S
Operating in the AH	Intutive use	2		(+)	S	(+)	S	(+)
	Ergonomicly designed for long use	3		(+)	(+)	(+)	S	(+)
	Joystick grip is adjusted for the majority of users	3		(+)	(+)	(+)	S	(+)
	Offer functionality	3		(+)	(+)	(+)	S	(+)
			The number of criteras that were better	15	14	14	2	10
			The number of criteras that were worse	1	1	1	1	3
			The number of criteras that were the same	3	4	4	16	6
			Total better (+) points	44	41	41	5	29
			Total worse (-) points	2	2	3	3	8
			TOTAL	42	39	38	2	21

Figure 40. Pugh`s matrix of concepts. Author's own copyright.

4.3.2 Evaluation Meeting with Engineering-, Ergonomics- and Design Departments

The external evaluation with the different departments facilitated in reviewing the 5 module combinations from the morphological analysis, the proposed business model with modularized joysticks and providing guidance regarding different aspects of the joystick.

Too see what questions were asked in order to conclude the following information that is presented, see appendix 4

Meeting with Engineers

A meeting with three engineers from CPAC was organised at their office in Mölndal. The engineers found the concept with modular thinking to be very interesting and innovative. They pointed out that it is good to be able to provide a range of solutions to a necessity but it is important to maintain the Volvo premium feeling. Premium feeling refers to fewer products to choose from, implying a quality before quantity feeling from a customer's point of view. If the customer wants a specific design then it is important to maintain the premium feeling when developing the module in order to not compromise the brand.

They emphasized that having the possibility to customize almost the entire joystick must never endanger the operator's safety or ability to operate the CE. The engineers expressed that the UI display in the new models released in 2021 should be utilized to increase intuitive usage and safety. This is due to the probability of an operator that might be put in a situation where they are forced to use a joystick that was not customized specifically for them.

When the Engineers were asked to choose which concept the felt was the best, they found the Smooth Mouse and Charge Mouse to be the most innovative and interesting configuration. They especially liked the mouse head since it offered varied grip and plenty of functionality. They also experienced charge grip and smooth grip to have a firm and good grip but they could not decide which one was better.

Meeting with Ergonomic Experts from Chalmers and VCE

Two meetings with ergonomic experts from Chalmers respectively VCE were organised by dialogue and video conference. The meetings gave further input on what to take in consideration regarding ergonomics. The ergonomic experts highlighted the importance of varied grip because not all operators use a joystick in the same way. They also highlighted the fact that it is important to make a joystick that strives to be neutral, even if it is customizable, because it is possible that multiple operators use the same joystick.

The ergonomic experts liked the Mouse Head because it together with any joystick grip provides the possibility to operate a CE in multiple ways. Regarding the grip, they found Smooth Grip and Charge Grip to be really good because the operator could use a power grip that gave full control of the joystick without any buttons interfering. Smooth Grip and Charge Grip were perceived to be very similar but the ergonomist from Chalmers preferred the Smooth Grip since it had a more neutral design that suited more operators. Altogether they preferred the Smooth Mouse concept the best.

The meetings also resulted in several ergonomic guidelines which complements the ergonomic principles in the theoretic framework (see 2.4). The recommendations were:

- *Wrist should be as straight as possible*
- *The joystick should provide unloading surface when not active used*
- *Decrease the static load*
- *Minimize the force requirement for usage*

Meeting with VCE Design Studio

The final meeting with three designers from VCE was organised in VCE Gothenburg to evaluate the design, expression and feeling of the concepts. They designers showed old concepts and typical design features that characterizes their CE joysticks. This gave guidelines on how the concepts could be further developed with regards to design and having the right expression. They expressed that they strive to have a design that feels sharp and edgy while also emphasizing a premium feeling, quality above quantity.

The designer's preferred the Mouse Head because they felt it provided something new that does not exist in the product range offered by Volvo today. The designers gave further recommendations on how the joystick head could be narrowed and reduced in some design aspects to get a more Volvo expression. Overall they preferred the Smooth Mouse concept since they experienced the concept to be very innovative and offered something that is not available in the current product catalogue.

5. Presentation of Final concept

The following chapter presents the final concept that was chosen. The final choice was made based on the internal evaluation and also with consideration to the external input from the different departments.

The presentation of the final concept consists of illustrations of the final concept while also describing it with regard to design, ergonomics and functionality. Furthermore, what is presented is the 3D modelling process of the final concept, ideas on the joystick compatibility with UI display for 2021 CE models and the final proposal on a business model that utilizes 3D printing to provide VCE's customers with customizable joysticks.

5.1 Description of Final Concept

The final concept that was chosen was the Smooth Mouse joystick which was considered to solve the problem optimally. It was regarded to provide functional use with the new mouse head which offers varied use while also providing full functionality across the EXC, WL and AH.

The Smooth Mouse joystick offers a traditional handheld grip which is designed with consideration to ergonomic principles. It also offers the power grip which enables the operator to use the joystick with the hand positioned in a natural manner. This minimizes the required force while also increasing precision which in turn reduces the strain load. When enfolding the joystick vertically like a traditional handheld joystick, four buttons in the joystick head are available to be pressed with the thumb on the front. A roll button is also placed on the back of the grip template which controls two CE functions and is used with the index finger.

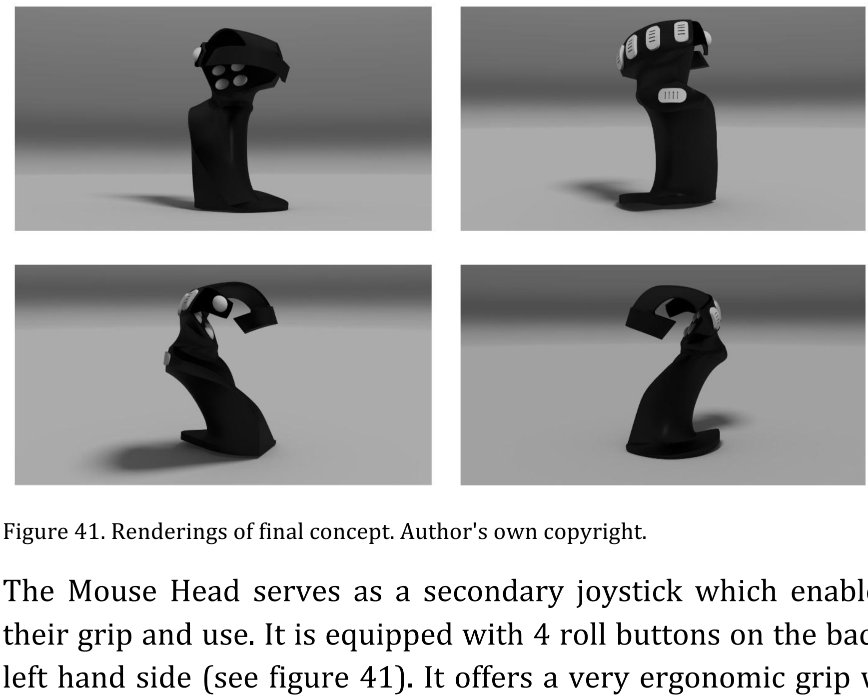


Figure 41. Renderings of final concept. Author's own copyright.

The Mouse Head serves as a secondary joystick which enables the operators to variate their grip and use. It is equipped with 4 roll buttons on the back and a push button on the left hand side (see figure 41). It offers a very ergonomic grip which withholds an organic design that fits naturally in the operator's hand with all the buttons placed where the fingers naturally end up. This in turn provides a very intuitive grip and use of the functions across all three CEs when gripping the joystick head.

5.1.1 Design

The design of the joystick grip is very organic while the joystick as a whole shows more edgy and aggressive expressions which are inspired from Volvo's design characteristics. The final design was refined and further developed from the original plasticine model of the mouse head combination from the morphological analysis which was presented at the VCE design studio (see table 4).

Figure 42. Final design. Author's own copyright.

The input from the design studio was taken into consideration to incorporate the edgy expression while also offering an organic and ergonomic grip. A balance between the two was found in order to provide an ergonomic grip while also designing a joystick that resembles a product which would fit in VCE's product catalogue.

5.1.2 Ergonomics

The design of the smooth mouse is based on ergonomic principles that are described in the theoretical framework (see 2.4). The design of the Smooth Mouse joystick is design with regard to the hand's natural position that decreases strain load on the wrist. When gripping the grip template or joystick head, the hand is as close as possible to the natural functional starting position.

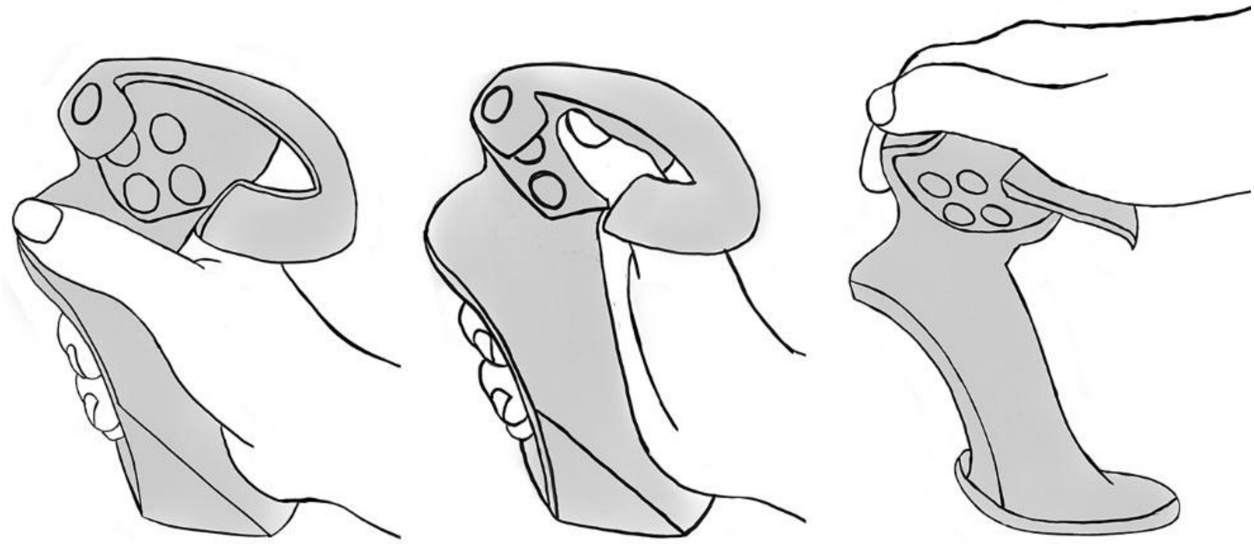


Figure 43. Illustrating the 3 various ways of gripping the Mouse Head Joystick. Power grip to the left, traditional handheld grip middle and mouse grip to the right. Author's own copyright.

