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Evaluating FPGA Technology From a Startup Perspective

Using startup methodology to try and create a feasible business model for FPGAs

Master's thesis in Management and Economics of Innovation

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Abstract

This thesis has been part of a project between students from "High Powered Computer Systems" and "Management and Economics of Innovation at Chalmers University of Technology" where before the project started the members of the project came up with a product vision that was going to be evaluated with the use of startup methodology. The vision was based on FPGA technology utilizing the capability to reconfigure itself between two different modes. Due to the need of a pivot, an evaluation of the technology was also made.

The research was performed using unstructured interviews with experts in the technology and players in its relevant markets in combination with the Customer Development framework by Steve Blank and Bob Dorf.

The study resulted in insights on the properties of the FPGA technology such as price, flexibility and performance. Along with this is technical information in the field of machine learning such as training at the edge, training on the FPGA and applications of machine learning in an autonomous vehicles. In addition, the results highlighted existing use-cases of FPGAs in industries and discussions on possible future developments. The interview also resulted in perspectives on how hardware is chosen with respect to factors such as power consumption, volume and other alternative hardware.

Lastly, The authors found the initial idea less feasible because of problems with both edge learning and training on the FPGA. There is a possibility to further develop training on the FPGA. In the pivoting process, the authors faced a difficulty developing a suitable alternative business case that involve using the switching mechanism due to the nature of the technology and its applications.

In conclusion, FPGA technology has many advantages and disadvantages. Its flexibility is a great strength but when considering price factors the industry move toward other options such as ASIC, especially in higher volumes. These factors make the FPGA suitable for a market that is low volume or requires higher flexibility. Space applications is one possible potential market as it fits well with these criteria. Therefore, it is worth further investigation in future research.

Keywords: startup, entrepreneurship, FPGA, business model

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Further, the authors would like to thank all of those that has taken their time to participate in this study through interviews. Throughout the project, the authors have had the opportunity to speak with many with expertise in the fields that this study has touched and without all that feedback, this project would have been much more difficult.

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1
Introduction

> In the last quarter of the 20th century, startups thought they knew the correct path for the startup journey. They adopted a methodology for product development, launch, and life-cycle management almost identical to the processes taught in business schools for use in large companies. These processes provide detailed business plans, checkpoints and goals for every step toward getting a product out the door—sizing markets, estimating sales, developing marketing-requirements documents, prioritizing product features. Yet at the end of the day, even with all these processes, the embarrassing fact is that in companies large and small, established corporate giants as well as new startups, more than nine of 10 new products fail. It's true in every product category—high-tech or low, online or off, consumer or business—well-funded or not. (Blank and Dorf, 2012)

1.1 Background

1.1.1 A joint start-up project

This thesis has been part of a larger project between students of the Master programmes of *Management and Economoics of Engineering* (MEI) and *High-Performance Computer Systems* (HPC) at Chalmers University of Technology. The project has included two students from each Master's programme and has had the goal of using prescriptive entrepreneurial theory to create a business model for FPGA technology. As mentioned by Blank and Dorf in the quote above, earlier startup methodology has been inefficient. That is why this project has chosen to utilize newer startup methodology to try and create a business model. While this thesis has had the goal of focusing on the business development, the other thesis, "A Dynamic FPGA platform for CNN Re-Training & Inference" by Gunnarsson and Samuelsson (2021), has researched the capability of machine learning on FPGAs, which is one reason why the FPGA technology was chosen.

The initial product idea of this project was to utilize FPGAs to create a more efficient platform for machine learning for autonomous vehicles. As cars are parked most of their lifetime (Barter, 2013) the members of the team thought to utilize hardware in the car during this down-time. These ideas and the technologies behind are further explained in the sections below.

During the project, time has been spent between the two groups to discuss the technology, business ideas and brainstorm for pivot options. Though both teams have had their own objectives with their own thesis, an aligned goal of trying to come up with a use-case for the technology of FPGAs, and utilizing its ability to reconfigure itself in the field, that is also a feasible business case has existed.

1.1.2 The technology: FPGA

Hardware plays a significant role in efficiently performing computational processes. One well-known type of processing hardware are central processing units (CPUs). They are categorized as a general hardware processors as they can perform all generic purpose tasks with an all-round acceptable performance. Another type of hardware is specialized hardware. This type of hardware is designed and built to process specific tasks from the beginning. Thus, most of the time, they have superior performance and efficiency than comparable CPUs when processing the same tasks (OmniSci, 2020). A prominent example of specialized hardware is a graphic processing unit (GPU) which is designed to execute a specific application (OmniSci, 2020).

Field-Programmable gate arrays (FPGAs) are another example of specialized hardware. They consist of an array of configurable logic blocks with programmable interconnections that can be reconfigured to suit a specific application (Shawahna et al., 2019). This makes FPGAs efficient in executing the specific task it is configured to do. However, unlike GPUs, FPGA logic blocks are configurable which makes FPGAs highly flexible on a hardware level since it can be reconfigured over and over again, even after it has been commissioned as remote over-the-air updates can be performed (Yan et al., 2014). In addition, it is also possible to reconfigure part of the FPGA while the other parts remain in-use which makes parallel processing and run time updates possible (Luo et al., 2020).

Generally, FPGAs are configurable and specialized hardware that provide hardware level flexibility, a characteristic CPUs similarly has on a software level and a fair level of efficiency as specialized hardware like GPUs have.

1.1.3 The technology: Machine learning in autonomous vehicles

The concept of deep learning has been around since 1950s (Amaratunga, 2021). However, with recent advances in hardware development, hardware is better at executing machine learning algorithms which is a fundamental requirement for autonomous driving (Grigorescu et al., 2020). Machine learning algorithms are applied to detect the environment around the vehicle from sensors and control the vehicles accordingly (Grigorescu et al., 2020).

Convolutional neural networks (CNNs), a subcategory of neural networks, are used when performing machine learning algorithms in autonomous driving applications.

A CNN consists of two different processes, an inference processes and a training processes. The training processes works by running multiple iterations on collected data sets to discover a pattern that is related to defined goals. It has to perform both forward and backward propagation in order to make a prediction (Luo et al., 2020). Meanwhile, the inference process takes a new set of data through a trained model that can speculate a new result based on that new set of data and requires only forward propagation (Bhavesh Patel, 2018). With multiple propagation required in the training processes, it demands more resources both in term of computations and memories when compare to less resource consuming inference processes. Therefore, each machine learning process requires a different design of hardware architecture (Gunnarsson & Samuelsson, 2021).

1.1.4 The technology: Training on the edge, and federated and swarm learning

Edge computing is a defined term describing a process where instead of collecting all the data and processing it in a computer centre, edge computing distributes computing resources to perform most of the processing as close to the source as possible. The benefits of this method are better privacy management, reduction of power consumption, and reduced network bandwidth requirements (Kukreja et al., 2019).

Inference on the edge has been widely implemented. However, training on the edge is less common because a variety of technical limitations make training on the edge less advantageous than anticipated (Kukreja et al., 2019).

Kukreja et al. (2019) highlighted three main challenges in implementing training on the edge. First, if the collected information on the edge devices is necessary to other devices, transfer of this information might increase communication bandwidth, latency and complexity within the network. In this case, a traditional centralised training process might be more efficient. Secondly, Kukreja et al. (2019) mentions that in order to independently train on an edge device, collected data on the device has to be automatically labelled so that there is no need to send training data back and forth from the center. Thirdly, in case that the collected data on the edge device is only relevant to itself and the training is performed locally on the device, there is limited edge computational capability that needs to be investigated whether they are sufficient and efficient or not (Kukreja et al., 2019).

In this project the authors and the development team investigated two relevant edge training approaches that have a possibility to be integrated with our initial business idea. The first approach is federated learning. This approach allows devices to share trained models while keeping all collected data on the devices (Konečný et al., 2016). With this approach there is no necessity to store the data centrally in the cloud as all the training data is kept locally on the devices. The devices then locally train on their own data to later update the global model which is shared across all devices (Konečný et al., 2016).

Warnat-Herresthal et al. (2020) argued that the concept of federated learning is still dependant on the central parameter server where settings of the system are centrally controlled (Warnat-Herresthal et al., 2020). Thus, making the method by design, vulnerable to legal jurisdiction and single point of failure (Warnat-Herresthal et al., 2020). The alternative approach Warnat-Herresthal et al. (2020) proposed is swarm learning. With this approach the centralised server is completely neglected by sharing the parameter settings across the network. The training is as well performed locally on the edge without sharing collected data with others. The locally trained model is then shared with other edge devices until they are all synchronised (Warnat-Herresthal et al., 2020). Additionally, blockchain is used to administrate the operation, to enable security and scalability (Warnat-Herresthal et al., 2020).

1.1.5 The initial idea

The initial vision that this start-up project was built on comes from the technologies described in the earlier sections, 1.1.2 The technology: FPGA, 1.1.3 The technology: Machine learning in autonomous vehicles and 1.1.4 The technology: Training on the edge, and federated and swarm learning. The specifics of the edge learning came into play during the first phases of the project, as the authors found that a more specific method of doing edge learning was required while doing initial interviews.

As cars are parked most of their time (Barter, 2013) the question was if the cars could be useful during this down-time. As more and more new cars are equipped with Advanced driver-assistance systems (ADAS) the members of the this project thought that FPGAs could be used due to their flexibility. As of now, most, if not all, training for machine learning are done in computer centres using Graphical-Processing Units (GPUs) and multiple car manufacturers use FPGAs for inference in the car. As the FPGA has the capability to be reconfigured on a hardware level the members of the team had the idea that FPGAs could be used for both training and inference, thus, skipping the transfer of data to data centres and allowing the car do be utilized while parked.

This would be done by having two different "modes" stored for the FPGA unit, one for training when the vehicle is parked, and one for inference, while the car is driving. The FPGA would then reconfigure itself depending on the state of the car. The training would be done using edge-training, where the machine-learning model is trained on the device itself, and not in a computer centre. Through this, hardware would be utilized more efficiently, and users of the cars would not have their data sent to data centres, it would be used in the car itself.

1.2 Purpose and Research Questions

The purpose of this project has been to use prescriptive entrepreneurship theories to try and design a business model around FPGA technology. The framework that has been used through the project is Customer Development, explained by Blank and Dorf (2012). Before the project started, the members of the project came up with the idea explained in section 1.1.5.

- Evaluate the initial start up idea mentioned in section 1.1.5.
- Evaluate the FPGA from a market and basic technical perspective to find possible pivot options
- Evaluate the feasibility of using FPGAs as a start up from the authors perspective

1.3 Limitations

There has been a few limitations for this report. The first one is time as this project has been conducted as Master's thesis during the spring semester of 2021. Therefore the authors has not been able to continue the start-up process to completion, as time has been available to go through all parts of the Customer Development process. As the authors has also worked with a technology that they had no previous experience of, the authors of this report has had to lean on other members of the joint-project for technical expertise.

The joint project has also been a limitation to the start-up process as there exists academic requirements for the thesis, especially for the technical side of the joint project, which made the authors of this report unable to pivot in the case of negative feedback for the technology and business idea from potential customers or other expertise.

1.4 Outline of the Report

The report is divided into multiple chapters, where the first two contains necessary background and theoretic knowledge. The third chapter, Methodology, contains methodology, including the overarching research methodology, a description on how data has been collected and which method has been used for analysis. The Methodology chapter is followed by Results where the results are consolidated, and then Discussion and Conclusion where the results, purpose, and research questions are discussed and concluded.

2

Literature Review

This chapter will focus on explaining the concepts and origin of the Customer Development framework developed by Steve Blank. These theories are therefore more prescriptive and has influenced the methodology of this project.

2.1 The Startup

> On a startup's first day, there's limited-if any- customer input for creating a formal product specification (Blank & Dorf, 2012, p.57)

In existing companies, a lot of information is known. They usually know who their customers are, the problems of the customer, and the necessary features of the product (Blank & Dorf, 2012). Blank and Dorf (2012) means that these companies work with execution. By comparison, they also mean that startups operate in a "search" mode. Startups are temporary organizations "in search of a scalable, repeatable, profitable business model" (Blank & Dorf, 2012, p.xviii) and are searching for customer input to create this business model.

This definition of a startup is similar to that of Eisenmann et al. (2016) who states:

> Startups are new organizations created by entrepreneurs to launch new products. A startup's founders typically confront significant resource constraints and considerable uncertainty about the viability of their proposed business model. (Eisenmann et al., 2016, p.1)

This information shows that startups differ from larger corporations, but this was not how startups organized in the last quarter of the 20^{th} where many startups used a methodology for product development, launch, and management similar to that of larger corporations. It is only in the last two decades that new tools for startups has emerged, together with the science of of entrepreneurial management (Blank & Dorf, 2012).