The ergonomic principles refers to the importance of grip variation which the Smooth Mouse joystick provides by the combination of Smooth Grip template and Mouse Head (see figure 43). The operator can choose between operating the smooth mouse by either gripping the Smooth Grip in a traditional vertical grip or by gripping the Mouse Head in a horizontal grip.

Taking advantage of the possibility to choose between different sizes of grip template or joystick head takes into consideration that hand dimensions varies significantly between different individuals, especially between men and women. Possibility to choose between different sizes allows the operator to operate the joystick with full control and high precision.

Based on the evaluation meetings with ergonomic experts from Chalmers and VCE (see 4.3.2), the smooth grip was considered the most ergonomic grip template since it offered a power grip that gave full control and unloading surface for the thumb without any buttons interfering.

5.1.3 Functionality

This section presents the universal functionality of the joystick and how it will provide function in the EXC, WL and AH.

Functionality in Excavator

When connected to the EXC the joystick provides the traditional use and functions of the current handheld EXC joystick when it is gripped vertically like a handheld joystick (see figure 44). This is offered for both hands whereas the joystick on left side is mirrored accordingly as it for the current EXC joysticks (see 2.2.3). What it now offers besides that is a grip that is more ergonomic and also enables the operator to work more freely with the option to use the unloading grip power grip. If e.g. an operator doesn’t need to use the buttons on the joystick or prefer to only use the joystick movement functions it enables them to do so.

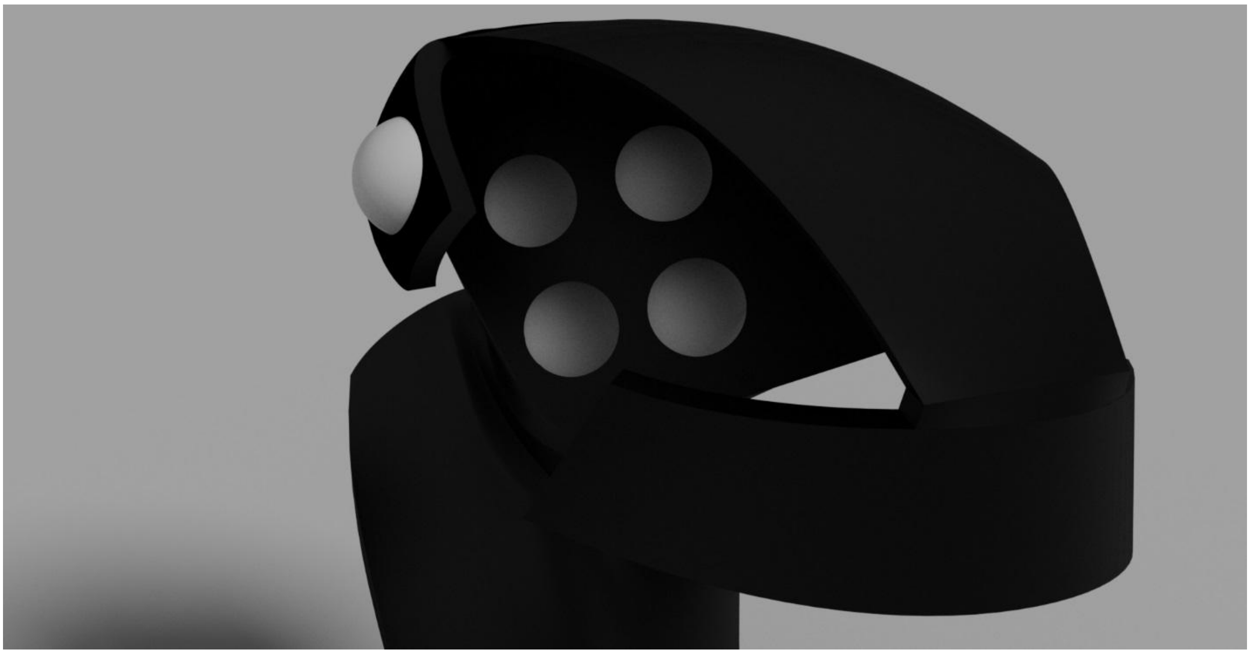


Figure 44. The four push buttons on the front offer traditional usage in the EXC. Author's own copyright.

The joystick head provides an alternative use as a secondary joystick. If the operator desires to vary their grip from the vertical grip with the four front buttons in the joystick head and use the four roll buttons on the back of the joystick head and the push button on the left hand side, it enables them to do so. The joystick also allows for comfortable use even if the joystick head is only for varied grip and not necessarily for using the buttons which is desirable because the joystick is used almost constantly throughout a work day.

Functionality in Wheel Loader

When connected to the WL the joystick head will serve as the main joystick for those operators who prefer to work with the traditional two lever-, three lever- or four lever configuration which provides what the operator described as “piano playing” control scheme (see figure 45). The ability to seamlessly control the different levers with the fingers was very desirable by the operators as expressed from the interviews. The majority disliked operating a fully equipped WL with the current hand held joystick configuration which is available in the WL.

Figure 45. Four rolls on the back offering the same function as up to four lever configuration. Author's own copyright.

It also offers a more ergonomical and developed “piano-playing” experience since the hand is able to grip the joystick head and in return get additional support which is not offered in today’s WL multiple lever configuration (see figure 46).

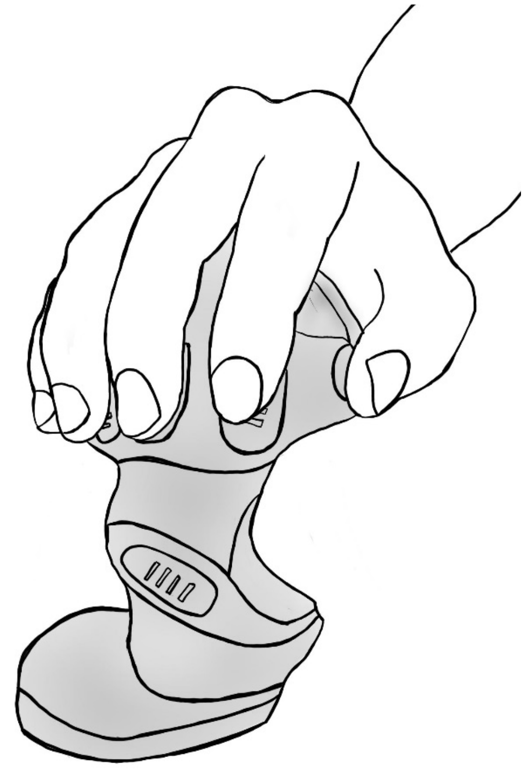


Figure 46. Showing the new ergonomically way of maneuvering the four lever functions with an additional button on the side. Author's own copyright.

The distance for finger movements that are needed to operate the buttons are shorter than the distance for the multiple levers today which is more optimal from an ergonomic perspective. The new joystick head also emulates the sensation of gripping a very ergonomical mouse but will also enable the WL to be operated with the handheld grip if it is gripped vertically and used as the current EXC joystick.

Functionality in Articulated Hauler

When connected to the AH the joystick provides a very ergonomic grip which can be used to control the hydraulics for the bucket.

The number of hydraulic functions and number of attachments in the AH are not as many as in the other two CE’s which results in having more functionality than necessary on the connected joystick. The additional buttons on the joystick does not however compromise the use of the ergonomical grip which also offer the natural power grip that enable the operator to use the joystick with lower effort and with higher precision. The joystick head serves as an alternative grip and can comfortable be used to operate the hydraulics if the operator wishes to variate their grip.

5.2 3D modelling of Final Concept

The final concept consisting of the 4 selected modules was 3D modelled with CAD-programs, Alias Autostudio and Catia. The 3D modelled files were later rendered to present the final concept. The process of modelling started with the final plasticine model being scanned and turned into a digital mesh (see figure 47). The scan was done at Cascade which is a company that provides measurement services which include 3D scanning of physical surfaces with precision and quality (Cascade, 2017).

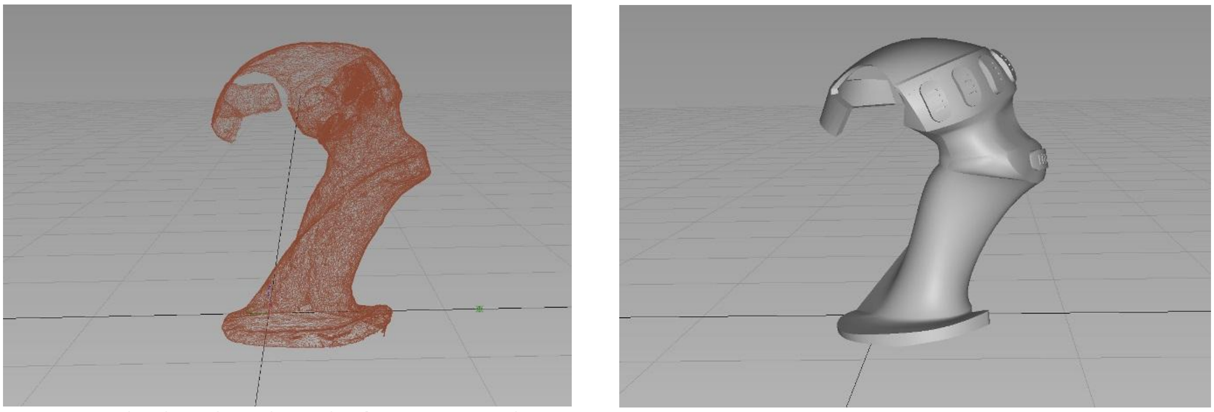


Figure 47. The digital mesh. Author's own copyright.