2.2 The Entrepreneur

In her article "What makes entrepreneurs entrepreneurial?", Sarasvathy (2007) mentions two distinctions in mindset. These are "effectual reasoning" and "casual reasoning". She argues that existing MBA (Master of Business Administration) are taught casual reasoning while the entrepreneur requires effectual reasoning. She writes:

> Unlike casual reasoning that comes to life through careful planning and *subsequent* execution, effectual reasoning lives and breathes execution. Plans are made and unmade and revised and recast through action and interaction with others on a daily basis." (Sarasvathy, 2007, p.3)

This can be compared to what Blank and Dorf (2012) writes about the entrepreneur. He says that the people behind successful startups are wired differently, as they are wired for "chaos, uncertainty and blinding speed". Blank and Dorf (2012) mentions another key thought process that the entrepreneur requires - the need to understand that failure is an integral part of the startup process.

2.3 Customer Development

Blank and Dorf (2012) the authors of *The Startup Owner's Manual The Step-by-Step Guide for Building a Great Company* described the customer development process as successful startup's best practice. The process aims to run in a fast cycle time using limited amount of cash as possible to provide startup more opportunity to iterate, pivot and be ability be success before running out of budget (Blank & Dorf, 2012).

2.3.1 Customer Discovery

According to Blank and Dorf (2012), customers discovery can be divided into four phases. The first phase is about turning vision and idea into hypothesises that is captured by different parts in business model canvas. These hypothesises are then put to the test in the second phase with the aim to get a better understanding of the customers. In phase three, a minimal viable product is created and tested against decided goals. In the last phase, all the results from the previous steps are use to decide for further progress, whether to go proceed to customer validation or repeat theses learning steps to have a better understanding the customers.

2.3.1.1 Phase 1: Business model hypothesis

Blank and Dorf (2012) suggests that hypothesis brief may be record in form of business model canvas. The canvas is able to show an overall summary of the business model in one page which make it east to refer, track and make change on the business model. In this step, the hypothesis is stated briefly but clear enough for everyone involve to have the same understanding. In later steps, these hypothesis must go against experiments to see if they bring an expected result or not (Blank & Dorf, 2012).

Market size
Market size is one of the first hypothesis to start investigating. It determines a scale of opportunity in your targeted market which is important for an entrepreneur

to judge a worthiness of their investment. The market size is consisted of three parts; Total addressable market (TAM), Served available market (SAM) and target market. Scaling from large to small, TAM is the largest possible market while SAM is the market after consider more detail factors. At the end, target market is the most possible market size you product will be bought. There are two approach to determine market sizes. First is a top-down approach that is an estimation from market analysis report, data from research firms and other available documents. The second approach is bottom-up which is more realistic for startup as it is a direct estimation from the existing facts. In addition, re-segmented market should also be consider if there is a chance that customers from adjacent markets might switch to your market. Further more, these proxies and adjacent markets are useful when it come to estimating new market's size as they can be used for reference and comparison (Blank & Dorf, 2012).

Value proposition

Value proposition is one of the main hypothesis in business model canvas. Blank and Dorf (2012) suggest to consider the value proposition as a contract between you and customers where the customers hire your company to solve their problem. The value proposition can be separated into three areas; product vision, feature & benefit and minimum viable product (MVP). The value hypothesis is also mentioned by Ries (2011, p.61) as one of the most important hypotheses that the entrepreneur can make. To this Ries (2011) also adds that if no one can be found that fits this value proposition/hypothesis, it is time to pivot.

A production vision is the long term vision the entrepreneur wants their company to become. It consists of brief element in form of bullet points that explain long term targets that are wanted to achieved. A clear vision could benefit customer development process as it can help pinpoint early adopter of the products.

When it comes to the product itself, product feature & benefits section should explain the product and a reason for customer to buy it. In term of features, they should be compose in a list called product feature list. The feature list can later be use to prioritize development of each function in MVP development stage.

Minimum viable product or MVP is a product that contains the least minimum features possible to provide a solution to the main problem as described in the value proposition. With MVP, product development resource is spent to a minimum level while we still able to perform customer learning process on early adopter with our working prototype.

Customers segments

In this part of the hypothesis, customers are briefly defined and described. It is first to take a look at how customers experience their problems and how scale of problem recognition they have. Blank and Dorf (2012) argue that the situation where customer define their problems and decided to make a solution by themselves is the best opportunity for startups to get-in that newly created business. Then type of customers have to be defined. Different type of customer may require different approach as their needs are not the same. With all these information on customers segments, they can be summarise in a form of customers archetypes that can visualise all the customers insight. Next, A run through method "A day in the life of customer" can help discover and understand what the customers have to get through and how our solution impact them (Blank & Dorf, 2012).

Channels
According to Blank and Dorf (2012), channels hypothesis describes how product or solution can get from startup to customer. It can be seen as an intermediate customers that need to be considered as it has an effect on cost, lead time and control over product distribution processes. There are two steps to consider when defining channels. First is to consider a fitment of products to the channel as it is highly related to cost and revenue model hypothesis. They must be reconsidered regularly when a condition of the chosen channel has changed. The second step is then to pick a sale channel that has the best potential upon the current incomplete customer validation process. Observation of established sale practice in the industries and evaluating complexity factors of each sale channels are a good practice when choosing sale channels (Blank & Dorf, 2012).

Market type
According to Blank and Dorf (2012), startup may take decision on market types after other hypothesis such as product features. The final decision can be made after customer creation process, but it is also a benefit to come up with initial hypothesis.

There are four market types, existing market, re-segmented market, new market and clone market. If a product is better than other competitors then it can be fit into existing market. However, if a product is more expensive but provide a better solution to a niche market, it may fit well in re-segmented market. On the other hand, a comparable product with lower price, may also fit within this types as well. In the last case, a product that have a similar existence in other geographical markets may adapt that already successful business model to its new market which is categorized as clone market type (Blank & Dorf, 2012).

Customer relationship
Customer relationship hypothesis is a proposal plan to get customers into the sale channel, keep them royal with the product and to grow more revenue from them. Blank and Dorf (2012) illustrated the overall customer relationship as a “two-end funnel” where getting-step is on the left, keeping-step is in the middle and growing-step is on the right. On the left funnel, the number of potential customers narrowly decline though the process as their interest grows to a level they purchase the product. In the middle, the number of customers are kept constant with strategy to interact and retain them. And lastly on the right, a number widely grows again though processes of expanding new revenue and referrals. Each steps requires its own strategy that suit with type of products and targeted customer segment (Blank & Dorf, 2012).

Key resources
Key resources are external resources that is needed for startup in order to achieve its goal. They are four types of resources, physical, financial, human and intellectual property. For Physical resources, they come in form of facilities such as office or retail

store, and in a form of product/service such as computing server or raw materials. Many of these resources could be traditionally acquire by fully purchasing or more cost-efficient access through renting, subscribing or outsourcing. Financial resources is also important as every company has to use them wisely and efficiently as possible. Financial resources can be raised from several sources such as venture capital, angle investors or crowd funding but there are also other additional sources such in form of leasing, loaning and factoring (Blank & Dorf, 2012).

Blank and Dorf (2012) suggests that Human resources play an important role in advancing company's and personal success. Teacher or mentor is essential for personal development while advisors help validate startup's visions based on their experience. Employee is definitely an essential part as qualified and motivated employee can make a difference between failing and archiving a goal. One last key resource is intellectual properties, they are used to protect company assets such as a core technology that essential to company's products. Intellectual properties come in difference forms depends on use case, technology is protected by a patent, logo is covered under trademark, for instance. Blank and Dorf (2012) states that intellectual properties should be treated as company's asset. Thus, it is needed to implementing intellectual properties strategy to acquire, protect and exploit them (Blank & Dorf, 2012).

Partners

Blank and Dorf (2012) argues that partners are an important resource that help full fill company lacking capability, product or services. Partnership are established based on "value exchange" between parties. Therefore, it is recommend to consider in "what they provide and what we provide" perspective. Partners can be established with in four key areas, strategic alliance, joint new business development, competition and key supplier relationship (Blank & Dorf, 2012). Strategic alliance mostly form between two noncompetitive company that can together build a better complete product or service than solely develop by their own. Joint new business development is a longer-term opportunity that come in a later phase when startup is better well-established. While competition seems to be opposite type of those mentioned above, partnership with direct competitor aims to share cost or market. Example can be seen in fashion show and trading fair. Lastly, key supplier relationship is instrumental but critical for startup as supply product or service might relate to core part of their business. Startup should identify and understand key suppliers conditions and plan a way to form a beneficial partnership (Blank & Dorf, 2012).

Revenue and pricing

Revenue and pricing hypothesis may be complicated to create according to Blank and Dorf (2012) as it involved looking into financial feasibility of startup business model. There are four main questions to consider when formulating revenue and pricing hypothesis, First, from earlier hypothesises, it may possible to estimate amount of product or service that is going to be sold. Then formulate revenue model-a method to get a revenue from the product or service, direct-sale, subscription or pay-per-use for instance. After that, price tactics has to be considered, startup has to answer, how much the product and its whole operation will cost? and how much "price" should be set? There are many factors that related to pricing hypothesis.

Hence, varies pricing models could be used but also need to be validated.

Blank and Dorf (2012) suggested when it comes to business-to-business type of customer, some pricing issues occur. First, business customer considers more on “total cost of ownership”, they tend to evaluate not only cost of a product/service but cost of adopting them as well. Additionally, business customer focuses more on “return on investment” than typical consumer as they need to evaluate their investment over typically a large amount of transactions.

Last question to formulate is the feasibility of this whole revenue and pricing model. Will the revenue model gain sufficient amount of income to cover their cost? how long it will last? and will they grown overtime? These are an important questions to considered based on previously made assumptions.

To conclude, the process of conducting this business model hypothesis it an initial assumptions and questions that get organized together in a structural form, They need to get proven in the next phase. These assumptions does not have to be correct in this first phase, which is mentioned by Alvarez (2014). She also mentions the importance of actually creating these assumptions, as they “serve as a critical reminder to you that you haven’t yet proven or disproven them” (Alvarez, 2014, p.20).

2.3.1.2 Phase 2: Problem testing

Blank and Dorf (2012) write that the second phase of Customer Discovery is the "Get out of the building phase to test the problem". During this phase they write that the startup needs to answer three key questions:

- Do we really understand the customer’s problem?
- Do enough people care enough about the problem for this to become a huge business?
- And will they care enough to tell their friends? (Blank & Dorf, 2012)

Blank and Dorf (2012) also mentions five key steps in this phase:

- Designing experiments for customer tests
- Preparing for customer contacts and engagement
- Testing customers understanding of the problem and assessing its importance to customers
- Gaining understanding of the customers
- Capturing competitive and market knowledge

As mentioned earlier in section 2.3 Customer Development there is a lot of focus on creating hypotheses in Customer Development. In Figure 2.1 a visualization of the process that is this phase is shown. From having our hypotheses, the startup will design experiments to get answers to either prove or disprove their hypotheses

(Blank & Dorf, 2012). After having completed the tests, the startup will look into the new insights gained, and from that create new hypotheses.

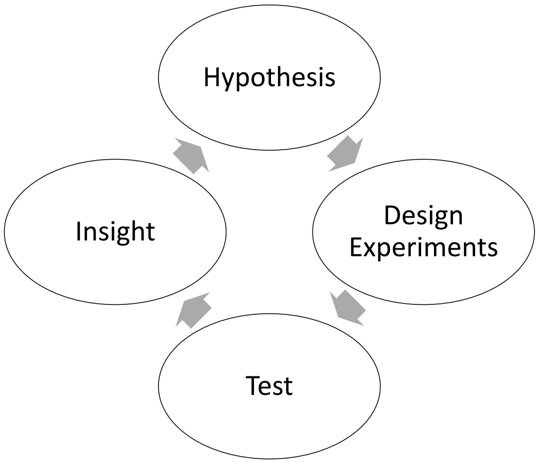

Figure 2.1: The Hypothesis/Experiment/Test/Insight loop from Blank and Dorf (2012)

It is important to note that the tests does not have to be complicated, and they do not need to include neither code nor hardware, nor a product (Blank & Dorf, 2012). Blank and Dorf (2012) also mentions that the startup might need to look past the data for insights. As an example, they write that the startup might have been dismissed in a phone call but that the words “Too bad you don’t sell x, because we can use a ton of those” were uttered, which could still be an insight to the problems of potential customers.

To gain enough insights, Blank and Dorf (2012) recommends the founders to start with 50 target customers. They also mention that a solid discovery phase usually involves 10-15 customer visits a week. But as not everyone the startup will contact will be interested in a meeting the startup will probably be required to contact 200 customers or more for 50 face-to-face meetings.

There are multiple channels to get in contact with customers in, e.g. phone calls, e-mail, LinkedIn and other social media. Blank and Dorf (2012) recommends to use one’s network when getting in contact with customers, even if it requires you to “call in every favor possible” (Blank & Dorf, 2012, p.195). They also recommend the contact to be initiated by the one introducing you, that will explain why the contact will take place. When getting in contact with businesses, Blank and Dorf (2012) also mentions that titles and position in the contacted company are irrelevant. The founders of the startup are not there to sell, but to get information, so any individual or business that in any way match the hypothetical customer profile will do (Blank & Dorf, 2012).

As mentioned, the point of the meeting is not to sell, but to gain information. The first hypothesis to test is the problem hypothesis. Is the vision of the startup solving a problem, and is it an urgent problem or a problem that “would be nice to fix ’someday’” (Blank & Dorf, 2012, p.203). It is important to understand what kind of problems the potential customers have, and how they understand the problems, and what their current solutions are. This is also explained in *The Mom Test* by Fitzpatrick (2013) where he brings up a misunderstanding of a customer problem that cost him a lot of time in wasted development.

Two other areas to capture knowledge in during the meetings are customer understanding and market knowledge (Blank & Dorf, 2012). Knowing the customers and how they conduct their work is an important part of understanding the problem and how the startup in the future can market their solution, as it at some point will need to create a demand for the solution (Blank & Dorf, 2012). Regarding the market knowledge, Blank and Dorf (2012) writes that even adjacent markets are important to observe and learn about. They also mention industry analysts, press and other key influences to be people that are helpful to speak to. By looking at competing products the startup will also gain important information about their new market (Blank & Dorf, 2012).

2.3.1.3 Pivot

Ries (2011, p.149) describes a pivot as a "structured course correction designed to test a new fundamental hypothesis about the product, strategy, and engine of growth [part of the lean start-up methodology]". Ries (2011) continues to describe how the process of pivoting is nothing that is standardised. It is impossible to to remove human elements such as vision, intuition, and judgement.

Blank and Dorf (2012) mentions multiple questions to ask yourself to see if there is a need for pivoting:

- Have we identified a problem lots of customers will eagerly pay to have solved?
- Does our product solve these needs distinctively, cost-effectively and profitably?
- If so, do we have a sizeable market and a viable, scalable and profitable business model?
- Can we draw a day in the life of our customers before and after purchase of our product?
- Can we create an organizational chart of users, buyers and channels? (Blank & Dorf, 2012, p.270)

Blank and Dorf (2012) continues to explain that the customer discovery phase usually requires multiple iterations for the entrepreneurs to fully understand the market of their product who the important customers are. As they explain, until the entrepreneurs find the "Holy Grail" they should use what's been learned through the previous steps and, modify, and iterate.

2.4 Product Evaluation

There are many different methods that can be used for different goals in product evaluations (Ozer, 1999). Some mentioned by Ozer (1999) are:

- Concept Testing: Expert Opinions
- Concept Testing: Multiattribute models
- Need/Usage Content Analysis

Ozer (1999) summarises these methods using the factors primary objective, product type, required data, environment, time, diagnostic information, and limitations and his descriptions are shown in table 2.1.

The methods in the summary in table 2.1 are all possible for new products and in a shorter time frame. Ozer (1999) mentions more methods in his paper but some has been left out due to them not fitting the idea and technology mentioned in the first chapter.

Using expert opinions for evaluating a new product can help in predicting what kind of events could affect the demand for the product, but also help to generate valuable insights for product design when there are no historical data (Ozer, 1999). In another paper, Ozer (2005) mentions how diversity in the expertise could help with product evaluations.

The need/usage content analysis can also be compared to what Christensen et al. (n.d.) mentions in in his article about finding the right job for the product. According to him, a product needs to find the right job to fulfill instead of trying to find more traditional market segmentation groups to market towards.

Table 2.1: Product evaluation methods summarised by Ozer (1999)

Stage (Method)	Primary Objective	Product Type	Required Data	Environment	Time	Diagnostic Information	Limitations
Concept Testing: Expert Opinions	Predicting performance and identifying likely and unlikely events in the market	Any new product as long as experts are not biased.	Opinions of different experts.	Effective in stable environment.	Effective for short term predictions. Can be conducted very quickly.	Insights for product design and positioning.	Subject to such biases as optimism, conservatism, anchoring, and supply orientation
Concept Testing: Multiattribute models	Predicting a new product's relative market position and designing its features	Products with clearly definable attributes. Less accurate with "new-to-the-world" products.	Consumer survey data	Effective when the environment and consumer perceptions are relatively stable.	Reliable in short term analyses. Can be conducted quickly.	Information about product attributes, relative positions of the new product in the market, and new opportunities in the category.	Based on the assumption that products have a finite set of attributes, and people base their opinions on them.
Need/Usage Content Analysis	Understanding unfilled needs and/or a product's usage situations and the type of problems it can solve	Can be used with every new product.	Opinions of lead users. Consumer survey data.	Can be helpful in unstable environments.	Can have a long-term focus. Can be conducted relatively quickly.	Insights for new product development and positioning.	More specific product and marketing attributes need to be tested by other methods.

3

Methodology

3.1 Startup and collaboration process

As mentioned earlier in the introduction section 1.1.1, this study is conducted through a startup project with collaboration of two teams. Gunnarsson and Samuelsson, the authors of "A Dynamic FPGA platform for CNN Re-Training & Inference" thesis represented technical development team while the authors of this thesis represented business development team.

As described in 1.1.2 The technology: FPGA the technology that the startup is built around is FPGA which is a research subject for the technical development team thesis. The FPGA research study were then performed in parallel with business development conducted by the authors of this thesis. The authors has mainly used one framework for the startup process, mainly Steve Blank's Customer Development which he describes in his book *The Startup Owner's Manual The Step-by-Step Guide for Building a Great Company* (2012).

In the initial phases, the project members started looking for an application that is suitable for the subject technology. This resulted in the initial idea described in section 1.1.5. Afterward, the teams analysed different key business hypotheses related to this business idea follow customer discovery framework reviewed in section 2.3. The hypotheses were then illustrated in business model canvas template.

In the next step the authors conducted many different interviews to explore the potential customers and to validate setting hypotheses. These interviews, which will be described further in 3.3.2 Data Collection has included people from the autonomous vehicle industry, venture capitalists and people with expertise with FPGAs.During this phase, a lot of time has been spent on trying to find individuals to interview, but as mentioned in section 3.3.2 there were difficulties getting in contact with individuals sending cold e-mails.

While the different interviews had been conducting, the teams kept validating the hypotheses as well as set new speculations in each revision of the canvas. One revised version of the business model canvas can be seen in figure 3.1.

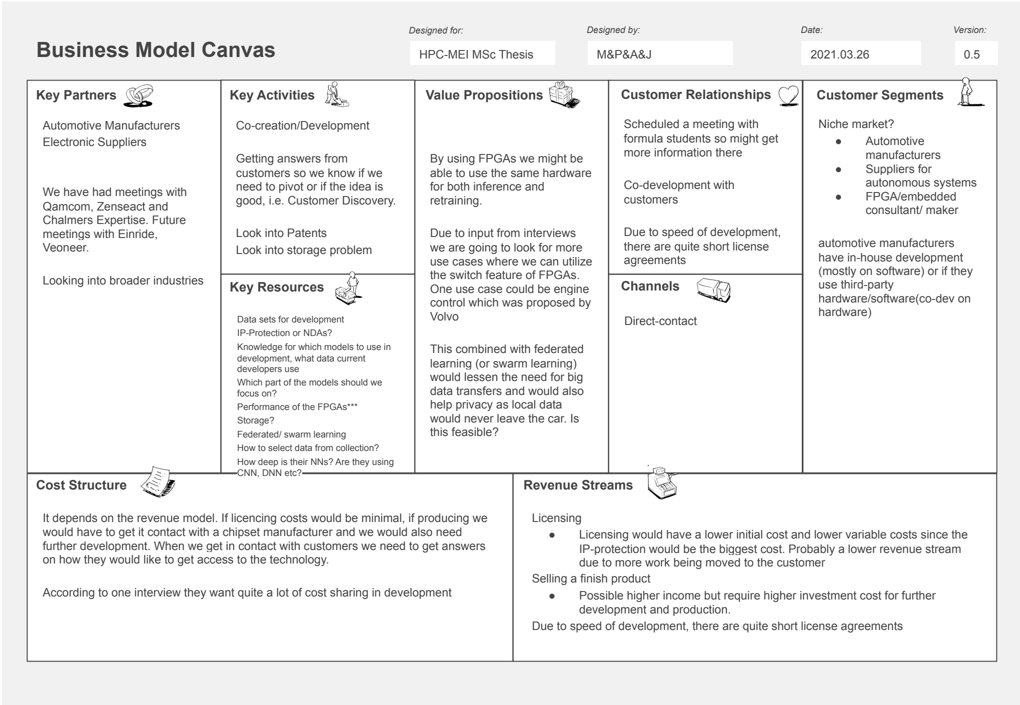

Figure 3.1: One version of hypotheses in a business model canvas using template designed by The Business Model Foundry and Neos Chronos Limited

As suggested by Blank and Dorf, a simple pass/fail experiment is one of design experiments that could be used to test a business model hypotheses (Blank & Dorf, 2012). However, with a complexity of the technology and product features in the initial idea, it was too complicated and time consuming to build a prototype on a software or hardware level. The teams decided to described the idea in a one page information sheet A.1 which then distributed to the interviewees. The idea was then tested by interviewees opinions and follow up discussion was then used to collected insight and better understanding of the customer.

With validated facts and knowledge gained from the continuing interviews as well as intuition and judgement of the teams, the decision was made to looking for possible improvements on the original idea together with alternative pivot applications. Theses were then brought up to discussed in the rest of the interviews sessions, again to validate and gain more knowledge that could be used to re-evaluate those alternative ideas.

At the end, a possible alternative cases were presented and discussed among teams. For the technical development team, they could beneficially use the ideas as targets for their FPGA development. While the business development team could propose a possible business idea applications that have a potential to be researched further.

3.2 Research Strategy

Bryman and Bell (2011) mentions the importance of choosing a research strategy. The two common categories of these are quantitative and qualitative research strategies. Quantitative research strategies have a focus on quantifiable data and to use large sets of measurable data. Qualitative instead is “a research strategy that usually emphasizes words rather than quantification in the collection and analysis of data” (Bryman & Bell, 2011, p.386).

Due to the nature of this project, it naturally falls in the category of qualitative research. However, qualitative research is a broad term and there exists many different subcategories. To further classify this study, the authors have chosen to go with "Action Research" which Bryman and Bell (2011) describes as:

> it [Action Research] can be defined as an approach in which the action researcher and a client collaborate in the diagnosis of a problem and in the development of a solution based on the diagnosis (Bryman & Bell, 2011, p.413).

One thing to note here is that the authors are both researchers, and the client as the authors are conducting this project as a startup. Therefor this study could also be described as an auto-ethnography approach. Bryman and Bell (2011) describes this as:

> Auto-ethnography involves the writing of a highly personalized text in which the personal is related to the cultural and the political in a way that claims the conventions associated with literary writing. (Bryman & Bell, 2011, p.707)

Autoethnography is also described by Ellis et al. (2015) as:

> Autoethnography is an approach to research and writing that seeks to describe and systematically analyze personal experience in order to understand cultural experience. (Ellis et al., 2015, p.1)

Adams et al. (2017) defines autoethnography as “autoethnography is a research method that uses personal experience (“auto”) to describe and interpret (“graphy”) cultural texts, experiences, beliefs, and practices (“ethno”)” (Adams et al., 2017, p.1).

Van Aken and Romme (2009, p.7) writes that design science research is “research that develops valid general knowledge to solve field problems”. Van Aken and Romme (2009, p.7) also mentions three characteristics:

- research questions are driven by field problems (as opposed to pure knowledge problems);
- there is an emphasis on solution-oriented knowledge, linking interventions or systems to outcomes, as the key to solve field problems;
- the justification of research products is largely based on pragmatic validity (do

the actions, based on this knowledge indeed produce the intended outcomes?)

There are also some guidelines which Hevner et al. (2004) has created for Design Research s research which are shown in table 3.1. As this study is part of a joint project described in section 1.1.1, it could be said that the artifact in question is the technology and that this study is the validation of the business side of the artifact, or it could be said that the attempted business model is the artifact. Peffers et al. (2007) also mentions, in accordance to the first guideline in table 3.1 that the artifact can be of different natures.