The scanning of the plasticine model was made in order to obtain a mesh which was used as a reference when 3D-modelling and to achieve the correct dimensions which had been verified with the rapid prototyping.

5.3 Joystick Compatibility with UI Display

The joystick customization and connectability across the EXC, WL and AH raises a few safety issues which was brought up during the concept evaluation meeting with the engineers from CPAC. The concerns are mostly regarding the issue where there have been resulting casualties due to misuse which is the reason for the Maskinleverantörerna agreement found in the competitor research (see 3.1.2). These concerns are very relevant to the new universal joystick since indications for the operators are even more crucial on how the joystick buttons are mapped out and what the button layout is since three CE models are involved and confusion can occur.

Some customers might want to offer every one of their employed operators with their own customized joystick with their preferred grip, joystick head, buttons and add-ons for which the operators know how they tailored their build of joystick for their preferred method of working. That will not however be the case with every customer and their work site. Some customers might only order one joystick that is going to be used by more than one operator in a specific CE on a work site.

This in turn opens up for ideas on how the misuse of joystick can be avoided by making the universal joysticks compatible with the UI displays that are assumed to be included in the 2021 CEs (see 4.3.2). Following section presents ideas on how the future universal joystick and UI display can be utilized and compatible to increase intuitive use, efficiency and safety.

5.3.1 UI Display

Currently, there are screens available in some of the CEs' cabins that the operator can interact with. There are different information and functions which the screen provides the operator with while in the cabin (see figure 48.

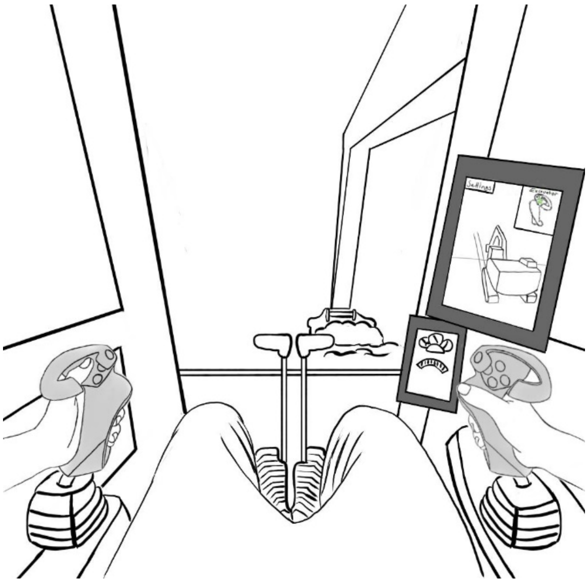


Figure 48. Illustration of how the operator would integrate with the UI display. Author's own copyright

Providing different information regarding fuel consumption, engine rpm and in some cases even enable the operator to map out one button or two on the joystick which is very limited are examples on that. The re-mapping of buttons and functions on the joystick can even in some cases be changed manually without a screen but is usually required to be performed by a technician. Aspects such as changing the sensitivity of the joystick movement can also be changed in some CEs but it is a troublesome and non-smooth process which requires external expertise and tools.

5.3.2 Joystick verification and settings

Assuming that the joystick connection interface requirements from the product specification (see 4.1.4) are fulfilled by VCE in the 2021 models then it will be possible to programme button layouts and sensitivity preferences directly to the joystick. It can then be used as an identification key and be recognized in the system. This will mean that when an operator connects their joystick to the interface in either CE for the first time they will be able to choose their settings on the UI screen such as button layouts and joystick sensitivity.

The level of customizing button layout will be freer and more accessible for the operators than it is currently with the CE models but certain buttons and functions will always be locked due to the ISO regulations which VCE has to follow (see 2.4.2). Recommended button layouts made by VCE will also be available. The idea is that the first choice of settings that the operator makes in each CE will be saved onto the joystick and the preferred settings will be activated thereafter. The pre saved settings will then be activated when switching between the CEs and will recognize the specific settings for each one. It will also be possible to easily change the settings throughout the use of the joystick by simple using the menus on the UI screen. Operators can e.g. map on the comradio or windshield wiper directly on a joystick button if there is a button that isn't connected to an attachment which was highlighted by two of the interviewed operators from the pre study.

The new level of customizability of the universal joystick and interchanging between different CEs transforms the view of the joystick in such a way that is more comparable to a personal work tool in the same way which a carpenter has their own hammer. This is of course based on the scenario of each operator on the work site being provided with their own customized joystick and will use the joystick across different CEs.

5.3.3 Safety measures for several operators on same joystick

Considering the scenario where work sites will have multiple operators working with the same customized joystick it will probably be customized in such a way that is more neutral and fits the specific task and attachments rather than to suit one operator. This differs from the previously described scenario (see 3.1.3) where the joystick will probably be tailored for each operator.

The scenario of several operators working with the same joystick will still raise safety concerns even if the customization of modules have been made to fit the task because the settings of the joystick will still be possible for the operator to change with the UI display. The concept of having predetermined settings for the joystick that are modified by the operator has to be reimagined somehow since it can cause confusion when switching operators. It will also cause dissatisfaction with the operators since always having to change the settings to their preferred one from the previous operator each time they sit in the CE, will be considered troublesome and create nuisance. The solution to this problem will be that it will be possible to create operator logins that work similar to the first scenario but will however provide the ability to connect specific settings with their own login. This will offer the same level of tailored settings without having to switch the settings every time another operator starts working in a CE where another operator already had their settings logged in.

5.3.4 Visual Aid on UI Display

The concept of having different settings can still become a crucial safety problem even if it is regarding an operator that has their own joystick since human error can lead to an operator forgetting that they have changed their settings during their last work session. The other scenario can e.g. be the work site with multiple operators using the same joystick where the previous operator has changed the settings. This can lead to the next operator taking for granted that they are logged in and forget to double check if the right settings are active.

Therefore it is crucial to heighten awareness of the settings which shows the button- and function layout that is active. The solution for how this risk will be eliminated is that there will always be a compulsory confirmation that the right settings are active and or if the right operator is logged in. The screen will also show an illustration of how the button- and function layout is active in order to provide increased awareness (see figure 49).

Figure 49. Illustration of how the mini map would display active functions. Author's own copyright.

The illustration of button layout will be active as a minimized window on the UI screen throughout the workday in order for the operator to quickly verify the layout if they become insecure or possibly forget. An important aspect of using the buttons on the joystick is that the work mode can be changed on the screen in order deactivate the buttons which are not meant to be used when alternating the grip. Since there will also be buttons with LED-lights available that was designed in the second stage concept generation that show which buttons are activated will also help increase cognitive awareness.

5.4 VCE Customize - Final 3D Printing Business Model

The finalized business model for how VCE can implement 3D printing was further developed from the second stage concept generation (see 4.2.2). A tree structure was created in order to define how the business model would function and provide service for VCE's customers.

The presented tree structure (see figure 50) illustrates how the build of the final concept was made for this project and also the basic principle of how the general customer order process would function regardless of how a joystick is customized.

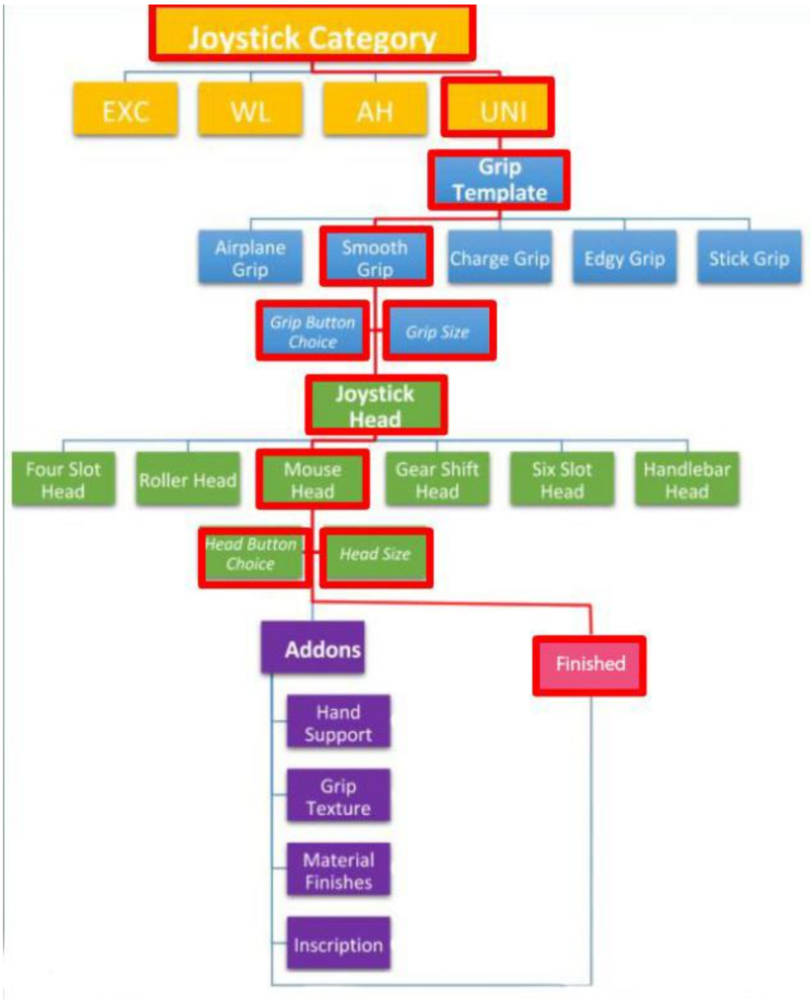


Figure 50. Final business model which illustrates the principle of how the customer would customize their joystick, in this case it is demonstrated how the Smooth mouse was customized. Authors own copyright.