Table 3.1: Design Research guidelines from Hevner et al. (2004, p.9)

Guideline	Description
Guideline 1: Design as an Artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
Guideline 6: Design as a Search Process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

3.3 Research Process

3.3.1 Literature Review

Literature review was performed in the initial phase of this thesis to create an overview understanding of entrepreneurship research in the current state. According to Bryman and Bell (2011), literature review provides an understanding of the research area that help formulate research question and research design. In addition, The literature review also point out method of collecting data and properly analyse them (Bryman & Bell, 2011). The processes of literature review involve scoping area of interests, reading, and demonstrating researcher's understanding of the subject area by describing, clarifying and evaluating known knowledge from the existing studies (Bryman & Bell, 2011; Easterby-Smith et al., 2018). The topics of the literature review in this thesis include concept of startup, definition of entrepreneur, customer development frameworks, for instance.

3.3.1.1 Lean Startup

Another prescriptive theory of entrepreneurship is the lean startup methodology developed by Ries (2011). Müller and Thoring (2012) writes that Lean Startup incorporates lean methodology regarding product development with the customer development methodology by Blank and Dorf (2012). Müller and Thoring (2012) mentions that the aim of lean startup is to build a "continuous feedback loop with customers during product development cycles".

Due to the length of this project, not much development would be able to be completed, so more focus has been placed on finding customer input, and analyse what experts of the technology and potential customers think of the technology and the initial idea. Due to this, the Customer Development methodology by Blank and Dorf (2012) was chosen as it focuses more on this part of the startup process.

3.3.2 Data Collection

In this study the data has been collected through multiple interviews. As shown in table 3.2 not all interviewees are potential customers, some of them have been interviewed due to their technical and/or market expertise, as mentioned in 2.3.1.2 Phase 2: Problem testing.

There are multiple ways of structuring interviews, of which two are common for qualitative studies, these are semi-structured and unstructured interviews (Bryman & Bell, 2011). Bryman and Bell (2011) describes unstructured interviews as interviews where the interviewer mostly have a list of topics which can be covered during the interview. The phrasing and sequence of questions might differ from interview to interview.

The semi-structured interview is a bit more fixed, where more questions are prepared before the interview, but this structure allows the interviewer to change the order of questions as well. It is also open for follow-up questions depending on answers (Bryman & Bell, 2011).

The interviews in this study has mostly been unstructured to allow for more input that may hold importance but might not have been thought of in the preparation of the interview. Due to this, the interviews has been prepared with topics that the interviewers would like to discuss with the interviewee. Some of the interviews has been more semi-structured, in the case of interviews with people of expertise, when more technical questions has been asked and prepared before the interview.

In the beginning of the project, the authors tried to get in contact with multiple companies through cold e-mailing, or cold messaging on LinkedIn. Through this way, few contacts where established. In the e-mails our background, and purpose of were stated, together with an attached PDF-file including our initial business idea. Due to the low response rate, the authors got in contact with their supervisor who helped them get in contact with individuals that were in, or adjacent to, the industry of FPGAs and the autonomous vehicle industry. Through these individuals, some more contacts where made.

Table 3.2: Table of interviewees and their role

Role	Number
FPGA Expertise	A
Potential Customer	B
FPGA Expertise	C
FPGA Expertise	D
Venture Capitalist	E
Venture Capitalist	F
FPGA Expertise	G
Potential Customer	H
Potential Customer	I
FPGA Expertise	J
Potential Customer	K

3.3.3 Analysis of Results

As the nature of data collecting method in this thesis were based on qualitative approach such as semi-structure interviews. Therefore, collected data can be seen in a complex form of interview transcriptions.

According to Bryman and Bell (2011), one of the common approaches to qualitative data analysis is a search for themes in those collected data (Bryman & Bell, 2011). However, criteria to identify the theme is often unclear. Thus, it was suggested by Bryman and Bell (2011) that occurrence frequency of certain keywords and phases could be used to form a theme (Bryman & Bell, 2011). In another words, an indirect quantitative approach may be used to identify themes as well as perform evaluation among them (Bryman & Bell, 2011). This analysis method is recognized as “Thematic analysis” (Virginia Clarke, 2019).

Thematic analysis is one unique qualitative analytic methods that only provide itself as method of data analysis but not include the way to collect data or setup a theoretical positions. This makes it highly flexible to apply on almost any type of research question and any kind of data (Virginia Clarke, 2019).

As it is suitable with the nature of this thesis, this method was used by the authors to analyse collected data in this thesis. The first step was to transcribed all the interviews. Then the authors went though the data sets to get familiar with all of the content. Later on, the authors performed coding - identifying each quote. Lastly, identified quotes were grouped in to themes reflecting important detail from each interviewees, each theme representing information that related to the research questions (Virginia Clarke, 2019).

A limitation of thematic analysis is that it is based on information being said not how they are said. Thus, it ignores the context of the information as people can have a different meaning to their answer or different reason to tell them (Easterby-Smith et al., 2018).

3.4 Research Quality

Foundations of quality in qualitative research are based on trustworthiness and authenticity criteria. Trustworthiness can be assesses by four dimensions: credibility, tranferability, dependability and confirmability (Bryman & Bell, 2011; Kuada, 2011).

- Credibility is represented by whether the qualitative research is conducted with an acceptable procedure or not. Kuada (2011) suggested a method of respondent validation where researcher send back interview transcripts to interviewees in order to confirm researcher understanding and validate the collected data (Bryman & Bell, 2011; Kuada, 2011). To archive a high level of credibility, the literature of chosen appropriate research frameworks are reviewed and listed in chapter 2 Literature Review.
- Transferability is determined by a detail of conducted studies provided that can be used by future researches to compare and further valid the study in other contexts (Kuada, 2011). To attain this criteria, the authors thoroughly described background and methodologies in chapter 1 and chapter 3.
- Dependability is about keeping records of research processes that have been done throughout the study. They could be presented as a evidence to backup credibility and transferability criteria mentioned (Kuada, 2011). In this thesis, authors kept record of documentation from every phases e.g interview transcripts, weekly progress report, business case hypothesis development logs.
- Confirmability is the last criteria that demonstrate a purpose of conducting a research has no hidden agenda but only done in order to gain knowledge on stated subjects (Kuada, 2011). This include ensure that researcher avoid personal or external factors to influence the result and fining of the research (Bryman & Bell, 2011). In order to comply with this criteria, a sufficient amount and diversify interviews were conducted as detailed in 3.2. An influence question such as lead questions were also consider their impacts to interviewee answer in the analysis process.

Meanwhile authenticity is based on fairness of the investigation in the research project. For example, including all relevant people and their opinion. It also include improving understanding about the investigating topic and providing opportunities for relevant people to get the acquired knowledge from the study as it may benefit them (Kuada, 2011). To attain a high level of authenticity, the authors also informed and provided access to this published thesis to all the interviewees and relevant people involved in the study processes.

4
Results

During the interviews conducted through this study, multiple themes were found. In the section 3.3.3 Analysis of Results the authors has described the thematic analysis which has been used to categorise these themes. These themes are here used as the different sections of the results.

4.1 Properties of FPGAs

In this section some properties of the FPGA will be discussed, including price, flexibility, performance, development and the switching mechanism. Some of these properties will also be discussed in other sections as some of the themes overlap each other.

4.1.1 Price of FPGA

One of the important properties that has been discussed in multiple interviews is price. It is also a property which is difficult to find out more about, i.e. more exact numbers. One interviewees that has been working with FPGAs said: “I don’t think you can extract the real price. It’s it’s impossible to to get anyone to tell you that.” He also said:

> I’ve seen a lot of cases where where the list price might be thousands of dollars and the actual price is like a hundred and twenty dollars. So it really, it really depends totally on on who you are, who’s going to buy.

The variation in price was also mentioned by an employee of a FPGA manufacturer, who mentioned that the price could vary a lot from the listing price depending on the volume and size of the buyer.

The listing prices themselves vary a lot depending on the quality and IO ports of the board, and FPGAs listing prices can range from anywhere between 51 SEK and 240 000 SEK (Digikey, n.d.).

According to another interviewee, individual "E" (see table 3.2, the price is also not linear: “half the size FPGA, which probably costs like 25, 30 percent because it’s not linear”.

There are multiple reasons why the price of the FPGAs can reach such highs, according to the first interview it's the actual size as to be reconfigurable, the board requires more silicon than other comparable hardware. Another reason, according to individual "E" is:

> (...) they [A chipset manufacturer] claim the reason why the FPGAs are much more expensive than a CPU with a similar gate count is that the customers are so much, they have so much more questions then take so much more time and require so much more support. So we have to have a much higher price on the FPGA, not for the production costs, all the support costs.

4.1.2 Flexibility of FPGAs

In the section 1.1.2 The technology: FPGA the flexibility of FPGAs was mentioned. This has also been a feature prominent in most interviews as one of the biggest advantages of FPGAs. In one interview, the interviewee said:

> And I mean, that's the more, the more flexible scenarios you have or the more changing environments where it's actually important to change shape on a on a transistor level or a logic level, it's then the FPGA have a unique advantage there. So anything that really needs that, if there is no way to avoid that, then the FPGAs are fantastic because the alternative is really, really bad.

This is concurred by the FPGA manufacturer employee that stated:

> So when you send something far away in a remote location and you would like to maybe modify it later, also there has been quite many products where they have like a firmware upgrade. So many, even consumer products, have a small FPGA somewhere on the board to to give some flexibility for bug fixes and small upgrades.

One of the reasons why FPGAs are flexible is also mentioned by Rizzatti (2018) who states: "They [FPGAs] are not limited to certain types of data. They can handle non-standard low precision more suitable to deliver higher throughput for DL [Deep Learning]."

4.1.3 Performance of FPGAs

Excluding the flexibility, FPGAs are also very good at certain tasks. Interviewee "E" mentions for example the low latency:

> Look for a few specialized applications, like in financial training engines, you used to use FPGA because you want very small latency to execute certain things, to learn trading patterns or to execute certain trades. And people used to use their FPGA s for that because you could get, you could implement very different things very quickly.

Another key feature of the FPGA that can increase the performance is the ability to do tasks in parallel since you as a developer can use the different logic blocks on the board for different tasks, or run the same algorithm on additional data on other logic blocks. As mentioned in section 4.1.2 the FPGA is not limited to certain types of data, and this includes different bit widths. In one interview with a company doing work with FPGAs (interviewee "G") one of the interviewees said:

> FPGAs have this large benefit compared to CPUs that you can choose bit width and if you go down, it will reduce the size of the code and you can get more done in parallel.

4.1.4 FPGA Development

One of the more negative properties of the FPGA seems to be the more difficult development. This is mentioned by multiple of the interviewees throughout the study and in interview C the interviewee said:

> (...) well, first of all, there is, in my experience, there is no such thing as easy and fast when it comes to FPGAs. Just having the tool itself running Vivado and doing something as simple as doing “hello world” with it can take one or two months.

One reason for this that was stated by interviewee "H" was:

> So apart from the technical issues, we do have issues with experience and knowledge, so actually it’s hard to find good FPGA engineers because it is slightly different than, OK, you need to have some understanding of software and data flow and things like that. But actually, FPGA are based on a different basic idea. So if you can’t take a normal software engineer and put him on producing FPGA, it doesn’t work.

To combat this, FPGA manufacturers have developed more tools to make the development easier (Interview "G"):

> I guess more or less every FPGA vendor nowadays has something half ready. Some sort of tool something. Xilinx, I haven’t really followed that the last half year, but they quite early came out with an approach where they said they have a tool.

Even thought there exists long development times and may exist a shortage of developers for FPGAs they still have shorter development time than *Application-Specific integrated circuits* (ASICs) according to one of the interviewees.

4.2 Machine Learning

In the beginning of this project, a lot of focus was also put on machine learning, as machine learning was part of the initial idea described in section 1.1.5.

4.2.1 Data

There are multiple important factors to take into account when the authors speak about the data required for machine learning, especially for autonomous vehicles. In interview "A" the interviewee stated:

> But you have a car and so on. It's much more difficult. But you have to collect a lot of different types of data, which you don't even know what what would be the most important one. If you want to go from the safety angle, you know, you cannot even collect that data because it very rarely is the car going to be in a really dangerous situation.

As he describes, the data required to train models for autonomous vehicles needs to be broad. That is due to the many different situations that can occur while driving. According to other interviews, the amount of data can reach hundreds of megabytes per second while collecting data.