This figure demonstrates the module library but the ambition is to have a website where the customer will see a live update of their joystick with the different modules selected when making an order. The ordering process for the Mouse Head joystick would function accordingly:

First stage choice, Joystick category (Yellow)

A new aspect of the business model which was not discussed earlier in the second stage concept generation was to have 4 categories of joysticks for which the customer can choose from before initiating the customization. The reason for including a specific category for a universal joystick and one for each CE was due to it was realized that some customers would still like to have the same level of customizability for joysticks that are not universal (UNI). Some customers would possibly desire a joystick which can be customized with e.g. grip templates and joystick heads that are specifically designed and more tailored for one CE. The tree structure will be divided in the same modules in each CE joystick category as in the universal joystick category which has been presented. The design of modules might however differ across the different joystick categories depending on identified customer needs etc.

After choosing the joystick category that the customer want to customize which in this case is the Universal joystick category the following step is to choose the grip template.

Second stage choice, Grip template (Blue)

The second stage of building the joystick consists of choosing the desired grip template, which in this case was the smooth grip. After choosing the smooth grip, the customer is asked to choose grip size and choice of buttons (see figure 51). The neutral sized smooth grip was then combined with the choice of a roll button which takes up the two predetermined slots on the back of the grip template.

Figure 51. Illustration what the customer would see when choosing grip template and adding buttons on the back. Authors own copyright.

After choosing the final grip template with defined size and buttons leads the customer to the third stage of choosing the joystick head.

Third stage choice, Joystick Head (Green)

The third stage of building the joystick then consists of choosing the desired joystick head which in this case was the mouse grip. Since the mouse head is a joystick head that can be enfolded it is also offered in three standardized sizes. The neutral sized mouse head is then chosen combined with the button choice of four push buttons on the front of the joystick head which fills up the four slots and the slot on the left side is filled with a push button (see figure 52). The eight slots on the back of the mouse head are filled up by four rolls (see figure 53).

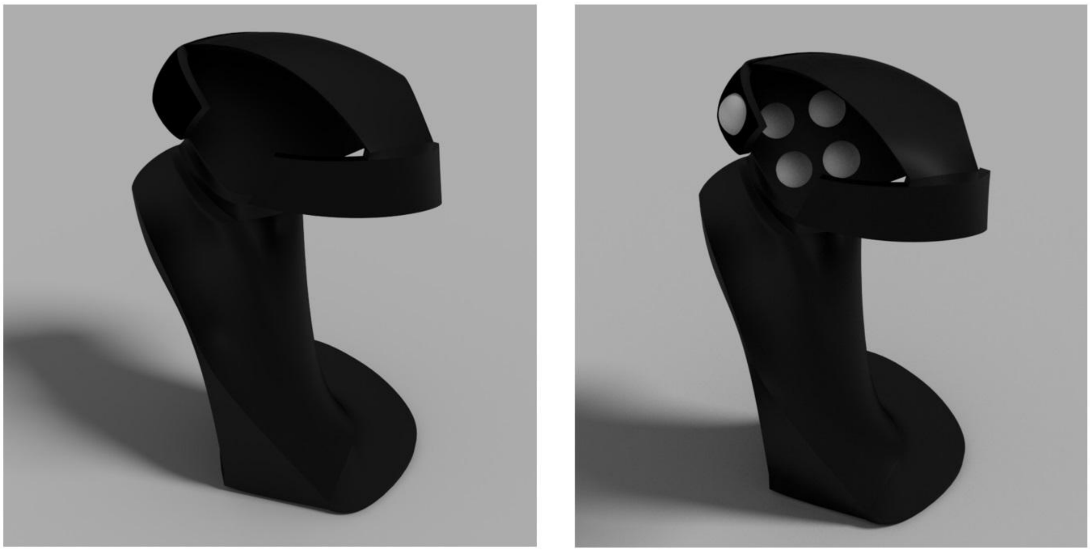


Figure 52. Illustration what the customer would see when choosing joystick head and adding buttons on the front. Author's own copyright.

Figure 53. Illustration what the customer would see when choosing joystick head and adding buttons on the back. Author's own copyright.

After choosing the desired joystick head with defined size and button, it results in a complete functional joystick. The customer could technically end their customization here and order their joystick since the fourth module is optional which done for the illustrated customization. For those customers that wishes to continue and include add-ons to their joystick, they are forwarded to the fourth and final stage of the ordering process.

Fourth stage choice, Add-ons (Purple)

If the customer chooses to continue their customization of their complete joystick they are directed to the add-on module. What is available here are the optional joystick add-ons which are either the hand support, grip texture or inscription. There are however no add-ons chosen for the final concept.

5.4.1 3D Printing Department in VCE and Customer Orders

The vision is to have a department within VCE that is dedicated to the joystick customization. They will put in the research and development (R&D) to design the joystick modules, the digital cad files and manage the website for which customers can view the catalogue and order the joysticks. The joysticks can ordered to either be installed directly when CE is assembled or separately to be installed post production. The aspect of installing the joystick post production will be seamless due to the new the connection interface which opens up for a customer to have several joysticks at their work site which are changed depending on e.g. the operator or post production added hydraulics. The development of new joystick modules will be made based on customer analyses and customer needs.

5.4.2 3D Printing Technology and Material

Based on the research made on different 3D printing technologies (see 2.3.2) and their developments identified in the market research (see 4.1.2), the decision was made that Carbon 3D's CLIP 3D printing technology is the most optimal for printing end-use joysticks based on what is currently available. The choice of this 3D printing technology for the final business model was largely motivated on the technology's ability to remove the layer by layer manufacturing which eliminates the structure flaws that are associated with layer by layer 3D printing. The trade-off between the excellent surface finish, details and mechanical properties is no longer needed. Combined with the up to 100 times faster printing speed compared to other technologies currently available and the large range of materials with engineering grade mechanical properties available, implies that Carbon 3D's CLIP technology is the most plausible 3D printing technology to manufacture the final end-use customized joysticks for the 2021 CE models.

Since the limitations disregards material properties from the project (see 1.4), the material for the 3D printed joysticks must fulfil VCE's requirements for a fully functional end use joystick. The suggestion for which material that the 3D printed end joysticks should be manufactured with depends on what materials are currently available the CLIP technology that fulfils VCE's requirements. Based the predicted rapid development of 3D printing (see 4.1.2), the range of materials will increase and the material costs will decrease. This implies that VCE might have access to a material that fulfils their requirements when releasing the new CE 2021 or in the near future.

5.4.3 Benefits of 3D Printing Business Model

Since the joystick will be 3D printed means that all the cad files can be stored digitally which in turn means that there will not be necessary for a physical warehouse. When a customer makes an order means that only those joysticks will be manufactured with 3D printing on demand. This in turn means that a joystick will never run out of stock as long as there is available material and working 3D printers. The research and development is only required to be made when converting customer needs into new joystick modules and designing them in a CAD-programme. The digital cad files will then be stored digitally and will always be available to 3D print for a customer with the similar needs down the line.

Constant customer orders and emerging needs will lead to new joystick modules being designed and developed through the years resulting in continuously expanding catalogue. This is obviously a positive outcome to be able to offer the customers a large range of solutions. However as it was discussed during the evaluation meeting with CPAC (see 4.3.2) it is important to find a balance between offering to many solutions and offering a few premium solutions which is a quality Volvo is known for. The solving of this dilemma can be made by offering recommended module combinations for different specific needs and tasks that are designed and suggested by VCE. This provides confidence for those customers that want to rely on VCE to provide the best solution possible and renounce the responsibility of making the customization themselves. The business model enables both type of customers to utilize it to their interest and which improves the customer experience.

6. Analysis of Results

The following chapter presents the analyses of the final concept and the VCE Customize business model which was done by analysing costs, environmental impact and customer value. Finally, the results from SWOT analysis are presented.

6.1 Cost Analysis

Cost is a one of the major advantages that comes with using 3D printing and as stated before (see 2.3.2), the economic benefits are generally divided into three main categories: machine operation costs, material costs and labor cost. The advantages such as decreasing lead time, the single step manufacturing and avoiding inaccurate tool investments are also large contributors to the economic advantages that leads to profitability.

One of the reasons more industries are applying the technology is the reduction of lead time which means the time from when a project starts to when it is finished (Karlsson, 2014). The aerospace- and medical industry are the ones that has come the furthest with using it in their operation. During the 2010s, Rolls Royce wrote in a newsletter that even if the direct building time for a component is one week when using 3D printing, it is considered nothing compared to a lead time of 18 months for the first version of a component that is manufactured with traditional methods.

The economic advantages are however restricted by the 3D technologies that are currently available (see 2.3.2). This restriction is the number of components produced for which 3D printing is no longer profitable compared to traditional manufacturing (see figure 54). This turnaround is generally between 1000 to 10000 which is identified in the 3D printing market research and is also dependent on the design complexity (see figure 54) and material used.

The schematic diagrams illustrates the high upfront tooling investment with traditional manufacturing and that the cost per component is reduced at higher volumes (Metal AM, 2013). The second schematic diagram illustrates the substantial impact on cost the more complex component. 3D printing cost per component remains however the same no matter how many components are produced and cost per component is also not impacted by shape complexity.