> I mean, typically when you're out doing data collection, you try to record as much as possible, of course, since this is quite costly. But they they probably usually record something like a couple of hundred megabytes per second. So it goes directly into large hard drives. And either over the night they they download the data from the hard drives to central storage, but that's usually not very effective. So in the end, they just ship the drives that's the highest bandwidth that you can find and upload it to central servers. And then it's used in the training.

As also stated in the last quote, the data is then transferred to central servers for training. At the moment, according to the interviews, most, if not all of the training is done on computer centres. It can also be seen that the amount of data can reach sizes that are too much to transfer over cellular networks. This is further concurred in interview "B" where the interviewee stated: "And with 5G, I think we're planning to send up more data. Yeah. We're probably not going to be able to send raw data anyways. So still way too much".

4.2.2 Training on the Edge

One technology that was discussed in the interviews and that was part of the initial idea mentioned in section 1.1.5 was training at the edge. This technology is described in section 1.1.4. During all the interviews, there seems to be an interest in edge training, and in interview "D" the interviewee said: "It's the edge training that I guess is sort of the key, the key feature of this".

One of the reasons edge training is interesting is that it could, as mentioned in section 1.1.5 help to utilize hardware more efficiently, which was also concurred in interview "H":

> So I'm pretty sure it [edge learning] will come because it is a waste of processing power if we don't use the hardware in the car, when it is not driving, of course

Though, multiple problems with edge training was discovered during the interviews. For example, as mentioned in section 4.2.1 autonomous cars require a wide selection of data. For example in interview "D" the interviewee said:

> It's a lot of data, but it's still very, very specific data sets for for that particular car and its experiences. And then you're locally training that one. And the the other method of spinning this out into the cloud has the drawback of having to transport a lot of data. On the other hand, it trains the model on a far wider set of data and then distributes that model back to all the cars.

This was further strengthened in interview "G" where one interviewee stated:

> if you do any kind of of data gathering on a single car, wouldn't you have to collaborate with all the other cars and all the other data? Basically that collective pool would become the model that you would be training on, would still have a bandwidth requirement to upload all of them to collect the data centrally anyway.

One way to solve this problem with data which was discussed in the interviews is federated learning, which basics were described in section 1.1.4. This was discussed in a couple of interviews but this technology, at least for this use case, is in R&D at the moment. According to interview "H", edge learning will not happen in the autonomous vehicle industry for at least 5-10 years.

Another problem with edge learning is defining ground truth. Ground truth is a term which defines the reality, compared to the what the machine learning model thinks. An example could be in image recognition, where the data is labeled either "dog" or "cat" and then put into the machine learning model, so that after the model "guesses", its' answer can be compared to the label, or ground truth. Defining ground truth in the data collected for autonomous vehicles is a lot of work according to the interviews, and is one interviewee stated that they outsourced this task. When training at the edge however, the data is used directly, and therefor needs automatic labeling. This is a safety problem with training at the edge, since if the data for example is labeled by the driver's input, it could be labeled wrongly due to the driver not driving correctly, or as one interviewee put it: “How do you know the driver is not trying to teach the system incorrect things by all the time driving off the road?”

4.2.3 Machine Learning on FPGAs

In section 1.1.5 the authors described the initial product idea. Part of this idea was training on FPGAs, which has been discussed in most of the interviews conducted in this study.

Almost unanimously, the interviewees were sceptical about machine learning training on FPGAs. In interview "C" the interviewee said: “there aren't many implementations on training because FPGAs are not really built for training”. This is concurred in interview "A" where the interviewee mentioned that training is to intensive for

FPGAs.

However, in some interviews the interviewees expressed thoughts on if training on FPGAs could be done in the future. In interview "A" the interviewee said:

> So how can you make best use of your hardware to run deep learning models? This is a very big area that is in big flux right now. Nobody knows what is the right way to do it and FPGA in particular. I mean, they're very interesting because they're very flexible and you can do so many things with it, but it remains to be seen exactly how well you can do it.

Another way, according to one interviewee, that training might be possible on FPGAs in the future is through changes in how training is done. In one interview with an FPGA manufacturer employee the interviewee stated: “But yeah, of course, later down the road, there may be a new ways of doing new neural networks and things can change, will probably change.”

In interview "G" one of the interviewees said:

> FPGA are usually very good at the inference, but not necessarily good at training that is usually done by, well, normal computers or computers equipped with GPU, things like that.

In this interview there was negative feedback for training on FPGAs as well, but as he also mentioned, FPGAs are very good at inference. This is strengthened by one interviewee (interview "H") from a company that works in the autonomous vehicle industry who mentions that FPGAs are used for inference in cars.

4.2.4 Development of autonomous vehicles

Due to the initial idea being a product for the autonomous vehicle industry, this subject was discussed in many interviews. According to one interviewee in interview "B" one of the most difficult things with the development of autonomous vehicles is the integrity of the neural networks and the data used for for training the models.

> I think the hardest part right now is building high integrity neural networks, because the big issue that I mean, we will be looking at everything from unsupervised learning systems to very supervised learning systems to somewhere where we have simulations built on real data. But then the whole solution is learnt at the top of simulated data, really.
>
> So it is a supervised learning thing, but it's kind of unsupervised, just the data anyway. So what is really hard then is to build a solution where you can guarantee that the system works in a particular way, the way most companies do. This is what you have, your eyes of the world, and there you're just super certain about the data coming in and the consistency of that. And then you know a lot about the model and how you can diagnose it, and then you can understand the resource to get out of and then you can kind of see the whole system. The hard part with that

> is building a consistence data set that is adapted for the learning task to try to do, because you need to really understand your data, which is super hard.

This is further concurred in interview "D" where the interviewee brought up the challenges regarding safety in the development of autonomous vehicles, and the possible result if the system fails:

> And because there are there are a number of challenging points, especially sort of around safety, sort of system-safety, function and safety, because this is tedious. (...) if something goes wrong, someone might die.

There are also a lot of actors included in the development of autonomous vehicles. In interview "D" the interviewee mentioned bigger investments when speaking about the use of FPGAs in the mentioned market:

> If you're saying that, let's let's move from GPU to FPGA. I mean, it's tens of billions of dollars that is transferred between strong industry partners in that sentence. And of course, there is extremely strong incentives on both sides and they're not going to give it up easily. So they're going to argue, they're going to argue forever.

As an example, he brings up a GPU manufacturer that has a strong position in the market:

> And this is happening all the time, the argumentation between different different approaches and Nvidia super strong in arguing. And they've sort of given away their stuffs for for ages to get the design wins and end up in the costs. So it's not a coincidence that the GPU position is pretty strong, even in the automotive industry. They've invested billions and billions of dollars in order to get it to that point.

In interview "H" the interviewee also mentioned how many of the products in an autonomous car is cost sensitive:

> So all of these products are, of course, very cost sensitive. Yeah, for obvious reasons, and therefore we try to find the, not the cheapest solution, but the solution that is most is best adapted to sort of cost versus performance and in some of our products that actually have shown to be FPGA

He later continues on the same theme, where he mentions how they do not want to put anything unnecessary in the car:

> So. I mean, in theory, there is of course, you can make a huge FPGA design that has reasonable data capability, but it's not optimized then for the interference, which is our main goal with what we put in the car. I think that's more the issue is, again, cost. We don't want to put anything more unnecessary in the car, but we do want to reuse it if it is possible later on.

4.3 FPGA Use-cases

According to the interviewees, FPGA have roles in many existing use cases and areas. They also foreseen a development of FPGA toward other new applications.

4.3.1 FPGAs today

Inference and switching
In interview "G", a potential customer described how his company uses FPGA in their driving assistance system products:

> We have mostly worked with the with the camera systems that typically is placed behind the rear-view mirror. And these systems, they usually collect information about, as I called it, other traffic participants, that [are] all other cars, it's pedestrians, it might be animals, bicyclists, whatever, anything that is on the road and that you have to cope with.

The interviewee "H" added that camera sensors they developed will be use differently for each car manufacturers. Therefore they used FPGA in this case for flexibility reason.

> The camera that we have is always the same. Yeah, but the functions that we put, the applications that we use the camera for is very different, depending on which manufacturer, car manufacturer we are selling to. So, yes, there are different configurations.

Apart from this switching capability were mentioned in other use case as well. In the interview "G" for example it was stated that FPGA is used as computation accelerator with the switching function changes a computing configuration from one step to another:

> For example, from time to time we have worked with accelerating computations on servers with FPGA. And of course they depending on exact what you are about to accelerate, you download a different file or personality or whatever you call it, that is tailored for exactly that [perform] computation. And then you do that computation and then you maybe switch the files for the next step in the computation chain and so on. So that is that is definitely feasible.

Moreover, the interviewee highlight an ability to partially reconfigure the FPGA as an interesting solution when the application require to have short amount of time switching:

> It's a partial reconfiguration is always discussed as an interesting topic. In the reality, it has a lot of limitations and it has a lot of hassles. So depending on well, depending on what you want to do with it, I guess the use case where it really is a good idea is if you need to swap between, the functionality very quickly and you can identify a large portion of some sort of framework that can be static and you only want to swap in a small difference somewhere in the middle of your construction, then it

> really makes sense. But like here in your case, where you're going to do two completely different things. I wouldn't bother with that. It's much simpler to have complete, complete different personalities if that takes a little time extra in your case does not matter because the training will take hours anyhow.

When asked about type of applications that commonly uses the FPGA. He highlight that the reason the FPGA is well adopted in embedded application due to the fact the embedded system has mostly specific purpose while in server application there are more chance to encounter versatile tasks.

> I guess it's on the server side. It's well, it comes natural because but for embedded applications, it's more rare since an embedded system typically is something with a static behavior.

Data center

The venture capital "F" highlighted in his interview that one common use case of FPGA is within networking area. Due to its ability to perform processing with low latency some type of applications are better to handle by FPGA:

> One of the applications I have seen FPGA is used been to and analyzed data streams, for example, look for patterns and maybe you need to look for different patterns, depending on what your current situation is, and to at the speed where a CPU just couldn't handle hundred gigabit Ethernet or several hundred gigabit Ethernet, then you wanted to do some advanced pattern matching, which you can do in FPGA.

Within the networking field, Employee "J" from an FPGA manufacturer added that data security application is as well a low volume application that suitable with FPGA competencies:

> And so it's an example with this security that it is actually it's a market where the volume is not so high as compared to. Maybe if could do a normal Ethernet switching, it is a high volume, but the security, you don't have so many. Typically a company only has one sort of gateway to Internet, and that's where they analyse the package. So that seems to be Cisco is doing lots of ASICS, but they also are using FPGA for for the security market and. There was one case to analyse the traffic and those kind of things.

A further raised an example of a large IT company that applied this method of utilizing a FPGA in data center applications:

> Yes. So. I think there are two parts there that one is for network. So actually what is available today is from Microsoft in the in this Azure data centre. They have a FPGA on on every board. As I understand it, I started with Altera and now it's maybe 50/50 Xilinx and Altera. So and they put FPGA on the network interface

The interviewee added another example of usage in a data center. In the case FPGA is used to perform compression during video streaming.

> Twitch exactly. Yes, they're using FPGA also. So the idea that they are different compared to Netflix, Netflix has just a few movies and they broadcast to too many people, of course, but they only have a relatively small catalogue. So they can do a very, very high quality. What do you say, compression on the movies before they broadcast? So they use minimum bandwidth for that, but Twitch they have many, many users who are broadcasting. So they need to do something faster on the fly compression. So they use FPGA to to do the compression before the broadcast

Another development is in a field of storage. Where FPGA acts as a computational part of a smart storage solution, the interviewee described:

> There are some companies working on this for storage. Smart, smart SSD or. Some kind of search or computation in the storage. So now that status, I think that that would be the new growth area for FPGAs, that's what people are hoping for at least.

In the same interview, he described one of his company targets is to growth further in this data center market:

> I think at least in [FPGA Manufacturer], they are hoping to to grow in datacenter. That would be a there's a hope that you could on those computers, on each computer server, if there could be an FPGA on the board. You could have some flexibility and and use this for computation. And that could be a quite big growth that does not exist so much today.

4.3.2 FPGA Market

In the interview "E" with the venture capital. He described the current situation of the market and raised that the development of FPGA has been saturated for a while. There have not been much of a players and thus less competition in the field. He speculated that the market might be in a mature stage as the trend is shifting more toward a general computation platform:

> In fact, I would say the interest in FPGA seems to be declining over time. I mean, if you look around and there are barely any independent large companies that make FPGA, it's Intel, which is already making chips. They use FPGA as a business development tool. They don't really want you to buy FPGA. They want you to eventually buy Intel chips. And then the other big company was Xilinx which is now part of AMD and then there are two or three smaller manufacturers.
>
> But it's also a sign of how quickly this market has matured over the last 15 to 20 years, that now I can do a lot on just general purpose programming engines like ARM cores or SoC rather than FPGA. So there aren't any startups, for example, that want to make a new FPGA or by using FPGA. It's not quite a active corner of the market.