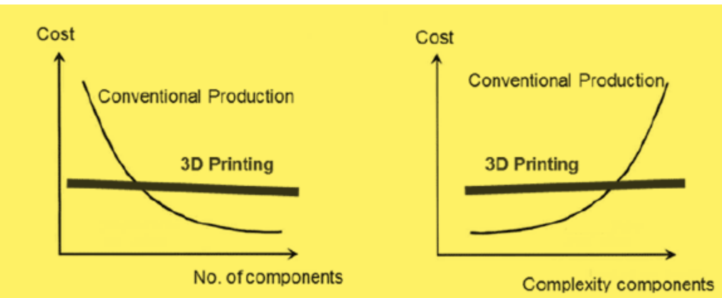


Figure 54. Schematic diagram to the left illustrating the turnaround for number of components produced for 3D printing and the right schematic diagram shows that cost is not affected by complexity. Authors own copyright.

That is why 3D printing has to be used in the right situation for it to be profitable when manufacturing end-use parts. Since cost is not related to the number of components manufactured with 3D printing, there is no penalty for only producing low volumes. Therefore it is optimal for VCE to implement the developed 3D printing business model (see 5.3) in order to offer the small percentage of customers with customized joysticks to fully exploit the economical advantages that comes with additive manufacturing that would otherwise be non-profitable with traditional manufacturing. The complex design that some of the modules share is also made possible in a profitable way since the cost per component is not increased due to the complexity

However, there is a probability that the number of customer orders increases to a number that exceeds the profitable limit of joysticks manufactured with 3D printing (Smith, 2015). Additive manufacturing is however still considered to be at its infancy stage and the technology's potential is definitive. Leaders from around the world states that 3D printing will change the process of how we manufacture things more in the coming decade (see figure 55) than the industrial revolution did 300 years ago. This implies that 3D printing will develop quickly to accommodate for the potential increase of customer orders from the VCE Customize business.

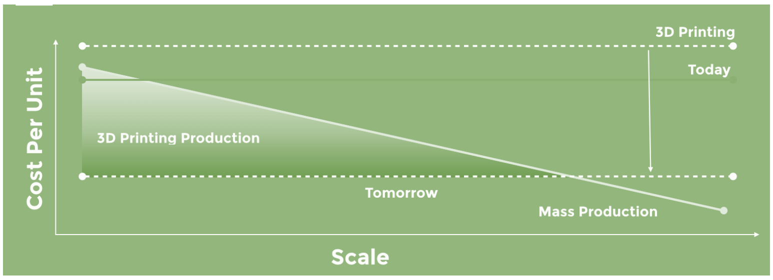


Figure 55. The white line represents where we are today approximately. The colored triangle does however represent the future that is predicted by leaders around the world. Authors own copyright.

Constant developments and trends are contributing to making the quality of 3D printing better and also more cost efficient such as e.g. the developments Carbon3D has made (Smith, 2017a). At the same quality and cost, the flexibility of additive manufacturing will always be chosen over traditional manufacturing. The day when 3D printing has been developed enough to show the same level of cost and quality in production as traditional manufacturing is the day it irreversibly becomes the preferred manufacturing method all over the world.

6.2 Environmental Analysis

Using 3D printing as a manufacturing method that is optimal, reduces the manufacturing process for VCE to three phases: creating a cad design, 3D printing and finally installing. A traditional manufacturing method consist of: creating a cad design, cutting steel, grinding, drilling holes, sanding, coating and other process until finally complete. By choosing 3D printing as a manufacturing method entails less transport time, less pollutant emissions and less used energy for producing a joystick. Using large 3D printers enables printing multiple joysticks simultaneously in one print which means more energy-efficient printing since the technical machine operator does not need to spend as much time making preparations for printing individual joysticks.

By taking advantage of the benefits that 3D printing gives, VCE will not need to ship prototypes, spare parts, joystick modules or other 3D printed products to customers or internally in VCE since they can directly 3D print the object by themselves if they have access to a 3D printer. It is also not necessary to send experts of specific manufacturing machines around the world since only a basic understanding is required in order to operate a 3D printer (see 2.3.3). Using 3D printing could offer big reductions of carbon emissions and fuel consumption for VCE which would decrease the environmental impact.

Compared to usage of traditional manufacturing methods like CNC drilling and turning, there is much less material waste using 3D printing as a manufacturing method since 3D printing generally only uses the amount of material that is needed in order to produce the desirable module combination (see 2.3.2). The waste that exist from 3D printing usually is support material that is needed in order to give support for parts of the joystick that are critical. Using 3D technologies like Carbon 3D's CLIP technology removes the need of support material by using innovative processing (see 4.1.2). Removing the need of support material reduces the need of post processing and how much material is essential to produce a 3D printed joystick.

The material used for the 3D printing should ideally be of recycled material and be durable for long usage in order to reduce the environmental impact. Taking into consideration the developments and trends of 3D printing, it is assumed there will be more materials to use for 3D printing and the materials will have better mechanical properties that does not affect surface finishes (see 4.1.2).

Increasing the 3D printing speed could produce more joysticks at a faster rate while providing more energy-efficient printing at the same time. Following trends and developments of 3D printing, it is assumed that the 3D printing speed will be multiple times faster in the near future compared to the majority printing speeds currently available (see 4.1.2). A 3D printing machine that can produce joysticks fast, does not need to be running and consuming as much energy as a slow 3D printing machine.

6.3 Customer Value Analysis

Providing customized joysticks heightens the customer value significantly since the VCE Customize business model enables the joysticks to be individually customized for operators directly when ordering a CE. The ability to also easily order new joysticks further down the road if new operators are hired with specific needs or if the attachments on the CEs are changed which results in the need of a joystick with more functions. Ultimately what is enabled by the user adjusted joysticks is the improvement of the working conditions of the operators who also are the primary end user. Better working conditions is desirable from the employer as well since they are the customer that will purchase the joysticks. Fulfilling the operators needs ultimately fulfil the needs of the employer which has been described when identifying the customer and end user (see 4.1.2).

6.3.1 Operator's Customer Value

The customer value which VCE Customize provides for operators becomes apparent in primarily two ways:

Hard Values

The hard values implies the functionality, ergonomics and design of the joystick which is directly related to the operator's ability to use the joystick and perform their tasks. What is considered to be categorized within the hard values are the first three modules that are required for a functional joystick which is the grip template, joystick head, buttons and some of the add-ons that provides some function such as hand support or grip texture. The better the joystick is adjusted for their operating needs, the higher satisfaction

Soft Values

The soft values refer to the customizability aspect of the joystick and focuses on the fact that the operator is in control of the overall design of their own joystick and that they can have some impact regarding its' aesthetic appeal as well (Insights, 2013). The value of having a personalized product has proven to raise the satisfaction and the relation to the product. Customer loyalty and engagement are elevated and the customer base can be utilized as an engine of advocacy to potential buyers.

6.3.2 Employer's Customer Value

The employers are not going to be using the joystick therefore their interest does not lie with having the joystick customized for themselves. Their ambition is to provide the best working conditions for their operators. Better working conditions leads to less sick leave, wellbeing and efficient working which all translates to profitability for their business. This in turn leads to their workplace becoming more attractive for potential job seeking operators. Ultimately by satisfying the needs of the operators leads to the employers being satisfied as well.

Therefore the conclusion can be drawn that the VCE Customize business model raises the overall customer value by satisfying the customers and the end users. This will be done to a greater extent than what is done today since the operators who refer to external companies will remain in VCE's operation while potentially also attracting new customers customer that currently do not buy products from VCE. It is proven that customers who had customized a product online engaged more with the company (Insights, 2013). They visited the company's website more frequently, stayed on the page longer and were more loyal to the brand.

The customers that will adopt quickly to the business model will be the customers that currently installs external joysticks. However, the orders will increase with time and more customers will start utilizing VCE customize to order their joysticks for their CEs.

6.4 SWOT Analysis

The SWOT analysis is divided into two internal factors, strengths and weaknesses while also taking into consideration external factors opportunities and threats. Taking into consideration all information from the different factors resulted in a discussion of which strategies VCE should approach in order to be more competitive in the future.

Strengths	Weaknesses
- Adapted to customer needs - Advantage of implementing the business model earlier than competitors - Freedom in design - Enabling complex design - Established and well-known company - Company known for quality and premium products - Can never run out of stock - Models from many years ago will be able to be ordered to a certain extent - CAD files are stored virtually - Less waste material and reduced shipping	- 3D printing is currently not efficient for high volume production compared to traditional manufacturing methods for larger production - Transition time - 3D printing is not yet a recognized by the vast majority as a manufacturing method that can produce end use products, which can affect the markets time for acceptance
Opportunities	**Threats**
- Unexplored market - Provide customer value where the competitors does not - Give possibility to adapt design to customer needs - Keep current and attract new customers - New products in the product range - Trends that support increase in production rate and higher quality of end products - 3D printing could be implemented in other business areas if it is profitable in the joystick market	- New technologies that offer better a better customizability - New future restrictions and laws that limit design and functionality can impact future and older modules - In order to always be competitive it is necessary to invest in new developments in order to increase production rate - No guarantee that the developments in 3D printing will develop in the pace that is predicted and counter the increasing number of customer orders - 3D printing can make it more challenging to protect copyright and intellectual property

Table 9. SWOT Analysis

7. Discussion

By assuming that all the limitations set outside our project are fulfilled, the final concept is considered to solve the problem of a universal handheld joystick and fulfil the requirements from the product specification set after the pre study. Other from the requirement "*Offer possibility to add additional button functions to joystick if extra attachments are added to the CE*" that might be viewed as unfulfilled, it has been solved by enabling the customer to customize their joystick before ordering their joystick with the developed business model. In this way, the joystick can be is designed with the desired number- and types of buttons to accommodate the added extra hydraulics.

The requirements from the product specification focused primarily on what was defined from the user studies and what needs the operators expressed in regard to design, ergonomics and functionality. The fact that the operators we managed to interview were only male is something that has possibly affected the concept development. This is however a natural outcome since the majority of CE operators in Sweden are male and it was very hard to find female operators that could participate in an interview. The expressed needs from the interviews and factors identified in the participating observations were however all translated into objective operator needs which were unrelated to the operator's sex. The developed business model VCE Customize does however at the end of the day enable the joysticks to be customized in such a way to accommodate all type of end users.

The ideas regarding the joystick compatibility with the UI screen is based on the ambition from VCE to implement screens in all of the 2021 CEs. The sketches on the new cabins are only conceptual and their purpose for this project is to illustrate where the screen would be put and how the operator would be able to interact with them. All of the ideas regarding the joystick connection interface are also based on an ambition to enable operators to switch joysticks easily in the future CEs. This was also a motivation for including customizability since it opened up for every operator having their own customized joystick further down the line.

Regarding the final suggestion of the 3D printing technology that VCE should use for manufacturing the customizable joysticks is based on current technologies and the advantages they demonstrate today. The development of 3D printing is definitive but since the future can not be predicted definitively, the suggestion is made based on where Carbon 3D's CLIP technology stands today. Their technology provides the best surface finishes combined with the material properties needed for an end use product since they have eliminated the layer by layer manufacturing which eliminates defects that are current with other 3D printing technologies.

8. Conclusion

In conclusion it can be assumed the project' purpose has been fulfilled which was to provide VCE with enough information about 3D printing and how its' advantages can be utilized. Based on the project results, it should facilitate VCE to make a decision regarding if the final developed VCE Customize business model is something that can be applied to their operation.

The VCE Customize business model has been developed with the intention of providing a proposal on how 3D printing can be implemented effectively and offer customers customizable end use joysticks. It was however developed in conjunction with another main goal of the project which was to design a universal handheld joystick that can function across the EXC, WL and AH. The final concept solves the problem of a fully functional and ergonomic universal handheld joystick that can be a solution on its own aside from the business model. The project is however based on VCE's ambition to include a fully functional joystick connection interface and UI displays in the 2021 CE models.

8.1 Recommendations for further work

The research for 3D printing is based on current technologies that are available, current trends and developments and supported predictions of its development in the near future. The VCE Customize business model is based on that research and could with more time be further developed to evaluate its' applicability. This could be done by verifying specific costs regarding research and development (R&D) and manufacturing to review how profitable 3D printing really could be. With more time, calculations could be done on how many of the current customers turn to external competitors for customized joysticks. Calculation can then be done regarding how it translates to revenue if the customers are retained within VCE´s operation. The heightened customer value can potentially raise loyalty to their company and purchase more products which also can be calculated as potential revenue.

The VCE Customize business model that offers customers customizability is a by-product from process of designing a customizable universal hand held joystick. It was also a result of trying to find a way to implement 3D printing effectively and increasing customer value. With further work, the business model could be verified by evaluating the different module combinations with customers and operators. Based on reflections and new potential needs that emerges from the evaluations of the modularized joysticks, further modifications could be made to refine the existing modules and potentially develop new ones to solve other needs.

Overall with more time available, certain project limitations could be removed and investigated to e.g. strengthen and evaluate the business model, module concepts, 3D printing manufacturing and ideas regarding the joystick compatibility with UI displays, to make it more realistic and applicable to VCE's operation for the 2021 models and further down the line.

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10. Appendixes

Here are the appendixes presented. All information and material from the appendixes are obtained during the period of the project.

Appendix 1 - CE Information Questions

The following questions were asked to VCE employees to gather information for the theoretical framework.

1) How does the cabin look today for an excavator, wheel loader and hauler? What is the biggest difference between them in regards to ergonomics, size and interior? What is the purpose has the cabin and how is it constructed?

2) What kind of joysticks do they use today in the excavators, wheel loaders, haulers in Volvo construction equipment and what are the specific reasons for using a particular joystick in the different CEs'?

3) What kind of attachments are available on each CE?

3) Specifications on the current joystick, such as ergonomics, size etc. And possibly other requirements/limitations you might have on the future 3D printed joysticks?

4) In the future, can we assume the construction vehicles will only use electronical and not hydraulically controlled steering for our joystick?

5) How does VCE work regarding joystick regulations?

Appendix 2 - 3D Technologies

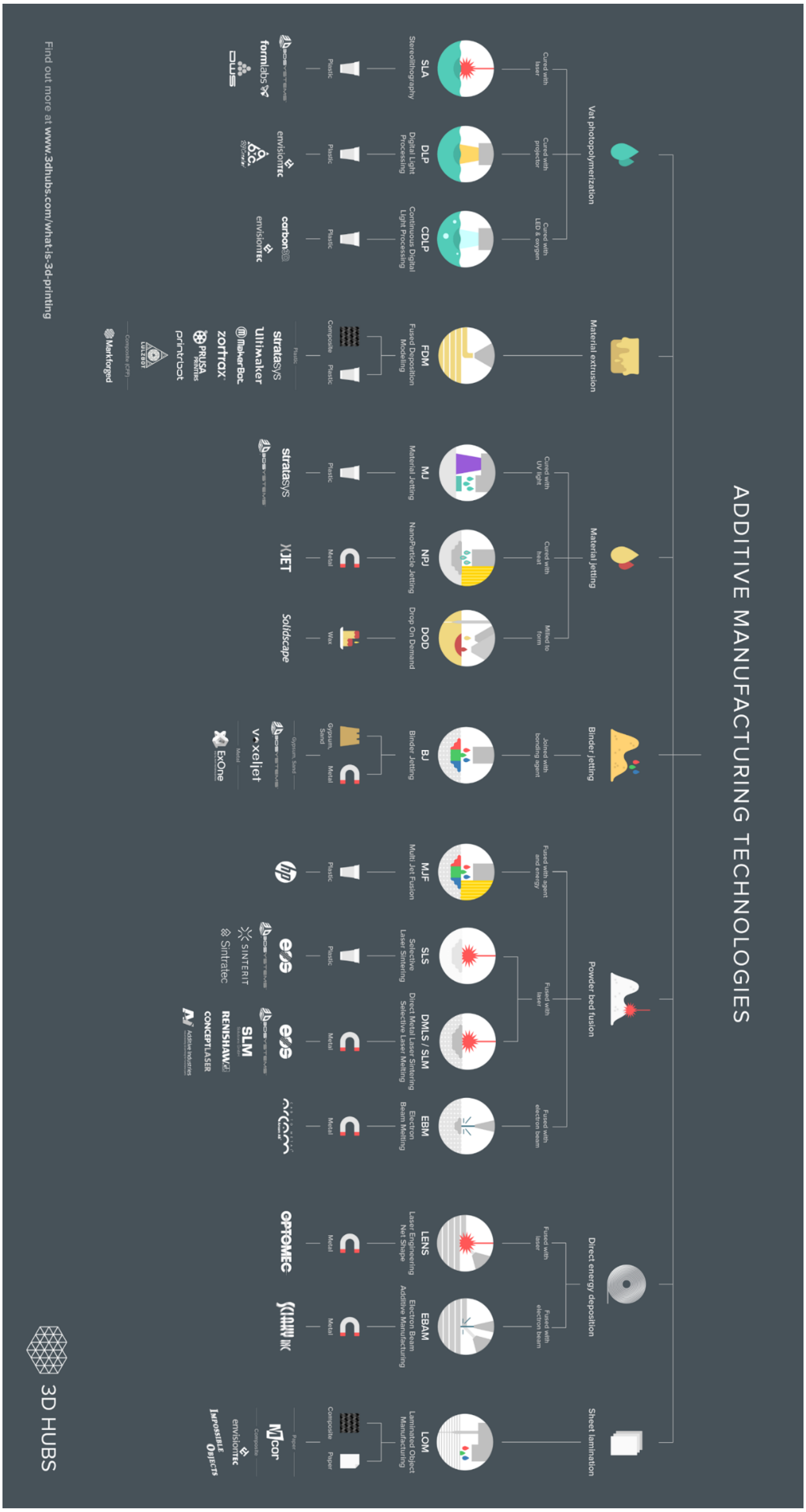

Figure XX. Additive manufacturing methods (3D HUBS, 2017h). Reprinted with permission.

Appendix 3 - Market Research Questions

The following questions were asked to VCE- and CPAC employees to gather information for the market research.

1) Who are the customers that purchase VCE's products and who are the end users?

2) Is there a specific reason behind the ambition to offer customized handheld joysticks?

3) Who are the other companies that offer joysticks to be installed externally?

Appendix 4 - Operator Interview Questions

The following questions were asked during the interviews in order to get their insight on operating Volvos CEs.

Sex:

Age:

How many years of experience do you have with Construction equipment?
Answer:

What kind of construction equipment do you operate right now?
Answer:

How much do you operate the CE per week?
Answer:

What do you like about the joysticks that are used today in the CE?

- Ergonomics:

- Design:

- Functionality:

- Experience:

What desirable functions do you experience are lacking in the current configuration of joysticks?
Answer:

What do you think about the possibility to get and customized joystick that is suited for you in regard to design, ergonomics and functionality?

Answer:

What do you think about the possibility to be able to connect your own customized joystick across the different CEs you work with?
Answer:

Would it add more value to your working environment to be able to have a joystick that is personalized for you?

Answer:

How do you think that the future joystick would look like and function?
Answer:

Appendix 5 - Alternative Solutions

The following appendix gives description of each product that were included in the Pugh´s matrix of alternative solutions.

Volvo Penta Joystick

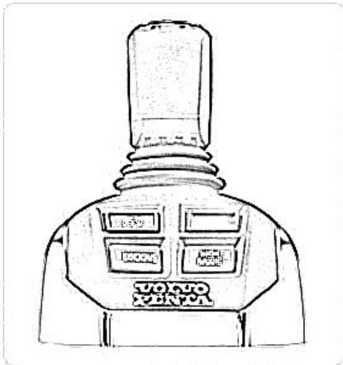

Figure A. VP Joystick. Author's own copyright.