The capitlist added his opinion that FPGAs may have few obvious place in today's markets: "Non-obvious market [is where] FGPA still may be very useful."

4.3.3 Future of FPGAs

In interview "J", the interviewee was asked about an ongoing acquisition of FPGA manufactures by general purpose processing manufactures. He hypothesised that there is a possibility to develop an integration processing platform that combined FPGA together with CPU:

> And the new products really this whole new combination of ASICS, FPGA, that's been really successful. And I think that is not the initial plan. That's what they said. I think there will be some a better integration of AMD processor to FPGA they can use the same PCI and share the memory, those kind of things.

On the other hand, FPGA expert "D" expressed his interest in using switching function of the FPGA to reduce hardware complexity:

> you could save some hardware complexity by changing profile. I'm not I haven't seen any project that has been based on that thought, but that could be an interesting day to to sort of discuss it.

Meanwhile, potential customer "H" raised his opinion that there might be a market for an FPGA where there is no definite solution that can apply ASIC:

> They are pushing really hard all the silicon suppliers to actually find, the problem if they cannot find one solution that fits all. So they have to make a bunch of them. And actually, it's an FPGA that is an easier solution in that sense, but it's hard to tell.

4.3.4 Other use-cases for us

During the interviews, the authors also looking for an alternative use case of FPGA that might be useful for pivoting the business idea.

In the interview with FPGA expert "A", he mentioned that one possible usage is in drone:

> That's actually another reason why drones is easier, because the kind of data you need to train a system that is flying a drone over a very limited area, you know, then you don't need to collect as much type of the amount of data, the type of data, the diversity of data, all that will be probably easier for drones because of that.

While the capitalist "F" posed an interesting area that is specialist and low volume.

> So I'm thinking of if there are other any other applications like trucks and lifts and stuff you have in a warehouse in a big automated warehouse. Would that make sense? Because it's typically a smaller volume. It may be more specialized.

He further described a possible use case on forklift and internal truck within a factory:

> And I was I was thinking about lift trucks and stuff like that. You have internal in a warehouse. There is a company that used to be called B.T. Trucks, and that makes forklifts there. But I think they were bought by Toyota and they're doing things like, you know, the truck let you have inside a warehouse to take pallets. I was just thinking that that is more specialized products and sometimes they have a requirement for a big customer. I mean, Audi is buying a new building, a new factory, and they need very specialized lift trucks for that factory. So it's lower volume, but it's higher price. And if you can kind of that, which is a good idea, I think if you want to tie in specialized solutions like using an FPGA, it would make more sense in a lift truck, in a car factory than in a Volvo car.

He later stated that a crowd computing using processors in an automotive may be useful but he did not see a connection with FPGA:

> I mean, if they're using like some car manufacturers are using NVIDIA chips, (...) I would use the cars as a distributed supercomputer to solve protein simulations to find a cure against the next covid 22 or whatever the next thing that is going to. So I think there's an idea there, but I am not sure that FPGAs are the thing. I think using the resources in the car to do other things is a good idea. But I do not think the connection is strong to FPGAs.

Another alternative use case were discuss in interview "G" for a feasibility of using FPGA as part of machine learning system for engine control. The interviewee, hypothesised that collected data might be easier to process than what they have from an autonomous system. However, latency is one of the concern in this type of application.

> It's probably I mean, image processing is always very difficult. It's in I would not say probably that engine control is simple, but the data is probably a little bit less complex. Uh, you have, uh, you have a number of sensors feeding you with Linear data that are not to 2D data as an image. And that is what you do will use for controlling whatever you can control fuel input. But not, uh. Probably it can be a simple case, I guess there is exactly as with with steering. I guess there is can be a problem of latency.

In addition to this, the interviewee raised a question whether it is or not to set a ground truth in this case. A difficulty of labeling correct behavior is another concern from him.

> The difficulty is that you, you only have data on what really happened. You do not really know what you would have liked to happen. What is the correct behavior, your system does not know that and the engine does not know that. The only one that knows that is maybe the driver,

> but not together with some sort of engine specialist. And some part of that I do not know where to get without doing some sort of annotation.

4.4 How to choose hardware

Apart from FPGA, there were other computing hardware that were mentioned in the interviews. A General purpose hardware and an Application-specific integrated circuit (ASIC) were the most two common hardware the interviewees brought up as a comparative option to an FPGA. Also mentioned in the interviews, there are several factors that developers and manufactures used to evaluate and choose a type of hardware that is more suitable to their products.

4.4.1 General purpose platforms

A used of general purpose platforms has been mentioned on a several occasion during the interviews as a comparable hardware solution to an FPGA.

The general purpose platforms have been well-developed in the recent years and they only require a software level development. Thus, makes them simpler to be adopted as mentioned by one of the venture capitalist:

> you see the CPUs are so cheap now than every active components that have a system, let's say, an autonomous system which has to navigate that has some kind of regional perception stack, and it has to run its internal operations or control system. I have ARM core that I will just put in anywhere and program them in general a propose way. And this the other part, FPGA is out to learn specialized programming languages program. That's true. Yeah. So instead I can write a simple python or a C programming on it straight on the processor.

Subsequently, he as well expressed his concern over losing advantage of an FPGA overtime:

> So one basic one is that FPGAs are useful entities. And I think you have to recognize that why they offer some benefits, over time, those benefits have eroded in value.

Further more, when consider a use-case in machine learning field as in the author's business value proposal. It was mentioned by a FPGA expert that FPGA is not the only solution to the application, training can be performed on a more general platform as well:

> I think, from one perspective, you don't have to you don't have to oversell on the FPGA dimension. I mean, you can run this training on a more general platform as well.

The FPGA expert also raised an opinion it depends on level of "change" a certain application is needed. If it only has to perform a change on software level then a general purpose platform should be able to handled the task:

> It's then depends on whether it's important that it is done on the logic level or if it's just a software. So, obviously you can run these algorithms on a general computational platform.

4.4.2 ASICs

When It come to an use case of ASICs, one of the potential customer in autonomous vehicle market mentioned that most sensors on their vehicles are equipped with ASIC:

> Yes, but that's part [Autonomous system] in particular in all the sensors, they have ASIC integrated.

He also stated that he planed to shift from using a general propose processor and a GPU to an ASIC system to better accommodate a specific CNN needed in their future system:

> So we have in the computers right now, it's just X86 and Nvidia Geforce, which are running in the vehicles.(...) for me, right now is looking into having an ASIC system specifically run for a certain type of CNN, which would then have up to 8K 60 FPS or 60 hertz, Cameras.

In many interviews, the interviewees mentioned an important role of FPGA as a prototype in ASIC development such that in this interview with a FPGA expert:

> (...) You use FPGAs to actually test it really thoroughly before you build the ASIC.

ASIC was mention multiple times along with GPU and general purpose platform in varies interviews as a comparable hardware solution to the FPGA. Factor such as power consumption, cost and volume are main factors used to evaluate a suitable hardware in each use case. Comparisons of ASIC and FPGA can be seen in the upcoming sections.

4.4.3 Power consumption

One of the venture capitalists stated in the interview that when consider a nature of FPGAs. They are not good when it comes to power consumption when compare to an ASIC but still useful when its flexibility and development pace are needed.

> If I'm going to implement specific data rules, we do need a FPGA because I might change it every day of the hour or according to policies of wherever I use this as kind of the machines. (...) the whole cryptocurrency started a few years ago. People said, I don't want to really design a ASIC to do this, but I can implement all of these in FPGA even though they're not very good from a power perspective.

The concern of FPGA power consumption also confirmed by a FPGA expert that a power constraint also play an important role for choosing a hardware on a certain application. In his example, a highly constraint application might go for an ASIC despite its cost and development time as it is the only feasible choice:

> (...) because the problem with the FPGAs in that case is that it draws more power and so it consumes more power, which you don't have in the satellite. So therefore, even if it's only 200 units, you still have to do an ASIC because you don't have the power. So the functionality will never happen. So there are also cases in those scenarios where the FPGAs do not win either because they lose on the power side. And then someone says that it doesn't matter if it costs 200 million Swedish to actually build the ASIC because otherwise we won't have functionality and that's worse.

This is corresponding to the power constraint mentioned by one of the potential customers that work in autonomous system development when developing the system on board an electric vehicle:

> The power consumption on electric vehicle is becoming an issue. So we need to keep that low

At end, power consumption factor relates to other factors as well as most processing applications have both power and cost constraint said the FPGA expert in the interview:

> (...) and that application will typically also be very sort of, there is a cost constraint and there is a power constraint.

4.4.4 Cost

Cost is another casual factor that come along with power and volume. One of the interview with venture capitalist "F" shown that the FPGA is considered expensive with limited suitable processing applications:

> but I remember the high performance FPGAs were very, very expensive a few years back, at least, which made some applications that you could efficiently and technically run on an FPGA. They just didn't make sense from a monetary perspective.

Furthermore, the venture capitalist added that cost of the FPGA is not linear to its performance. Thus other solutions might be more attractive:

> We have paid a lot of money for a big, expensive FPGA and at every point in time we're only using half of it. And if I let's say I could solve one of the problems with the standard CPU and by half the size FPGA, which probably costs like 25 - 30 percent because it's not linear, then I would have a much cheaper solution than having one FPGA where you switch between two images.

It was also mentioned in another interview with FPGA expert "D" that the price of FPGA may consider expensive for the products that no longer need the flexibility in the early development phases:

> Yeah, and in some cases that flexibility is important. But the more mature platform becomes, the less of that needs to be done in this FPGAs and it's always a cost burden to any product.

In the same interview, the expert pointed out the fact that it is obvious for the FPGA to be more expensive than its counterparts as FPGA is constructed with higher amount of silicon per computation:

> The challenge is that the FPGA always uses more silicon than, per equivalent to computation. So if you use it for pure computation, it's hard to see why that should be a more efficient solution.

When the authors ask for an opinion on the initial business proposing, the expert "D" raised his concern on the price point and pointed out to other more potential alternative hardware:

> I'm more worried about the cost point. And perhaps you could you could argue that they're a lot of actors [Other processing hardware] in this space.

Thus, the expert as well added that it is important to be able to prove the proposed idea is the most cost efficient solution amount others:

> Let's say that let's say that you would have this solution and everybody agrees that it's good. I think that it would be a lot of work put in by by anyone who want to use that to see if it's the most cost efficient way of implementing that technology.

As mention previously, some interviewee agree that FPGA may not be a solution to perform training. However, potential customer "H" argued in the interview that it is theoretically possible to handle training but a trade off would be a larger and more costly FPGA which is not suitable for automotive application:

> So. I mean, in theory, there is of course, you can make a huge FPGA design that has reasonable data capability, but it's not optimized then for the interference, which is our main goal with what we put in the car. I think that's more the issue is, again, cost.

In contrast, the expert "D" highlighted that ASIC might be more cost efficiency in high volume but on a small scale application it could be very expensive:

> Yeah. Because it is never going to make sense to to run an ASIC programme around that [small specific type of application].

The expert added that price prioritize in high volume products goes well with the model of ASIC that become more efficient in mass volume:

> So it's a balance and it just usually don't make it into the really high volume runners because they will always, in those applications, you always prioritize the price. So that's usually replaced by an ASIC. But in general, it's a very versatile too.

Expert "D" raised an interesting point that It could be a problem when the volume is difficult to justify whether switching to ASIC or staying with FPGA is more cost efficient:

> let's say [telecommunication company] and their base stations go out in volume. So 4 million or so per year. They have passed this point where it is much better to have an ASICs department developing ASICs because the the the volume scale you get, the advantages you get from that are so big that it doesn't matter what the cost of that department is But when you are the million, it is hard to calculate it. It's still going to be a substantial amount of money that moves into every piece because the cost is rather big, even if you want to build just one advanced ASIC.

4.4.5 Volume

When it comes to volume factor, it is obvious from both cost and power factors that FPGA is more suitable with lower volume. This is again mentioned by the FPGA expert "D":

> I mean, if you if you tend to think that you should build 10,000 units of something like a specific type of base station or something, then then you're not then. FPGAs is what you have to work with.

To further extend the reasons, the expert described one main benefit of using FPGA in a lower volume that is versatility of the chips make them reusable to multiple application:

> The other application that we sometimes see where we we use sort of pretty generic development board or platform and then you can run different types of equipment on top of that. So we use it for base band applications where we solve the front end problem in some way, and then we handle the more generic base band problem and can change into different modes, types and so on. And we can still reuse the same type of hardware.