The joystick from figure A has a luxurious design that fits in premium cars thanks to the combination of aluminium and black plastic. The joystick has big and square buttons that are easy to press. The form of the grip is not ergonomically designed because of the small and angular design.

Gaming Joystick - SVEN

Gaming joysticks are available in different configurations. The main purpose of gaming joysticks is to enable regulation of movement in a video game.

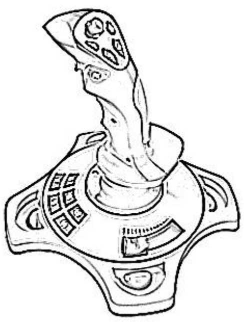

Figure B. SVEN Aggressor Joystick. Author's own copyright.

The controller called SVEN has a sharp design that provides an aggressive expression. The controller from figure B is mainly used for steering different aircrafts when playing video games. The joystick offers a variation of buttons which are placed close to the grip. This enables rapid movement between grip and buttons.

Gaming Joystick - XBOX

Figure C. Xbox One Accessorie. Author's own copyright.

The Xbox one Controller shown in figure C is a modern controller that is used for the eighth generation of video games. The controller has two sticks, usually the stick that is placed to the left is used for controlling the movement while the stick to the right is used for regulating the perspective.

RC Controller

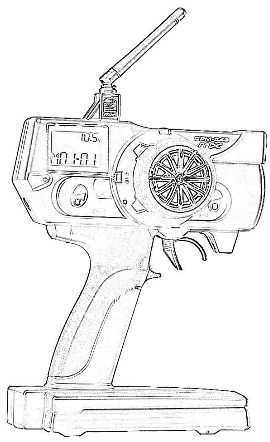

Figure F. Pistol Grip Transmitter. Author's own copyright.

The RC controllers are mainly used for controlling small toy cars, airplanes, drone and helicopters. The rc controller provides a good grip but it is not intuitive to use since the buttons are positioned at places that are hard to reach while gripping the rc controller.

Airplane Joystick

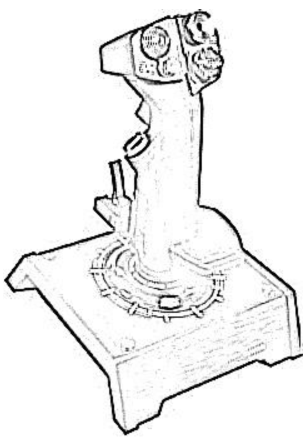

Figure E. PRO Flight X-65F Combat Control System. Author's own copyright.

The airplane joystick PRO Flight X-65F (see figure E) has an sleek and edgy design that expresses endurance and precision. The operator has a good grip of the joystick with the ability to rest the hand on the hand-support. The position of buttons prevent the user to operate the joystick with his palm because of the risk to press a button which limits the possibility of varied grip.

Ergonomic Mouse

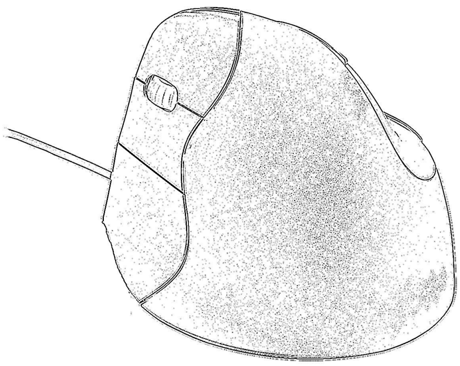

Figure F. VerticalMouse 4 Right. Author's own copyright.

The ergonomic mouse is made to support the hand in an upright posture that avoids forearm twist. The mouse is designed with a thumbrest, and easy to reach buttons. The mouse has integrated functions as pointer speed indicators, adjustable optical sensor and extended lip to prevent the last finger from rubbing the desk. The Verticalmouse 4 works like a regular mouse, the biggest difference is that the user works vertically instead of horizontally (Evoluent, 2017).

Appendix 6 - Results From Product Specification

This appendix presents the complete product specification

Product specification

Technical & Dimensions		
Requirements	Explanation of requirements	Comments
Dimension in length maximum 300mm		Same requirements which applies to current joysticks
Dimension in width maximum 300mm		Same requirements which applies to current joysticks
Dimension in height maximum 300mm		Same requirements which applies to current joysticks
Maximum weight 3kg		Same requirements which applies to current joysticks
Ergonomics		
Requirements	Explanation of requirements	Comments
Joystick angle of 20 degrees	70 degrees from the grip's horizontal line.	

Hand and wrist support	Some kind of hand and wrist support is to be integrated in the lever console in order to give support for full hand grip maneuvering and support for fingertip maneuvering.	
Joystick grip is adjusted for the majority of users		
Minimize physical load and strain		
Design		
Requirements	Explanation of requirements	Comments
Enable varied grip	Choose between hand- or finger operation	
Enable customer to impact the customization and design of joystick		
Capacitate space for buttons	Buttons, triggers to use CE functions	
Portable for transportation	When the operator detaches joystick and transports it to another location.	
Reduce risk for pinching		For example: rounded edges and latches
Aesthetic appeal		
Identified as joystick		
Intuitive usage		

Functionality		
Requirements	Explanation of requirements	Comments
Maneuver the CE's base hydraulics, functions and added attachments.		
Offer functionality that offers a minimum of manoeuvring of the base functions across all three CEs' (EXC, WHL & AH) without any added attachments		
Offer possibility to add additional button functions to joystick if extra attachments are added to the CE	EXC: Tilt in and out & lower and lift boom WL: blabla AH: Functions such as Kick Down, Engine Brake, Activation of FNR (Forward, Neutral, Reverse) switch and horn	This applies to the Universal joystick and the fact that it will be able to be connected to all three CE's
Provide precision in movement		
Operator's handling of joystick corresponds with the correct movement of CE movements/hydraulics/functions and prevent accidental usage		
Prevention of accidental activation		
Connection interface		
Requirements	Explanation of requirements	Comments
Enable operator to dismantle and attach joystick with ease		
Activate electrical connection, mechanism and functions		

Compatible with UI screen		
Joystick angle movement is determined and restricted by connected CE	The base for the joystick is where the lever is moving and therefore the movement of joystick is directly associated with the lever of connected CE	
Joystick connection interface shall seal mechanism and electronics	The encapsulated lever mechanism and electronics shall be protected against fine grain dust and against splashing water from above when handle is mounted	Same requirements which applies to current joysticks

Table 10. Product specification

Appendix 7 - Results From Rapid Prototyping

The final design of the modules are based on sketches which were made from the brainstorming process. Some changes regarding e.g proportions and form factor were made when the objects could be seen in a physical model compared to the sketch models (see 4.2.2). All figures included in this appendix are author's own copyright.

When designing the modules, ergonomic principles regarding natural position, grip size, grip shape and grip variation was taken into consideration. Also legal requirements which has been established from Arbetsmiljöverket has been taken into consideration when designing the joystick modules (see 2.4).

Comments and reflections that emerged from the user studies were also taken into consideration (see 4.1.3). For example, a majority of operators expressed that they preferred to operate the WL with the multiple levers and they wanted to preserve the form of use. During the participating observation it appeared among other things that it was desirable to use the multiple levers without having to move the palm from the base position.

The result from the Pugh's Matrix with alternative solutions showed that the gaming joysticks and ergonomic mouse had aspects that gave higher value to the user compared to the reference joystick (see 4.2.1).

Grip template

The airplane grip, smooth grip, charge grip, edgy grip and stick grip were the grips that were made from the rapid prototyping. Each grip except the stick grip provides slots that gives opportunity to place a button or buttons. Edgy grip and stick grip has a neutral grip while the airplane grip, smooth grip and charge grip has a grip that places the hand in a determined position. The grips come in either a neutral grip or power grip.

Airplane Grip

Figure G. 3D perspective of grip *Figure H.* Side view of grip *Figure I.* Front view of grip

The airplane grip is designed with slot for a button on the back of the grip (see figure H). It is designed with a resting place for the thumb (see figure G). The design idiom has a similar expression like a airplane joystick, due to the placement of button and shape (see figure I & figure E).

Smooth Grip


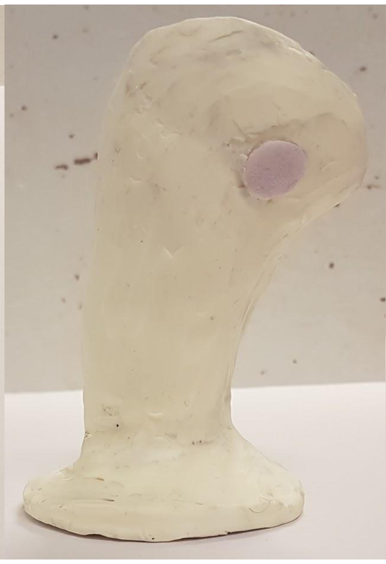


Figure J. 3D perspective of grip *Figure K.* Back view of grip *Figure L.* Side view of grip

The grip called smooth grip has soft curves and clean surfaces (see figure J). A support for the thumb follows the bottom of the grip to the top (see figure L). A slot for an button is placed on the back in order provide desired function (see figure K).

Charge Grip



Figure M. 3D perspective of grip *Figure N.* Back view of grip *Figure O.* Front view of grip

The charge grip shows where the hand should be placed thanks to the clear lines and design that places your hand on the right position (see figure M). The charge grip offers an slot for a button on the back (see figure N). The design is organic which is ergonomically optimal for the user whose hands fits the grip.

Edgy Grip

Figure P. Side perspective of grip

Figure Q. Back view of grip

Figure R. Front view of grip

The edgy grip has a simple form of expression with few curves and lines. The sharp surfaces that creates a sharp edge that gives the grip a tough expression (see figure P). The straight surface that is not horizontal can be used to place the thumb on in order to give more precision in movement. There is one slot available on the back of the joystick (see figure Q).