He further emphasised that this provides quite a benefit in development process as well when the need to develop a dedicated hardware is minimize by reusable FPGA based hardware:

> I mean, that problem is more from there not having to build a dedicated piece of hardware because we only need like 10 or so. Then you can use it for several different variants of something

Of course, on the opposite side, the expert hypothesised that ASIC is still more of an attractive option for the market when it comes to a higher volume:

> Whenever something moves to volume, people will always be they will always be inclined to to making an ASIC out of it because it looks it looks attractive.

4.4.6 FPGA roles in ASIC development

In the interview with venture capitalist "E", He stated from his experience that FPGA traditionally has been widely use as a development platform due its flexibility and rapid development pace. When the design is locked down then it can further develop into ASIC:

> Well, like I said, people used to use FPGA if let's say I was developing a new kind of routing machine for home or for whatever, right. In the development part, I would use FPGA so I can very quickly try out all these things. And then eventually, if the idea is successful, then the performance is there, then I can reduce that design to to an ASIC once I have everything else worked out for it. That's the traditional values.

FPGA expert "D" mentioned the same approach with a more specific volume :"You might say you use it for R&D purposes or space programmes or whatever, where the number of units is in the order of thousand." This is the same fact described by FPGA developer "C" :"And FPGAs are usually used to prove concepts and then if it works then you go to make an ASIC chip out of it."

4.4.7 Transition from FPGAs to ASICs

As mentioned several times by the interviewees that it is a common practice to shift from FPGA to ASIC when the volume increase to a certain point. This is stated by the venture capitalist "F" when the authors ask about hardware choices on the business value proposition.

> I mean, as you said, if it's high volume like cars, then there will be the traditional manufacturers doing ASICs.

The reason that price of ASIC is lower in a higher volume come from the face that it uses less amount of silicon per performance when compare to the counterpart FPGA as described by FPGA expert "D":

> But there is always there's always the silicon. I mean, the actual cost for for anything silicon is proportional to the area and technology know how and so on but and the area of silicon you need for FPGA is sort of pretty pretty much larger than than what you would need in ASIC. So that usually drives the difference. And I've studied that many times because there's always there's usually always a candidate platform that is sort of ASIC oriented for processor specific and applications specific implementation.

Another factor that make the transition happened is a stage of development. When the requirment is know and and design is fixed, there will be less need of the FPGA's flexibility but more on efficiency. Thus making transition to ASIC seasonable. Examples of this are mentioned in section 4.4.6 as well as highlighted in the interview with FPGA expert "D" quoted:

> And then and then you have the FPGA tracks and what you're after

> the FPGA track because you might not know what the requirements and it feels good to be able to change things until you have to pay the bill to the for the bill of materials. So then usually all those things are forgotten that you have all these advantages and then everybody just want to drop the price and start building an ASIC instead.

He then concluded this hardware development logic as quote:

> I mean, the FPGAs is an interesting thing because it's if you know how you want your hardware to be configured, it is always going to be better to move it to an ASIC. And it always is.

An example of use case that follow this hardware transition logic was described in interview with developer "J" from one of the FPGA manufacturers as quote:

> [Telecommunication company] usually make their first generation of 5G that's finished now. they working on second generation 5G and they would maybe remove some of the FPGA in that one and make it more efficient [with the ASIC]. And so that that's how it's been done always. But it's always very useful, some part to provide flexibility for upgrades in the field. To support some new changing requirements.

5

Discussion

5.1 The Initial Idea

The initial idea of this project has been described in section 1.1.5. In short, the idea was to use FPGAs in cars for both inference and training of autonomous driving models. The FPGA would utilize training on the edge technology, i.e., the training would not be done in computer centres. The FPGA would be able to do both training and inference through utilizing the flexibility of the FPGA which lies in the ability to reconfigure it on a hardware level after it has been installed. The FPGA could then switch between two different hardware modes, one for inference and one for training.

Using the same hardware for both training and inference could have the effect of increasing the utilization of the hardware base installed in cars. It would also have the effect of lowering the amount of data that would otherwise need to be transferred between the cars and the computer centres.

This was the first idea of this startup project, and with the Customer Development framework by Blank and Dorf (2012) the authors started to work out if this was a feasible idea or not. As mentioned in the chapter 2, section 2.3.1.2 two of the key steps in the second phase of Customer Discovery is to gain an understanding of the customers and capture competitive and market knowledge. This can as, mentioned in the Literature Review be done by talking to individuals in both the market the product is aimed towards, but also adjacent ones. In this project, the authors has spoken to people in the market of autonomous vehicles, and with people with expertise in FPGAs.

As shown in the Results chapter the current state of the market of autonomous cars is that most companies use GPUs for inference and training, where the training is done in computer centres, with some companies using FPGAs for inference in cars. The results show quite clear reason of why this is the case, the biggest being the performance of FPGAs in regard to training the models. As stated in the results, there were a lot of negative feedback on the idea of using FPGAs for training. Many of the interviewees mentioned that FPGAs are not built for training and that there is a requirement of a very low amount of data to actually do training on the FPGA. This aligns with the literature that the development team found. One example being “F-CNN: An FPGA-based framework for training Convolutional Neural Networks” by Zhao et al. (2016). When the authors first got this feedback some scepticism of the idea did start to grow, but the idea still lived on until the authors would get more data regarding training on the FPGA.

Another aspect of the FPGA that was brought up frequently was the cost, and as mentioned in the results, the listing prices did not have to be the actual price of the board due to purchased volume and who the buyer is. However, as mentioned in the results, one of the interviewees claimed that FPGAs always was “a cost burden to any product”. This high cost of the FPGAs was a concern to many of the interviewees the authors spoke to. This would probably be a real concern for the product idea if the training were actually going to be done on the FPGA, since, as mentioned in one interview, the price of FPGAs are not linear compared to the performance, and therefore an FPGA with higher performance would have a very large cost for the product. It also seemed like the market of autonomous cars could be cost sensitive, as one of the interviewees who is working in the field brought up that they did not want to put any unnecessary hardware in the car.

The authors initial thought regarding the price was that this could be less of a problem with a higher volume, but as stated by multiple interviewees and shown in the results, most actors in the market would probably gravitate towards using ASICs if the volume would increase as a lot of the cost of ASICs is in the development, so with a higher volume the average price drops. This will be spoken more about later on in the discussion when pivot alternatives are discussed.

With all of these factors included, it is difficult to see a place of the initial idea in the market of autonomous vehicles, and in the current state of FPGAs it might not even be possible due to the performance in training. One thing, however, that got positive feedback in earlier interviews was the part of the idea regarding edge training. Both the advantage of utilizing more of the car’s hardware and the advantage of not having to transfer the same amount of data had positive feedback. This could, for example, be seen in that one actor in the market had started to do more R&D in the field of edge training.

However, even for this part of the idea, there was also some negative feedback from individuals within the autonomous vehicle market. According to one of the interviewees, the technology is about 5-10 years away from the market due to the many unsolved problems with it. One of these problems is the amount of data itself. To train on the edge, the data would not have to be transferred, but it would have to be analyzed and used in the car, and therefore stored. According to one of the interviewees, one of the most efficient ways of transferring collected data at the moment is through normal postal services, i.e. transferring the physical hard drives. This is due to the very high amount of data collected, which as mentioned in the results could reach multiple hundreds of megabytes each second of collecting. This means that if edge learning was to be used, as the initial idea suggested, there would also have to be a lot of installed data storage in the car, adding additional costs and possible points of failure, but also reducing the available physical space for other hardware.

Another problem mentioned for training on the edge was defining ground truth. In multiple interviews, the interviewees spoke about this problem. The authors initial plan to do ground truth was through using driver input as ground truth. However, as mentioned by one of the interviewees, the problem lies in corrupted data, with malicious intent or not. Without handling the filtering of data correctly, this could be compared to the Microsoft chatbot "Tay" that was fed bad data by Twitter users to corrupt the chatbot to become more hateful in its posts (Vincent, 2016).

5.2 Pivot or continue?

The authors followed Blank and Dorf customer discovery framework, reviewed in section 2.3.1.3. It suggests startup to pivot an idea after important criteria questions are proven and discussed.

With the stated negative feedback on FPGAs and scepticism on its role in the initial idea of this project, the authors considered examining other pivot alternatives to find a proper alternative business proposition. In this section, the authors first, briefly evaluate benefits and limitations of FPGAs then discuss possible pivoting alternatives using the collected interview results.

5.2.1 FPGA: evaluating the technology

The authors found that FPGAs as processing hardware holds a more versatile position than its counterpart, ASICs, regarding the level of flexibility. The ability to readjust itself is mentioned widely by interviewees as the greatest strength of the FPGA. This capability is useful in many ways such as rapid switching between different modes, updating post-production hardware and acting as a development platform. In machine learning applications, FPGAs are as mentioned earlier in the discussion and the results not good at training, but are according to interviewees “really good” at inference. However, it was suggested by one interviewee that that future developments in machine learning could create a possibility for more efficient training on FPGAs.

The flexibility of FPGAs comes at a cost of performance. When comparing FPGAs directly to ASICs, FPGAs require a larger silicon space to match the same level of computing performance produced on a smaller ASIC. Thus, making it less efficient in terms of performance as well as in power consumption.

From a development perspective, the interviewees has stated the long development time of FPGAs. In the results it is also mentioned that there is a deficit in experience and knowledge when it comes to FPGA development. This is explained by one interviewee that mentions the differences in normal software development and the hardware development of FPGAs. This could lead to FPGAs becoming a less popular choice as general purpose platforms are easier to adopt for developers.

From a cost perspective, the high purchasing cost of FPGAs has been mentioned earlier, and that in a higher volume market, most actors will gravitate towards using ASICs as their average cost becomes lower with a higher volume. Therefore FPGAs are a better choice when the volume is lower. However, there are exceptions to this.

One interviewee brought up the example of some satellites, where there are other constraints as power. As ASICs tend to have a lower power consumption, some satellites, according to the interviewee, are required to use ASICs even though the cost would be greater, as the FPGA would not be able to comply with the power constraint.

To be concluded, FPGA is a strong contender when it comes to low volume, and high flexibility applications that may require low latency but has no extreme power constraint. The cost of this solution could be high, thus it should be a specific type application that other more cost efficient hardware are not applicable.

5.2.2 FPGA: evaluating the current roles

As seen in chapter 4 , FPGAs are used in different applications throughout varies industries. In the field of machine learning, the authors found that they are commonly placed together with sensors to perform inference for IoT-devices such as Lidar-sensors and for cameras within autonomous driving vehicles.

Another type of use cases are data centres where FGPAs are used to compute specific tasks on running data that goes through a server. This type of computing task mostly requires low latency communication. Thus, FPGAs are chosen as a suitable solution. These type of tasks involve data analyses, security screening and video compression. The switching ability of FPGA also plays a role here as FPGAs can quickly switch between modes of preset algorithms that works on each type of data to make the process even more efficient.

FPGAs also has a prominent role in the development of ASICs with its ability to reconfigure itself on the hardware level. They are commonly used as a development platform for developers to test their ASIC prototype on a flexible environment. After the design has been tested and fixed, it can then transition into a mass-produced ASIC.

However, in some types of applications, developers intend to use FPGAs as the final hardware for their tasks due to either low volumes, requirements of flexibility, or both. Two examples of this are the Mars Rover, which cannot be retrieved or reconfigured after launch and therefore can utilize the reconfiguration capability of the FPGA, and first generation mobile base stations that constantly need upgrading on a hardware level. Nevertheless, other factors has to be considered when dealing with these specific type of application. This could for example be seen in a previous mentioned example of satellites, where AISCs can be chosen, even at the low volume and therefore high cost, due to the FPGA not being compliant with the low power requirements.

5.2.3 The alternatives

With all the mentioned negative feedback on the FPGAs and the initial idea described in section 5.1, and the evaluation on advantages and disadvantages of FPGAs, the authors along with the development team brainstormed and pinpointed several possible alternatives. Later on, during the interviews the authors discussed these possible pivot alternatives with the interviewees.

Autonomous drone
The first alternative was discussed in the interview with FPGA expert "A". The idea was to apply the same model as the initial idea but on an autonomous drone platform instead. The authors hypothesised that drones may work in an environment that is more individually confined or remotely separate than an automotive. Hence, training on the edge becomes more of a viable approach as centralised training may be less efficient in this case. In addition, the set of data that needs to be collected for training also becomes smaller which puts less strain on the hardware, making FPGAs a potential choice. Though, after analysing the drone market the authors found that autonomous drone technologies and their market are quite mature with strong players already providing well-develop solutions.

Engine control system
In the second pivot alternative, the application of machine learning was adapted for engine control systems instead of autonomous driving systems. The idea was to use machine learning to assist engine control systems by improving efficiency and as a result produce less emissions. The concept aimed to have each individual vehicle re-train the model according to each driver's driving behavior. The re-training process would then be done in the car and with a smaller requirements on the amount of data some of the problems mentioned regarding edge learning would disappear.

With this concept the collected data are assumed to be smaller and less complicated than data collected by an autonomous vehicle. Even so, some experts pointed out that there could be a problem with defining ground truth as it is difficult to define the absolute right approach to drive a car or running an engine. The latency was also a concern since the engine control requires a very low latency, and the both the interviewees and the authors were unsure if the proposed system would be able to comply with that requirement. Another aspect of this idea that makes it less attractive is the phaseout of fossil vehicles.

Autonomous construction vehicle
During the interview with transportation manufacturer company "I", there was also a discussion regarding a possible application for FPGAs in autonomous construction vehicles. The authors found that the remote working areas of these vehicles, such as a remote forest or mining sites, might be a good condition for edge training as communication networks are a constraint in these environments. However the authors could not manage to arrange a follow up meeting with interviewee "I" afterwards. Though, the authors believes that this area of the industry has a potential to be developed further in the future.

Satellite and space vehicle
Another interesting field of applications for FPGAs is the space industry. Despite the fact that the authors did not manage to interview anyone inside the industry, using the knowledge gained from interviews, the authors hypothesised that FPGAs may have a place in the satellite industry which is a low volume and a high level of complexity. One of the interviewees hypothesised that the FPGA might be able

to help reducing the complexity in the systems if utilizing the switching ability of the FPGA. The cost of the FPGA would also be lower than an ASIC with this low volume as well. However, as mentioned before, power constrains would need to be taken into account. This alternative could be worth investigating in future research or business situations.

5.2.4 Pivot: a difficult development

There were also other alternatives that were discussed among the authors and the development team such as vehicles in an enclosed space, such as automated guided vehicles (AGVs) or forklifts in factories.

During these discussions, the authors found that most of the alternative ideas the authors tried to develop, that were not connected to vehicles, were in the form of embedded IoT-devices. According to one of the interviewees, these embedded technology devices tend to have a static behaviour by design. This goes against the main strength of the FPGA, which as mentioned is flexibility, which includes the switching mechanism. Due to this, FPGAs hardly go hand in hand with the nature of the embedded IoT-devices aimed to develop. Along with the requirement to incorporate the switching mechanism in the business model, the authors found it difficult to develop a feasible business model for the FPGA with the given constraints.

5.3 Author's reflection on the startup process

As mentioned in chapter 1, this project was a collaboration between students of the HPC and MEI programme at Chalmers University of Technology. The HPC-students formed a "development team" and the MEI-students formed a team for business development. Using startup methodology, this project were setup to try and find a suitable business model for FPGAs using the switching feature, and initially to use this for switching between machine learning training and inference as mentioned in section 1.1.5 which was the subject of the thesis of the HPC-students mentioned in Chapter 1.

Though there was a sharing of knowledge throughout the project, the authors of this thesis believes that there was a difficulty in developing a business model for a technology that they initially did not have much knowledge of. This might be one of the reasons the authors had a problem coming up with feasible pivot options, and with more experience and expertise in the technology of FPGAs the authors would maybe have been able to find a good business model.

Without much earlier experience in entrepreneurship, the authors probably did not utilize the Customer Development framework to its full extent. The framework itself is not complicated, but it requires a specific mindset that might differ from earlier projects the authors has taken part in. Some difficulties might also have to do with the vision the authors had in the beginning, the FPGA technology and the use-case described in section 1.1.5 was aimed towards a market that is under development by both smaller, more R&D focused firms, and bigger vehicle manufacturers. The idea itself was based on technologies that the authors were unsure of the technical capabilities of.

The Customer Discovery part of the Customer Development contains four phases, (1) creating business model hypotheses, (2) testing the problem, (3) testing the solution and (4) verifying the business model. In the process of collecting information about both the market, the technology and customer interest the authors might have mixed these phases to some degree. This could be the case due to many reasons, one being the limitation on time. As the authors found it difficult to get in contact with both people with expertise in the market and potential customers, the authors felt a need to utilize the contacts that were established as much as possible by asking more questions. This mix-up of the different phases might have led to a more unstructured use of Customer Development and therefore the process might have become more difficult and complex to follow in regards to both tests and exit criteria for the different phases.

In retrospect the authors believes that they could maybe have used another methodology that would have been more adapted for a lower time frame than Customer Development for the business model analysis.

6

Conclusion

In regards to the first initial idea, described in 1.1.5, the conclusion is that due to problems with both edge learning and training on the FPGA the idea is not feasible at the moment. However, as mentioned in the discussion, future development in machine learning could possibly allow for better training on the FPGAs in the future.

During the project, the authors had problems finding alternative business cases for the FPGA when it utilises the switching mechanism. However, the authors cannot draw a precise conclusion that there are no new business cases for this technology, as the authors might not have thought of every possibility. As mentioned in the discussion one possible industry where this could be used could be the space industry.

FPGAs have a lot of advantages, but also some disadvantages. The big advantage of the FPGA is the flexibility, but it comes at the price of cost. According to many of the interviews, most industries seem to gravitate towards ASICs when the volume gets high enough, as the average cost would then be lower. Therefore, FPGAs need a market of lower volumes, or one that requires high flexibility that ASICs cannot provide.

In the discussion some potential markets are mentioned, and one which the authors were not able to investigate further is the space industry, which is low volume, but could utilize the flexibility of the FPGA, and its ability to reconfigure on a hardware level remotely.

Bibliography

Adams, T. E., Ellis, C., & Jones, S. H. (2017). Autoethnography. *The international encyclopedia of communication research methods*, 1–11.

Alvarez, C. (2014). *Lean customer development: Building products your customers will buy.* " O'Reilly Media, Inc."

Amaratunga, T. (2021). What Is Deep Learning? https://doi.org/10.1007/978-1-4842-6431-7{_}1

Barter, P. (2013). "Cars are parked 95% of the time". Let's check! https://www.reinventingparking.org/2013/02/cars-are-parked-95-of-time-lets-check.html

Bhavesh Patel. (2018). Where The FPGA Hits The Server Road For Inference Acceleration. https://www.nextplatform.com/2018/10/15/where-the-fpga-hits-the-server-road-for-inference-acceleration/

Blank, S., & Dorf, B. (2012). *The Startup Owner's Manual The Step-by-Step Guide for Building a Great Company* (1st ed.). K&S Ranch, Inc.

Bryman, A., & Bell, E. (2011). *Business research methods* (3. ed.). Oxford University Press.

Christensen, C. M., Anthony, S. D., Christensen, C. M., & Anthony, S. D. (n.d.). Christensen, C. M., Anthony, S. D., Berstell, G., & Nitterhouse, D. (2007). Finding the right job for your product. MIT Sloan Management Review. (48301).

Digikey. (n.d.). Evaluation Boards - Embedded - Complex Logic (FPGA, CPLD).

Easterby-Smith, M., Thorpe, R., Jackson, P. R., & Jaspersen, L. J. (2018). *Management and Business Research.* SAGE Publications. https://books.google.se/books?id=97NTDwAAQBAJ

Eisenmann, T., Ries, E., & Dillard, S. (2016). Hypothesis-Driven Entrepreneurship : The Lean Startup, 1–26.

Ellis, C., Adams, T. E., & Bochner, A. P. (2015). Autoethnography : An Overview. *Historical Social Research*, *36*(4), 273–290. https://www.jstor.org/stable/23032294

Fitzpatrick, R. (2013). *The Mom Test: How to talk to customers & learn if your business is a good idea when everyone is lying to you.* Robfitz Ltd.

Grigorescu, S., Trasnea, B., Cocias, T., & Macesanu, G. (2020). A survey of deep learning techniques for autonomous driving. *Journal of Field Robotics*, *37*(3), 362–386. https://doi.org/10.1002/rob.21918

Gunnarsson, A., & Samuelsson, J. (2021). *A Dynamic FPGA platform for CNN Re-Training & Inference*, Chalmers University of Technology.

Hevner, B. A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly*, *28*(1), 75–105.

Konečný, J., McMahan, H. B., Yu, F. X., Richtárik, P., Suresh, A. T., & Bacon, D. (2016). Federated Learning: Strategies for Improving Communication Efficiency, 1–10. http://arxiv.org/abs/1610.05492

Kuada, J. (2011). Research Methodology A Project Guide for University Students.

Kukreja, N., Shilova, A., Beaumont, O., Huckelheim, J., Ferrier, N., Hovland, P., & Gorman, G. (2019). Training on the Edge: The why and the how. *Proceedings - 2019 IEEE 33rd International Parallel and Distributed Processing Symposium Workshops, IPDPSW 2019*, 899–903. https://doi.org/10.1109/IPDPSW.2019.00148

Luo, C., Sit, M. K., Fan, H., Liu, S., Luk, W., & Guo, C. (2020). Towards efficient deep neural network training by FPGA-based batch-level parallelism. *Journal of Semiconductors*, *41*(2). https://doi.org/10.1088/1674-4926/41/2/022403

Müller, R. M., & Thoring, K. (2012). Design thinking vs. lean startup: A comparison of two user-driven innovation strategies. *Leading through design*, *151*, 91–106.

OmniSci. (2020). What is Interoperability? Definition and FAQs | OmniSci. https://www.omnisci.com/technical-glossary/interoperability

Ozer, M. (1999). A Survey of New Product Evaluation Models. *Journal of Product Innovation Management*, *16*(1), 77–94. https://doi.org/https://doi.org/10.1111/1540-5885.1610077

Ozer, M. (2005). Factors which influence decision making in new product evaluation. *European Journal of Operational Research*, *163*(3), 784–801. https://doi.org/10.1016/j.ejor.2003.11.002

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, *24*(3), 45–77. https://doi.org/10.2753/MIS0742-1222240302

Ries, E. (2011). *The Lean Startup*. Crown Business.

Rizzatti, L. (2018). Leveraging FPGAs for deep learning. *Embedded*.

Sarasvathy, S. (2007). What makes entrepreneurs entrepreneurial? *Business & Society Review*, 1–9. http://www.effectuation.org/sites/default/files/documents/what-makes-entrepreneurs-entrepreneurial-sarasvathy.pdf

Shawahna, A., Sait, S. M., & El-Maleh, A. (2019). FPGA-based accelerators of deep learning networks for learning and classification: A review. *arXiv*. https://doi.org/10.17010/ijcs/2020/v5/i4-5/154787

Van Aken, J. E., & Romme, G. (2009). Reinventing the future: Adding design science to the repertoire of organization and management studies. *Organisation Management Journal*, *6*(1), 5–12. https://doi.org/10.1057/omj.2009.1

Vincent, J. (2016). Twitter taught Microsoft's AI chatbot to be a racist asshole in less than a day. *The Verge*. https://www.theverge.com/2016/3/24/11297050/tay-microsoft-chatbot-racist

Virginia Clarke, V. B. (2019). *Successful qualitative research a practical guide for beginners*.

Warnat-Herresthal, S., Schultze, H., Shastry, K. L., Manamohan, S., Mukherjee, S., Garg, V., Sarveswara, R., Händler, K., Pickkers, P., Aziz, N. A., Ktena, S., Siever, C., Kraut, M., Desai, M., Monnet, B., Saridaki, M., Siegel, C. M., Drews, A., Nuesch-Germano, M., … Schultze, J. L. (2020). Swarm Learning as a privacy-preserving machine learning approach for disease classification. https://doi.org/10.1101/2020.06.25.171009

Yan, F., Liu, J., & Chun, S. (2014). Study of the way to firmware program upgrade in FPGA reconfiguration of distributed geophysical instruments. *Sensors and Transducers*, *172*(6), 130–138. https://www.researchgate.net/publication/290348452_Study_of_the_Way_to_Firmware_Program_Upgrade_in_FPGA_Reconfiguration_of_Distributed_Geophysical_Instruments

Zhao, W., Fu, H., Luk, W., Yu, T., Wang, S., Feng, B., Ma, Y., & Yang, G. (2016). F-CNN: An FPGA-based framework for training Convolutional Neural Networks. *2016 IEEE 27th International Conference on Application-specific Systems, Architectures and Processors (ASAP)*, 107–114. https://doi.org/10.1109/ASAP.2016.7760779

A

Appendix

A.1 Information Sheet

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
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