Stick Grip

Figure S. 3D perspective of grip

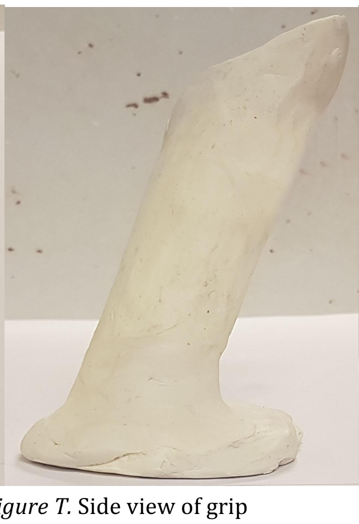

Figure T. Side view of grip

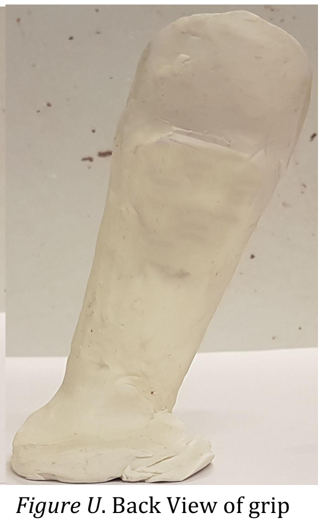

Figure U. Back View of grip

The stick grip is very similar to the grip on the EXC joystick that VCE offers currently offers (see figure 7). The stick grip offers no slots for buttons and has a simple design. There are no surfaces that guides your hand to a specific position which gives a neutral grip.

Joystick head

In total were six different joystick head created. The four button head and six button head have a similar design like VCE's current EXC joysticks (see figure 7). The mouse head and gearshift head are adapted to have big similarities with the EXC joystick while taking into consideration how the AH and WL operates.

Four Slot Head

Figure V Front view of head

Figure W. Back view of head

Figure X. Side view of head

The four slot head is designed with the possibility for maximally four slots. The design is similar to a crescent moon that has been cut to give a narrower design.

Roller Head

Figure Y. 3D perspective of head

Figure Z. Second 3D perspective of head

The roller head takes inspiration from the WL handheld joystick (see figure 8) that has place for two slots on top of the joystick head. The design of the roller head is optimized to be used in a AH or WL even if it can be used in an EXC since there is only one slot available.

Mouse Head

Figure AA. 3D perspective of head

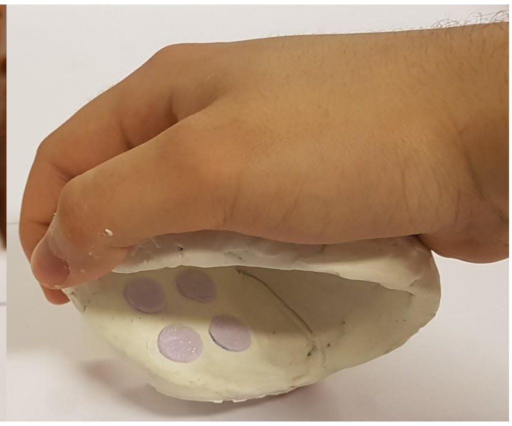

Figure AB. A hand grips the head

The mouse head is designed to give an enclosing grip on top of the joystick head while offering a traditional button layout inside the joystick head (see figure AA & AB). There are 4 slots available on the front of the joystick head and five slots on the mouse head.

The grip of the mouse head takes inspiration from the results that came from the alternative solutions research (see 4.2.1) and interviews (see 4.1.3). The ergonomic mouse (see figure F) offered a good grip and easy to reach buttons which were elements that were implemented to the concept.

From the interviews it appeared that a majority of operators favored usage of multiple levers instead of a single lever. In order to enable a similar usage, slots were placed on the fingertips from a firm grip on the back of the joystick head (see figure AD). One slot is available on the side of the joystick head when gripping the joystick head. Four slots were placed on the front of the joystick head in order to make the buttons accessible and easy to reach from the grip template (see figure AC).

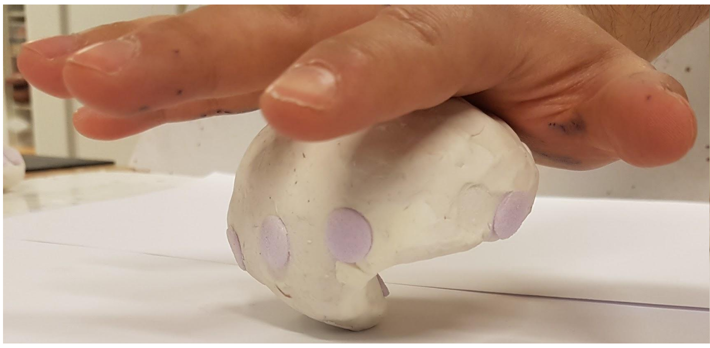

Figure AC. A hand is pressing the head

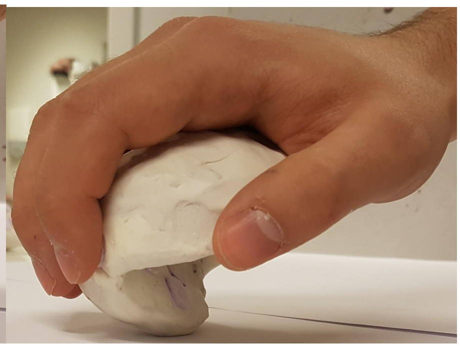

Figure AD. A hand grips the head

Gear shift Head

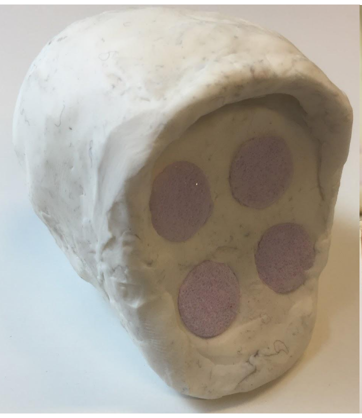

Figure AE. 3D perspective of head

Figure AF. A hand grips the head

The gear shift head is designed with six slots. Four slots are available on the front of the joystick head and two slots are available on the back of the gear shift head. The top of the joystick head gives opportunity to similar usage like when operating a single lever for the AH (see figure 10). The design of the gearshift is similar to the mouse head, the main difference lies in the fact that the gearshift joystick is not as extraordinary and protrusive as the mouse head.

Six Slot Head

Figure AG. 3D perspective of head

Figure AH. Side view of head

Figure AI. Back view of head

The six slot head is designed with to access maximally six slots which enables six push buttons or three rollers. The design of the six button head is similar to the four button head, the main difference is in the rectangular design with rounded edges and six available slots (see figure AG).

Handlebar Head

Figure AJ. 3D perspective of head

Figure AK. A hand grips the bicycle head

The Handlebar head is designed to be used horizontally with four available slots. There are three slots available on the fingertips and one slot available on the side where the thumb is placed (see figure AJ). Multiple buttons are available and close to reach from the fingertips, which takes inspiration to solve the demand of having multiple levers instead of one single lever as expressed by the interviews (see 4.3.1).

Buttons

In total there are three different kind of buttons available: push-, 4Axis- and roll button. All buttons that were created in the rapid prototyping excluded LED lights since they could not be created with plasticine.

Push button

Figure AL. Push button

The push button has a concave shape that is comfortable to press. The button takes up one slot and offers one function.

4Axis Button

Figure AM. 3D perspective of button *Figure AN.* Top view off button

The 4 axis button takes up one slot and offers four functions. The button can be operated in four directions, up, down, left and right. The 4axis button takes inspiration from the four function button that exist in the standard Xbox one controller (see figure C).

Roll Button

Figure AO. Side view of button *Figure AP.* 3D perspective of button

The roll button has a rectangular design. The button takes up two slots and offers two functions by using a scroll function. The button is designed with a ribbed surface in order to increase the friction when operating the button.

Appendix 8 - Evaluation Meetings

What is presented in this appendix is the questions that were asked during the external evaluations with the engineering-, ergonomics-, and design department. These are the official questions that were asked. The answers also led to further discussions that has been presented in the results of the external evaluations (see 4.3.2)

Engineering Department

1. What do you think of the modularized joysticks in regard to design, function and ergonomics?
2. Does the modularized joysticks provide the desired customer value efficiently?
3. Is the level of customizability balanced and if not how can this balance be found?
4. Are there any displays in the CEs today and what functions and services are currently provided to for the operators?
5. Can we assume that the UI displays in the 2021 CEs is going to be compatible with the joystick when the electrical connection is activated?
6. What aspects are important to take into consideration when designing products that are going to be used by the operator in the cabin environment?
7. Which module combination do you feel solves the need of a universal hand held joystick optimally?

Ergonomics Department

1. What do you think of the modularized joysticks in regard to design, function and ergonomics?
2. Besides the described ergonomic principles which we have included in our theoretical framework, do you have any other guidelines for designing a joystick?
3. Which grip template do you feel offers the most comfortable grip?
4. Which joystick head do you feel offers the best ergonomical varied use besides the traditional handheld grip on the template?
5. What module combination do you consider to provide full functionality as a universal joystick combined with providing the optimal ergonomics?

Design Department

1. What do you think of the modularized joysticks in regard to design, function and ergonomics?
2. Which modules do you consider to be most aesthetic appealing?

3. Which grip template do you consider to be most aesthetic appealing?
4. How can the designs be refined in order to express Volvo’s design characteristics?
5. Can you provide visual examples of products that share Volvo’s “typical” design features?
6. Which module combination do you consider to have solve the problem optimally with regard to design, ergonomics and functionality?
7. Do you have any requests or desires for how we can refine the design of your favorite module combination and make it more aesthetically appealing?

Appendix 9 - VCE Pictures

All pictures from VCE got permission to be used in the report. The following pictures were provided by VCE: