Master Thesis

Identification and Analysis of Specific Challenges of Hardware Start-ups

written for the purpose of acquiring the academic degree of a

Master of Science (Dipl. Ing.)

under the supervision of

Univ.-Prof. Dr.-Ing. Sebastian Schlund
(E330 Institute for Management Sciences,
Field: Human Centred Cyber Physical Production and Assembly Systems)

Associate Prof. Mag. Rer.soc.oec. Michael Filzmoser, PhD
(E330 Institute for Management Sciences,
Field: Research Unit of Labour Science and Organization)

submitted at the TU Wien

Faculty for Mechanical and Industrial Engineering

by

David Kames, B.Sc.

01129141

[redacted]

[redacted]

Vienna, June of 2022

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David Kames

TECHNISCHE UNIVERSITÄT WIEN

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Vienna, June of 2022

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David Kames

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Synopsis

Ziel dieser Arbeit ist es, relevante Herausforderungen von Hardware-Start-ups im deutschen und österreichischen Raum zu identifizieren. Gleichzeitig werden interne und externe Ursachen erläutert. Der Fokus liegt auf den Aufgaben in den Bereichen Produktdesign, Produktentwicklung, Qualitätssicherung, Zertifizierung, Patentwesen, Lieferantenmanagement, Testing, Investitionen und Teamzusammensetzung. Die folgende Forschungsfrage wurde formuliert: Was sind die größten Herausforderungen, denen sich Hardware-Start-ups aus Österreich und Deutschland in ihrem Lebenszyklus stellen müssen?

Zur Beantwortung dieser Frage wurden eine systematische Literaturrecherche und qualitative Interviews mit neun relevanten Stakeholdern durchgeführt. Basierend auf den Herausforderungen, die in den Stakeholder-Interviews identifiziert wurden, wurde eine quantitative Umfrage unter österreichischen und deutschen Start-ups erstellt und durchgeführt, um die Relevanz der identifizierten Herausforderungen einzuschätzen. Die quantitative Studie erreichte 40 Befragte aus dem gesamten Ökosystem der Hardware-Start-ups.

Die qualitative Studie führte zur Formulierung von 17 Herausforderungen, die in drei Hauptkategorien (ökosystembezogen, technologiebezogen, geschäftsbezogen) aufgeteilt wurden, und zur Formulierung der Hypothese, dass die Umwandlung eines Prototyps in ein Produkt die schwierigste Phase eines Hardware-Unternehmens ist. Diese Hypothese wurde sowohl in finanzieller Hinsicht als auch im Hinblick auf die erforderlichen Fähigkeiten und den Zeitaufwand bestätigt.

Das hohe Maß an Multidisziplinarität wurde von den befragten Unternehmen als ein wesentliches Problem erkannt. Die Vielfalt der Aufgaben im Zusammenhang mit der physischen Produktentwicklung und deren Weg zur Marktreife führt zu einer Abhängigkeit von externen Unternehmen und einem hohen Bedarf an Fachkräften. Darüber hinaus erwies sich die Finanzierung mit privatem Beteiligungskapital als eine große Herausforderung für Hardware-Start-ups. Der Hintergrund der Abneigung von Venture Capitalists, Business Angels und anderen Investoren liegt in der mangelnden Akzeptanz eines langen Entwicklungszyklus und der hohen Kapitalintensität. Investoren vermeiden es, dieses Risiko einzugehen und bevorzugen andere Arten von Unternehmungen. Darüber hinaus sehen die Stakeholder der investierenden Stellen ein Problem in der Erwartungshaltung der Unternehmer und in der mangelnden strategischen Planung bei der Suche nach Investoren.

Die Ergebnisse dieser Masterarbeit beschreiben die Herausforderungen, mit denen Hardware-Unternehmer konfrontiert sind, und eröffnen Raum für die Entwicklung gezielter Maßnahmen zu deren Unterstützung. Darüber hinaus können weitere Studien durchgeführt werden, um regionale Unterschiede in Europa zu erkennen und Synergien zu nutzen, um die technologische Souveränität Europas zu stärken.

Abstract

This thesis aims to identify relevant challenges of hardware start-ups in the German and Austrian region and the internal and external impact that causes these. The focus lies on hardware start-up specific tasks in product design, product development, quality assurance, certification, patent, supplier management, testing, capital expenditure and team composition. The following research question was formulated: What are the main challenges that hardware start-ups from Austria and Germany face in their life cycle?

A systematic literature review and qualitative interviews with nine relevant stakeholders was conducted to answer this question. Based on the set of challenges that were defined out of the stakeholder interviews, a quantitative survey was created and performed across Austrian and German start-ups to estimate the relevance of the identified challenges. The quantitative study reached 40 respondents across the hardware start-up ecosystem.

The qualitative study led to the formulation of 17 challenges clustered into three main categories (ecosystem-related, technology-related, business-related) and the formulation of a hypothesis about the transformation of a prototype into a product being the most challenging phase of a hardware venture. This hypothesis was confirmed from the financial, as well as from the required skills as well as the time perspective-

The high level of multi-disciplinarity was identified as a significant issue of the companies surveyed. The variety of tasks related to physical product development and its way to market leads to a dependency on external companies and a high demand for skilled workers. Furthermore, financing with private equity turned out to be a significant challenge for hardware start-ups. The background of the aversion of Venture Capitalists, Business Angels and other investors is based on the lack of acceptance of a long development cycle and the high capital intensity. The investors avoid taking this risk and prefer other types of ventures. Moreover, the stakeholders of the investing bodies see a problem in the expectation of entrepreneurs and a lack of strategic planning when it comes to searching for investors.

The results of this master thesis describe the challenges that hardware entrepreneurs face and open room for developing targeted measures to support them. Moreover, subsequent studies can be conducted to see regional differences across Europe and use synergies to strengthen the technological sovereignty of Europe.

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1 Introduction

1.1 General Introduction to the topic area

Entrepreneurship is one of the key drivers to an innovative economy. Moreover, it can significantly impact national economic growth (Stel, 2004). To secure a high level of entrepreneurial activities, the stakeholders from politics, universities, and the private sector are fostering an environment where entrepreneurship is strongly backed through a broad range of services and initiatives. This fact manifests through the growing infrastructure of incubators, accelerators, seed, and venture capital investors during the past decades (Braunerhjelm, Desai, & Eklund, 2015).

In comparison to the recent scientific work, this master thesis aims to focus on the area of hardware start-ups and analyse their hurdles in a broad spectre. This primarily addressed area covers industrial technology, production, and electronics/electrical engineering. It includes companies focusing on developing hardware components and products like sensors, gateways, wearable devices, robots, and many more. The variety is ranging from simple consumer goods to sophisticated technology. Besides B2B and B2C segments, hardware start-ups also work on breakthrough technologies like quantum computing that aim to revolutionise our society.

One in ten start-ups in Austria can be characterised as a hardware start-up. The hardware category shares the second place with life sciences and consumer goods. Only software start-ups are more strongly represented with 24%. While the share of hardware start-ups remains stable and the total number of start-ups increased over the past decade, a positive trend can be seen for the hardware category in absolute numbers. Moreover, 20,2% of start-ups in Austria have a business model based on hardware (product sales) or engineering (Karl-Heinz Leitner, 2019). Although these businesses are by definition not part of the hardware group, they presumably face similar challenges in at least some areas, such as product design or distribution.

The barriers for hardware entrepreneurs are constantly lowering. On the one hand, this is backed by the easy accessibility of rapid prototyping, tools, and electronic components in makerspaces, hackerspaces, and even at home. On the other hand, knowledge platforms make gaining of relevant Know-How easy for the interested public. This leads to the possibility for entrepreneurs to build their DIY projects and try to monetise them. Besides specific accelerator programs, there are platforms like Kickstarter and Indiegogo which enable a direct money raising from potential customers. These platforms have a significant number of users looking to fund new entrepreneurs and receiving the products in return, when produced. (DiResta, 2015)

1.2 Motivation

The authors' motivation for this thesis was, therefore:

Personal interests, especially for start-ups developing physical products that are often less prominent than ventures operating in the software or financial sector at the time of conducting the study.

Closing the research gap in the of specific challenges of hardware start-ups creates a basis for a better understanding of specific challenges that differentiate them from other entrepreneurial activities.

By evaluating specific hurdles, this thesis will provide a foundation for accelerators, investors, politics, or companies to build an infrastructure supporting entrepreneurs around hardware. Especially the European Institute of Innovation and Technology (EIT) is planning to implement an action plan for supporting relevant companies based on this thesis.

1.3 Problem Definition/ Research Questions

Succeeding with a new innovative venture is a difficult path with many obstacles, and the rule of thumb states that one of ten start-ups succeed. The failure is often caused by the fact that entrepreneurs lack business experience, they must learn to communicate with external stakeholders and implement new processes and practices very quickly to achieve the desired break-even point (Stinchcombe, 2000). Additionally, understanding and fitting the market needs is indispensable for success. Even if these initial problems were overcome, the management of the fast growth represents another hurdle that entrepreneurs must face. These general challenges have been described extensively in the literature, mostly very specific to traditional software ventures.

Start-ups operating in hardware are facing some unique challenges which exceed the typical problems of entrepreneurs in other areas. Moreover, since more and more hardware products are connected to the internet or at least communicating with other devices in their surroundings, a significant share of hardware start-ups must combine software and hardware development. This additional complexity is having a waste impact on the speed and agility of development. The construction of hardware products is very costly and requires external service providers or component manufacturers (Berg, 2020). These issues are resulting in long development cycles and a high dependency on third-party vendors.

The development of hardware products in established companies follows strict processes. It stands a high contrast to the agile and scrum methods that focus on a fast-changing environment and more room for manoeuvre of software development.

The “Lean Start-up” approach is considered as a standard framework for a successful venture building. It focuses on meeting customers’ needs and adapting the product by an ongoing reconciliation with the target group. The focus on time and cost is prevalent in the start-up ecosystem. (Ries, 2011)

Besides of organisational and developing problem there are additional problems, hardware start-ups are facing. This work aims to create an overview of typical problems and serve as a basis for developing possible frameworks for accelerators, angel investors, and other stakeholders which aim to support start-ups.

The research questions of this thesis are explorative. The main purpose of this study is to explore an area where a lack of knowledge was identified.

The following question was therefore derived as the **main research question**:

- What are the main challenges that hardware start-ups from Austria and Germany face in their life cycle?

Based on this research question, further **undermining questions** were answered in this master thesis:

- What are the unique problems that distinguish hardware start-ups from other ventures?
- What are hurdles related to the development phase between the first physical prototype and the mass production?
- What demand do hardware start-ups have in terms of infrastructure to be able to master the identified challenges?

The aim of the work is to identify relevant challenges of hardware start-ups in the German and Austrian region and the internal and external impact that causes these. The focus lies on hardware start-up specific tasks in the areas of product design, product development, quality assurance, certification, patent, supplier management, testing, capital expenditure and team composition. Moreover, the study aims to examine contradictions between high-quality physical products, agility during product development and short iterations in adapting to customer expectations. It does not intend to cover general organisational challenges, which were already the subject of scientific research. (Davila, 2007) (Ries, 2011) (Ghezzi, 2019)

The findings will be processed in such a way that measures can be derived from them that enable stakeholders from politics and business, as well as the start-up scene in the German and Austrian region, to support innovative entrepreneurs in a targeted and effective manner. The thesis also intends to provide a framework for conducting studies across Europe to examine regional differences.

2 State of the Art

This chapter explores existing literature, determines a framework for this thesis and discusses current literature about Hardware Start-ups.

At the same time, it is necessary to define and clarify the basic concepts of this work. As the concept of hardware, start-up and entrepreneurship need to be clarified, as there is no generally accepted definition regarding these terms. For illustration, the term entrepreneurship has no generally accepted definition (Robert F. Hébert, 2010) and the research shows different perceptions of it (W. D. Bygrave, 1991).

2.1 Definition of Terms

2.1.1 Definition of Start-up

The term “start-up” or “startup” is omnipresent in the media nowadays; the public and the research use it for many different types of ventures. Accordingly, there are many definitions of this term in academic and professional work.

Very general and widely accepted:

- Eric Rise’s definition (Ries, 2011)*“A start-up is a human institution designed to deliver a new product or service under conditions of extreme uncertainty”*

Definitions that are focused on the customer relationship and the market fit and the rapid adaptation and scaling of the underlying business model:

- Steve Blank’s definition (Steve Blank, 2012)*“A start-up is an organization formed to search for a repeatable and scalable business model. The goal of your early business model can be revenue, or profits, or users, or click-throughs-whatever you and your investors have agreed upon. Customer and Agile Development is the way for start-ups to quickly iterate and test their hypotheses about their business model. Most start-ups change their business model multiple times”*
- Gnome Report’s definition (Max Marmer, 2011) “Start-ups are temporary organizations designed to scale into large companies. Early-stage start-ups are designed to search for product/market fit under conditions of extreme uncertainty. Late-stage start-ups are designed to search for a repeatable and scalable business model and then scale into large companies designed to execute under conditions of high certainty.”

However, there are also novel definitions that focus on the product life cycle or the company’s sustainability:

- A relatively new definition proposal by (B. Reisdorfer-Leite, 2020) is comparing the start-up and product lifecycle beginning of life (BOL), including design and production; middle of life (MOL), including logistics (distribution), use, service, and maintenance; and end of life (EOL), including reverse logistics (collecting), remanufacturing (disassembly, refurbishment, reassembly, etc.), reuse, recycle, and disposal. The conceptual model proposes to equate the pre-start-up phase with the BOL of the product life cycle, the start-up phase with the MOL and the consolidation to an enterprise with the EOL phase.

Although the proposed definition by (B. Reisdorfer-Leite, 2020) using the product lifecycle seems to be accurate in the context of hardware developing start-ups, due to its novelty and the unclear distinction of small and medium enterprises (SMEs), the author follows the Gnome Report's definition as it takes the objective of rapid growth into account which can be seen as the major difference to traditional SMEs.

2.1.2 Definition of Hardware Start-up

The term hardware is used in various contexts and has different definitions used. The Cambridge dictionary[1] offers several possible definitions based on the context in which the term is used:

- IT "The physical and electronic parts of a computer or other piece of equipment rather than software"
- Equipment for military use
- Equipment for industrial use

In the context of this thesis the author uses the term hardware start-up as a start-up whose aim is to take a physical product to distribution. Regardless of the product's final use, this thesis cover start-ups developing traditional IT components and systems as well as purely physical products without any data processing or sensing. This definition corresponds to the definition of DiResta's Book "The Hardware Startup" (DiResta, 2015), that is perceived as a reference work among the participants of the hardware ecosystem.

2.1.3 Definition of start-up ecosystem

The term ecosystem is also defined in different ways in the literature:

- Moore (Moore, 1997) defines this term as *"an economic community supported by a foundation of interacting organisations- the organisms of the business world"*

[1] Cambridge dictionary "Hardware "https://dictionary.cambridge.org/us/dictionary/english/hardware, last accessed February 02, 2022

- Isenberg (Isenberg, 2011) defines it by the following characteristics:
    1. An ecosystem consists of six domains (policy, finance, culture, supports, human capital markets).
    2. Each Entrepreneurship Ecosystem is unique.
    3. Specifying generic root causes of the Entrepreneurial Ecosystem have limited practical value due to multidimensional cause-effect relations that are impossible to track down to one or fundamental key roots.
    4. Entrepreneurship Ecosystems become (relatively) self-sustaining as soon as all six domains are strong enough
- The OECD (Mason & Brown, 2016) defines the term start-up ecosystem as follows: *"A set of interconnected entrepreneurial actors (both potential and existing), organisations (e.g. firms, venture capitalists, business angels and banks), institutions (universities, public sector agencies and financial bodies), and processes (business birth rate, rate of HGFs, number of serial entrepreneurs and blockbuster entrepreneurs, and levels of entrepreneurial ambition and sell-out mentality in the society) which formally and informally coalesce to connect, mediate, and govern the performance within the local entrepreneurial environment"*

This thesis uses Isenberg's model as it examines the challenges connected to the six postulated domains. Namely:

- policy
- finance
- culture
- supports
- human capital markets

Further terms that are used in this thesis and their definition:

- Business Angel (McKaskill, 2009)

Is an individual who provides equity or debt capital for start-ups, usually in a very early stage where the risk of failure is very high and other investors are not prepared to back them.

- Venture capitalist (Schmitt, Rosing, Zhang, & Leatherbee, 2017)

Financial stakeholder that invests into start-ups in the seed/early-stage phase with equity capital. The focus lies on innovative technology or business model. The investments are perceived as risky, as they have high rates of failure.

2.2 Previous work on challenges of hardware start-ups

The current theoretical work focuses mainly on start-up's in general, covering a wide spectre of challenges ranging from organisational (Davila, 2007), gender (Gomes Neto, 2020), innovation and lean methods (Gallop, 2019) (Ghezzi, 2019), systematic risk (Hall, 2010) to human resources management (Wise, 2014). On the other hand, several publications focus on specific challenges and failure causes of start-up's whose business models are based on software (Giardino, 2014) (Wang, 2016).

Numerous publications have dealt with start-up ecosystem in different regions from different perspectives, such as the overall analysis of the Austrian start-up ecosystem and its comparison with other countries (Merzlyakov, 2019) or the examination of challenges that ventures operating in the information and technology in Vienna are facing (Bartnik, 2018), another rather specific works focused on very narrowly defined areas like robotics and identified strategies to build up a base for robotic start-ups (Hauer, 2016).

An assumption about unique challenges a company with a business model based on technology and hardware is facing was already described in (Werwath, 2019); the article focuses on the fact that the lean start-up methodology by (Ries, 2011) is not entirely suitable for hard-science technologies. Werwath claims that there are more fundamental questions to be asked and answered to find the right market fit in the case of hardware start-ups than in typical software ventures. This is based on the fact that the technology developed is usually able to serve many different markets. Werwath introduced the assumption of 6 characteristics of hard science-based start-ups that differ from the soft science or IT-based ones that ware considered for the design of the qualitative questionnaire (Werwath, 2019):

1. Longer gestation periods with higher technical risk
2. More intense Intellectual property considerations. IP becomes a foundational a concern for this type of start-up
3. Less available seed and investment capital for the start-up
4. Often less competition pursuing the same type of problem or solution, for a variety of reasons
5. Much more non-dilutive capital is available for the student entrepreneur
6. Corporations are often quite interested in this type of start-up, in many cases to access the IP underlying the business

Currently, only the contradiction between the agility of a start-up and the quality of product development is being addressed by a qualitative study (Berg, 2020), which examines this specific contradiction. However, there is no quantitative survey for a holistic overview, and no framework was set up to examine the challenges of hardware start-ups operating in a certain region. From the results of the master thesis, new

insights can be gained for the niche of hardware start-up's, which has only been dealt with superficially in the existing scientific work.

2.3 Definition of relevant Thematic Areas

The literature review was completed by a graphical expression of areas that are relevant for start-ups operating in hardware. These were used as a starting premise for the methods used in this thesis.

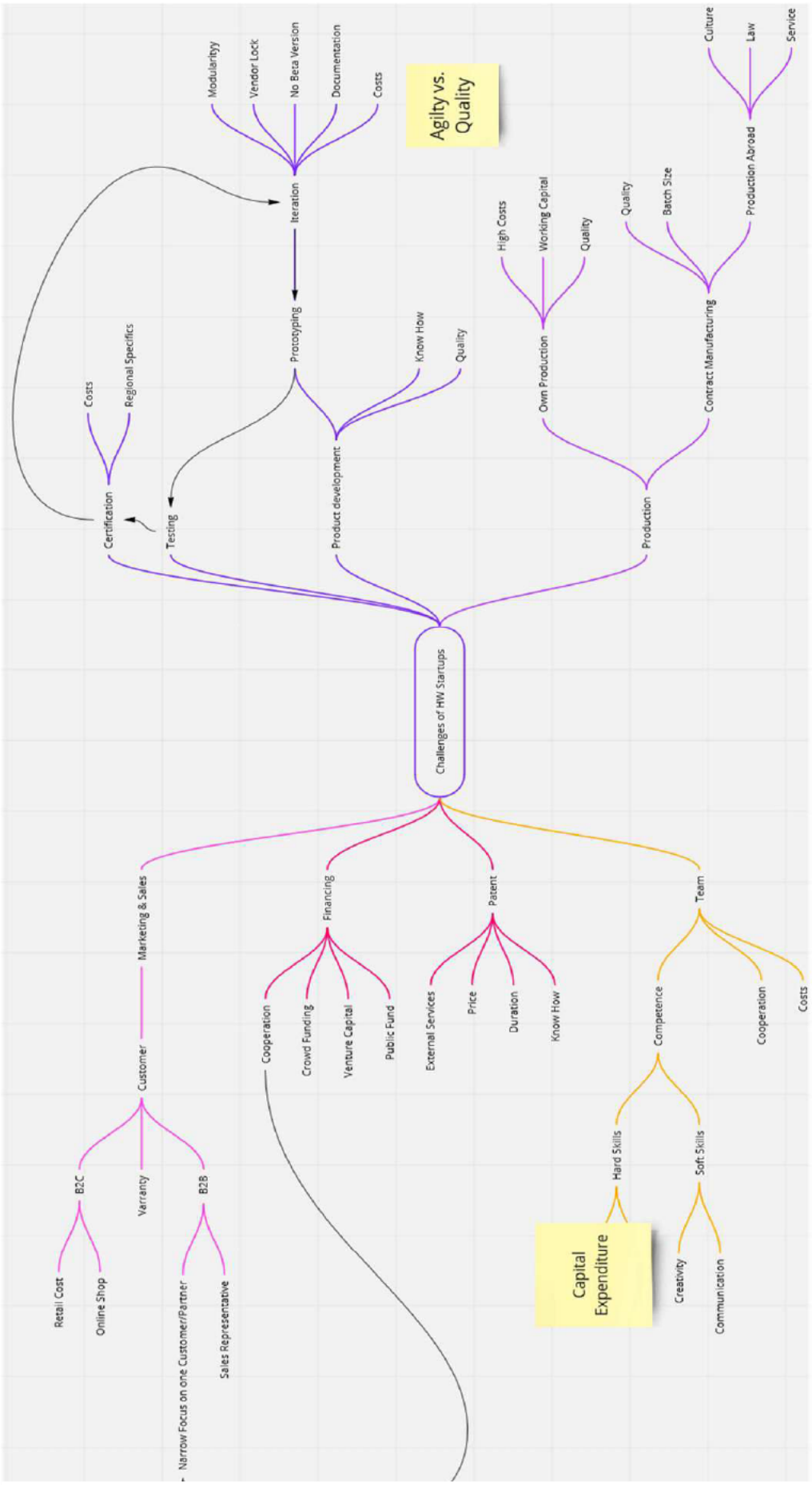

Figure 1 Identified areas according to the literature review

3 Method

An analysis of the methodological fit is crucial for the right choice of research methods. Therefore, the author conducted research on the existing literature to identify the extent to which the topic has already been addressed and to identify areas of existing disagreement among researchers. Moreover, related work covering other areas than hardware start-ups was used to identify possible similarities and build hypotheses which then were tested in the qualitative and quantitative part of the work.

To assess the state of the prior knowledge, literature on challenges of start-ups in general and literature that focuses on hardware start-ups was analysed. Although there were many scientific works focusing on the challenges of start-ups in general, the examination of the specific area of hardware start-ups had not progressed far. Due to this finding, the prior research was categorised as intermediate regarding to (C. Edmondson, 2007).

The entire process was carried out according to the four key elements of a field research project defined by Edmondson and McManus (C. Edmondson, 2007):

- Research question
  - Focuses a study
  - Narrows the topic area to a meaningful, manageable size
  - Addresses issues of theoretical and practical significance
  - Points toward a viable research project—that is, the question can be
  - answered
- Prior work
  - The state of the literature
  - Existing theoretical and empirical research papers that pertain to the topic of the current study
  - An aid in identifying unanswered questions, unexplored areas, relevant constructs, and areas of low agreement
- Research design
  - Type of data to be collected
  - Data collection tools and procedures
  - Type of analysis planned
  - Finding/selection of sites for collecting data
- Contribution to literature
  - The theory developed as an outcome of the study
  - New ideas that contest conventional wisdom, challenge prior assumptions, integrate prior streams of research to produce a new model, or refine an understanding of a phenomenon

- Any practical insights drawn from the findings that may be suggested by the researcher

Edmondson and McManus differentiate between three different states of prior theory and research (C. Edmondson, 2007). As previous research was identified during the literature review, the intermediate state was selected for further proceeding. The "archetype of methodological fit" of choice was the hybrid collection of data combining qualitative and quantitative surveys. This strategy enables observation and validation of real-life challenges that hardware entrepreneurs face during the realisation of their business idea.

3.1 Research Process

The work consisted of several research steps. The process started with the definition of the problem and intensive literature examination, which led to formulating a research question. The literature review started from a broad perspective and considered as many relevant challenges as possible. The research was based on relevant publications and a systematic proceeding to further literature, focusing mainly on scientific papers and books. Due to the highly dynamic nature of the topic, articles in business magazines and scene relevant blogs, as well as websites, were taken into consideration to reflect recent developments in the results. After formulating the research question, the identified challenges were clustered into thematic areas and used for the design of the qualitative survey.

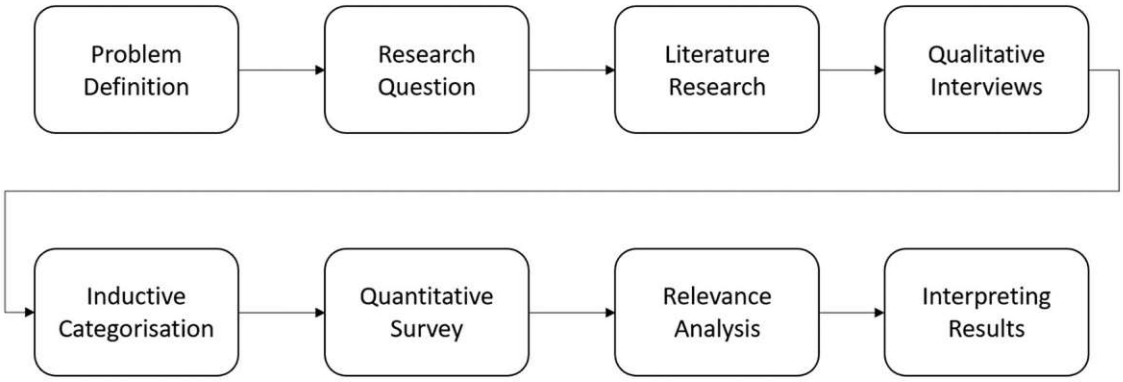

Figure 2 Graphic representation of the research process

3.2 Qualitative Method

As the first phase of the was focusing on the practical nature of the research question, the decision fell on a semi-structured interview to obtain the opinions of different

stakeholders operating in the hardware start-up ecosystem and to get new insights into the real-life context of the phenomena (Robson, 2002). Actors in the scene were divided into entrepreneurs and experts from the financing ecosystem. The goal was to interview five respondents, evaluate the theoretical hypotheses about challenges, and code them according to the inductive method (Mayring, 2008). The final phase consisted of the data interpretation and finalisation of a research report.

3.2.1 Sampling

Sampling for the qualitative research phase was carried out by applying a snowball sampling strategy; the author contacted relevant stakeholders from the ecosystem and followed their recommendations for other potential interview partners. The requirements on the interview stakeholders were active operation in the Austrian. German, or both ecosystem and a business model that is based on a hardware product.

Table 1 and Table 2 show basic information about the interviewed stakeholders and their Start-up. The sampling targeted Start-up that had already reached a certain maturity. Besides two of the interviewed start-ups that were in the phase of improving their prototype, all of them had already sold their products.

Company	Team Size	Industry	Role	Professional Background
Start-up 1	7	Music	CEO; Co-Founder	Engineering
Start-up 2	5	Media Automation	CEO; Co-Founder	Engineering, Management
Start-up 3	23	Electronics & Health	CEO; Co-Founder	Engineering, Management
Start-up 4	6	Materials	CEO; Founder	Physicists
Start-up 5	16	Health	CEO	Management
Start-up 6	28	Automation	CTO, Co-Founder	Engineering
Start-up 7	3	Laboratory equipment	Founder	Chemistry

Table 1: List of Start-ups interviewed

Stakeholder	Investments	Type	Role	Professional Background
Stakeholder 1	10	Venture Capital	Investment Manager	Physician, Entrepreneur
Stakeholder 2	28	Business Angel	Business Angel	Software Executive

Table 2: List of Stakeholders interviewed

3.2.2 Data Collection

The interviews were conducted to gather real live data and context for the sub-research questions that focused on the understanding of the uniqueness of start-up challenges that operate in the area of hardware in Austria and Germany. The participants were informed about the interview goals and the intention of the study and about how gathered data will be handled. Moreover, informed consent was provided to ensure a compliant research process. All the interviews were conducted via the platform

Microsoft Teams and were recorded for transcription. In addition to the video recording, the author kept written notes during the interviews.

The ethics and compliance of the research process was prioritised. The interviewees were informed about their rights and about the storage of their personal data. They were also made aware of the purposes for which the study was being conducted.

3.2.3 The Data Coding and Analysis

All interviews were transcribed by the researcher using Microsoft Word[2]. The answers of the interviewee, as well as the questions by the interviewer were part of the transcription. The transcribed data was analysed with the research software MAXQDA[3] which enables computer-assisted qualitative data and text analysis.

The inductive category creation followed the framework of (Mayring, 2008). The used software MAXQDA was used to highlight and collect the relevant statements and to cluster them into thematic topics by creating categories. The overall goal of this research step was to understand specific topics that are relevant in the hardware start-up ecosystem by collecting information from relevant stakeholders in the ecosystems.

The results of the qualitative part were summarised in the Qualitative Part and Results section of this thesis. The results were used for creating challenge hypotheses and subsequently transferred into a quantitative survey, to assess their relevance.

3.3 Quantitative Method

By using online questionnaires to collect data, the author intended to enrich the data gathered in the qualitative part from a sample to the examined population. (Babbie, 1990) The quantitative survey was conducted to use data analytics to classify the relevance of the identified challenges. The final phase was to interpret data and create a report. Subsequently, the framework of this study was summarised to enable the creation of subsequent studies in other geographical areas.

3.3.1 Questionnaire development

Questions for the conducted quantitative survey were derived from the qualitative Mayring analysis (Mayring, 2008), and a four-point gradual response scale by Likert (Likert, 1932) was used to quantify the relevance of the observed challenges. In addition to the responses to the individual challenges, questions about the quality of the ecosystem supporting infrastructure and services were asked to understand the areas where entrepreneurs face challenges and receive little external support—the

[2] https://www.microsoft.com/
[3] https://www.maxqda.de/

questionnaires targeted hardware entrepreneurs from the examined area. In addition to the Likert questions, detailed matters were asked about the causes of individual problems, both via open and multiple-choice questions.

The quantitative survey was conducted between 28.11.2021 and 10.01.2022 using the online survey platform Respeak[4] This novel tool combines the functionality of a traditional survey with AI technology that makes it possible to ask further questions and estimate the quality of the answer. Especially the open questions are monitored, and answers that are not seriously answered are repeated. This enables the elimination of answers that were not answered thoughtfully by the surveyed person. On the other hand, a deep dive into some problems can be done by setting up particular reactions for concrete keywords. In the context of this thesis, the function was used to determine detailed information about certain topics depending on the answer given by the user.

3.3.2 Sampling

The survey's target group was hardware entrepreneurs who have already passed the initial phase of a start-up, meaning that they have passed the so-called pre-seed phase and have at least developed a functional prototype. Snowball sampling was used for the data collection for the quantitative part of the study. It consists of two phases:

Contacting stakeholders known by the author and the supervisor (Prof. Schlund)

Asking stakeholders to refer to other colleagues from the ecosystem

The initial contact with the stakeholders was established via e-mail. A total of 232 stakeholders were contacted, and 40 completed the study. After reviewing the answers, four answer data sets were filtered out as they did not meet the criteria on maturity, were not from the examined region or had no physical product as part of the business model.

3.3.3 Data Analysis

The data was downloaded from the Respeak online survey platform and entered into Microsoft Excel[5]. The data was cleaned and organised by fixing missing values and encoding. The author started with a general analysis of the individual challenges' performance and the ecosystem's shortages. This analysis led to a breakdown according to the relevance of the hurdles identified. Subsequently, the related follow-up questions and open questions were analysed to get a better understanding of the identified problems.

[4] https://respeak.io/
[5] https://www.microsoft.com/

4 Qualitative Part and Results

4.1 Summary of Qualitative Results

The approach of inductive category development by (Mayring, 2008) led to the formulation of 17 challenges clustered into three main categories.

Ecosystem-related challenges

1. Quality of Supports
2. Feedback Culture

The first category of *ecosystem-related challenges* considers the external influences which affect hardware ventures. The focus here is on “soft aspects”, such as the challenge of building a qualified and diverse founding team and searching for employees who are willing to work under difficult circumstances, which are given in a typical start-up and are described below. Within the ecosystem-related challenges, the quality of support focuses on the community, courses, mentorship, and other supportive measures. Feedback Culture was raised by several interviewees and was identified as a significant pain point. Due to cultural conditions and the lack of experts in physical product development, it is challenging for ventures to get honest and valuable feedback from stakeholders within the system.

Business-related challenges

3. Strategy
4. Team and HR
5. Partner Collaboration
6. Time-to-Market
7. Marketing & Sales
8. Market fit
9. Financing
10. Grants

The second category formulated is *business-related challenges*. As most of the start-ups operating in the area of hardware products are founded by entrepreneurs with skills mainly in technology-related aspects of entrepreneurship, this subcategory was identified as extremely important during the interviews. The first topic is connected to the overall strategy of the venture. As most start-ups are technology-driven and aim to disrupt with new technologies, the strategy and the ability to adapt are vital for entrepreneurial success. Team and HR challenges change throughout the life cycle of a venture. In the early phase the companies struggle to recruit suitable employees, in the later phase, successful start-ups have to deal with the rapid growth of employee numbers. Partner collaboration focuses on different forms of collaboration with external entities as hardware start-ups are dependent on these. The subcategory Time-to-

Market is strongly linked to the Product Developments subcategory in the *Technology-related challenges*; it examines how this issue affects the possibilities of using typical financial instruments and grants for start-ups. Marketing & Sales and the following subcategory market fit examine which challenges the companies face in attracting new customers and adapting their product or business models towards customer wishes. The subcategories financing and grants were identified as significant pain points, as stakeholders perceive hardware-based ventures as very risky compared to software as a service-oriented company.

Technology-related challenges

11. Product Development
12. Certification
13. Intellectual Property – Patents
14. Production
15. Sourcing
16. Scaling
17. Design

The subcategory of *technology-related challenges* examines topics related to physical product development, including prototyping, the realisation of a production-ready product and its certification for compliance with existing norms. The subcategory intellectual property covers topics that relate to the challenge of patents for physical products and the holistic strategy of managing the intellectual property. Production covers challenges that are unique for hardware start-ups and relates to the subsequent subcategories of sourcing and scaling. This area is the primary reason for the strong dependency on external influences, stakeholders, and organisations. The last identified subcategory is the design work that could be understood as a part of product development. However, in the context of this thesis, it focuses on the professional design of a product, as this was mentioned just by one stakeholder in the context of being a topic that entrepreneurs from the region usually neglect. The author assumed that start-ups indeed do not invest much effort into creating a product that is handy and attractive to the potential customer. It seems that they focus solely on the initial function and technology improvement.

This categorisation was subsequently used for the quantitative survey. This survey investigates the respective relevance of these topics.

4.2 Discussion Qualitative Part

The qualitative part of this thesis was designed to answer the research question and correspondingly analyse the challenges of start-ups with a hardware-based business model and determine how these challenges differ from other ventures. The phase

between the first physical prototype and the production was of particular importance, as the assumption was made that this is the most challenging and unique aspect of hardware entrepreneurship. Moreover, the questionnaire aimed to examine the demand for infrastructure by these companies. Infrastructure is understood to mean, on the one hand, physical offerings for prototyping, product development, certification, and related facilities, and, on the other hand, training, networking, and consulting. The assumption that Germany and Austria are similar regarding the start-up ecosystem was agreed upon in the exploratory discussions with representatives before the official starting of the study. Furthermore, the ecosystems are well connected due to the geographical and linguistic connections.

Mayring's (Mayring, 2008) approach has proven to be suitable for highlighting the problems in different areas. These show strong interactions, which should enable a holistic presentation and further consideration in the quantitative part of this study.

The development time and subsequently time-to-market was identified as a significant issue in hardware start-ups; these findings can be well incorporated with the existing literature that examines the agility in production business (Anh Nguyen-Duc, 2018) and the contradiction between agility and quality in product development in hardware start-ups (Berg, 2020). Furthermore, the observation of the influence of development time on time-to-market led to developing a framework that combines start-up development and product development phases (B. Reisdorfer-Leite, 2020). The qualitative part of this thesis reveals a new perspective on this known problem. This perspective focuses on the underlying challenges and connects them to an overreaching interdisciplinary comprehension. The interviews revealed a lack of practical know-how in product development in the existing supporting programmes offered by accelerators, incubators and supporting organisations and showed that the development of a prototype is a less significant problem than the actual development of a product. The prototypes are commonly designed and produced in either research laboratories, private workshops, or maker spaces. The way between a prototype and a scalable production-ready product is more challenging than the initial phase. From the technical perspective, the development of products consists of various fields of expertise, including but not limited to sensors, programming, product design, material, process theory, manufacturing and kinematics. This overwhelming variety of challenges brings a very diverse need for the know-how of the entrepreneurs. Moreover, the high complexity makes pivoting the business model or the product arduous and lengthy. In the context of the ecosystem, this fact questions the upper limit age until which a company is perceived as a star-up by some institutions.

Entrepreneurs pointed out that the support measures available are usually very theoretical. In addition, most entrepreneurship programmes are not designed to develop physical products, and companies lack networking opportunities with this

thematic focus. The interviewees' perception is that existing programmes are much more software and fintech oriented. The biggest challenge of the entrepreneurs is to handle the multidisciplinary nature of developing hardware products and find practical support in the ecosystem.

Subsequently, financing a venture is very problematic, as most investors are restrained in investments in hardware start-ups, due to the lack of acceptance for a long development cycle and the high capital intensity both linked to the issue of product development. However, the cooperation with investors reveals tension on both sides. Investors are indeed more interested in more easily scalable business models such as software as a service, while hardware entrepreneurs typically have very naive ideas about how to finance their start-ups. On the one hand, entrepreneurs often expect investment to finance their entire production and development work. On the other hand, investors expect a clear strategy in which their investment is only one part. It is up to the entrepreneurs to present a combination of bank loans, advance payments from customers, investments, and a clear business plan. The requirements for the hardware companies are therefore extremely high, especially regarding the fact that customers only want to pay in advance when there is a product or when they have a specific guarantee. Not having a resilient guarantee for orders is usually a case for start-ups, as they usually do not have any production-ready products, or the possibility of production is in the phase between completed prototype development and production, where financing is essential. Simultaneously the pre-production phase of a company is unique if compared to companies that do not have physical products as part of the business model. According to the interviews conducted, these aspects are often neglected in the available accelerator programmes. As mentioned before, these are held in a very theoretical way.

Additionally, to the explained know-how areas, the entrepreneurs need to display expertise in the area of marketing, regardless of the focus on either B2B, B2C or both markets. The composition of the interviewee sample was disadvantageous regarding the challenge of marketing. Due to the fact that the author focused on CEOs of hardware ventures, most of the respondents had just brief marketing knowledge. Furthermore, it is difficult to carry out appropriate structuring of the marketing challenges as these vary extremely in dependence on the product and targeted market. As described above, the main challenge of B2B ventures is to get the first customer for co-development, whereas B2C start-ups usually search for either direct marketing or a cooperation with a retail or distribution company.

The described situation pushes entrepreneurs to collaborate with corporates. Operating in a similar field, they usually better understand the benefits and the technological innovation and can support through know-how in different areas. In the last years, these corporations led to different models for connecting corporates and

start-ups available in the ecosystem. However, it puts the entrepreneurs in a difficult position to weigh up the pros and cons of said collaboration. The representatives' interviews for this thesis mentioned concerns that the corporate's goal in such a collaboration is to quickly buy complementary technology or capabilities to solve their problems and enter new markets. This start-up scouting behaviour corresponds with existing literature (Lermer, 2013) (T. Weiblen, 2015). However, the fear of being swallowed by a big corporate is often outweighed by the benefits of such a collaboration - —especially the challenge of searching for a pilot customer ready to co-finance the development.

Another measure that can improve the chance of acquiring investments and financing the production of a product and the development of a business model, is securing intellectual property with patents that allow the investor of the company exclusive rights to the invention. This would prevent competitors from copying the technology. According to (Conti & Thursby, 2013), some of the interviewees perceived the patents as essential signals for external parties. The problems connected with patents were weighted very differently across the entrepreneurs. The different perceptions of the patenting challenge resulted from the start-up's various founder structures and origins. The interviews showed that companies from the academic sector had access to services that allow patent applications or had the know-how from previous activities. Non-academia, on the other hand, perceived the challenge as significant, but surprisingly not because of the costs, but more due to the time-consuming application process. The fact that the costs are not perceived as a significant issue is most probably due to the availability of grants that support patent applications.

Moreover, the interviews showed a need for high interdisciplinarity in the team. Considering the challenges above, a team with know-how from the described areas is essential to bring the usually technologically driven development to customers in a meaningful way and develop a suitable financing strategy. Stakeholders expressed that the needed financing know-how is exceptionally high and comes close to the know-how requirements in a fintech start-up.

This interdisciplinarity in start-ups was already described in the literature. The most critical issues which cause start-ups to fail were identified in areas that usually are outside of the know-how of a typical technology-driven entrepreneur (marketing, strategic management, finance management, project management and leadership). (Zbierowski, 2016) Regarding the literature that refers to the examined ecosystem of hardware start-us, the interdisciplinarity in technical development focuses on the interaction between engineers and designers. (Blanco, 2015)

New aspects of the multidisciplinary alignment evolved, especially the tension between having the necessary know-how in the team and getting it from external sources was omnipresent in the interviews. In other words, a make or buy decision must be made.

The entrepreneurs tend to source technical development from companies which are specialised in that field, especially during the challenging phase of transforming a prototype into a production-ready product. However, the business strategy and financing alignment, that are especially of interest to the investing parties, are often done on the side by entrepreneurs who lack the necessary skill set, which leads to problems and discrepancies of expectations between investors and entrepreneurs. Some of the entrepreneurs even admitted that they are having problems hiring business developers as their colleagues prefer to work with technicians or scientists and want to hire more of said professionals as they see them as more valuable for the enterprise. The author interpreted this phenomenon as a representation of "a behavioural state where a person operates in an anxiety-neutral position" (Bardwick, 1995), working in a familiar environment and in a homogenous group of people, which is often leading to weaker performance of the team.

Examining this phenomenon from a psychological group dynamic perspective, a heterogenous group can be difficult to manage (MacLeod, 2018). This typical environment in a venture sums up the need for professional management of the human resources of the said venture, especially considering the challenge of attracting employees to a start-up and the potential of rapid growth after reaching a certain level of maturity.

Another aspect of a hardware start-up is to set up production for the product. This is the next challenge that influences both dimensions, financial and technical. As production needs are highly dependent on the product, challenge types differ across various start-ups. The decision for outsourcing turned out to be dependent mainly on the area of know-how of the venture and their product. Often the product is innovative so that new production processes and machines must be set up so that either tight cooperation with a producing company or a company that develops production machines is necessary. On the contrary, even if entrepreneurs have a product whose production can be outsourced, they often are confronted with the challenge of finding a contract manufacturer that is ready to cooperate with a start-up. The interviewees repeatedly reported that the readiness to cooperate with a new venture is very limited and that they are not taken seriously by the provider.

Moreover, companies providing services or parts are used to collaborating with customers which order high volumes, and the start-ups are not perceived as attractive customers. Although, an exception was identified as stakeholders reported that issues started to arise at the time when they had to extend their production of a high-volume product for a B2C market. The European contract manufacturers were overwhelmed by the orders, and the interviews revealed that European suppliers and manufacturers could operate in a particular volume spectre and get into problems if the order is outside of that span. Hence, scaling up production in high volume markets is perceived

as problematic by the entrepreneurs as the situation in other geographical areas is more suitable and welcoming for start-ups than in Europe. Respectively scaling the business is very difficult as on top on the marketing demand the need for physical production facilities is an additional hurdle compared to software ventures.

Another difficulty that came out of the interviews is the design of the products. Many products are developed from a purely technological point of view, without any focus on functional design or even attractive design. This seems to be a cultural phenomenon in the examined area. The product is designed from the perspective of minimum technological requirements, and the appearance or functionality is often neglected. This was perceived as contrary to other regions by the interviewees. Regarding the statements, Anglo-Saxon entrepreneurs focus much more intensively on the design than Austrian and German ones.

4.3 Description and Representation of the specific challenges of hardware start-ups

The qualitative summary of the semi-structured interviews with start-up representatives and start-up investors is categorised into “ecosystem-related”, “business-related”, and “technology-related” challenges. These categories are subsequently divided into subcategories that were derived from the transcript of the interviews with the help of inductive categorisation (Mayring, 2008).

4.4 Ecosystem-related challenges

4.4.1 Quality of supports

The quality of supports offered was present in four of seven interviews with start-ups and both stakeholder interviews. This topic cluster covers statements about the possibility of getting non-material support from institutions and experts operating in the ecosystem and exchanging on thematic events.

Dominant in this context was the lack of programmes and institutions with practically experienced mentors that can offer relevant support. One of the statements has negatively rated the programs offered by universities because of the theoretical focus and lack of experts with practical experience.

Start-up 3*: “The university programmes are also rather questionable because the work here is extremely theoretical and theoretical knowledge is imparted by people who do not really have a clue about the subject matter in the practical sense.”*

The representative of Start-up 3 also mentioned that there is no "Beginner’s guide" for setting up a hardware business. This was underlined by the statement of the

interviewee of Start-up 2, as he expressed that even though he has been operating in the hardware start-up scene for several years, he still does not know which institutions or stakeholders he can contact to get support or relevant information. Moreover, he said that there is no real ecosystem of hardware start-ups and no entry point into the scene.

Start-up 5: *"As a hardware start-up, I have no idea whom to turn to with my problems! There is no ecosystem or advice centre where those responsible can guide me to the knowledge I need. This doesn't exist specifically for hardware; I don't know where to start to get into the scene. One could say that there is no ecosystem for hardware start-ups."*

A more specific issue was identified by Start-up 5. Namely a lack of support by people with the experience of managing successful product development and getting a product into a B2C market in Europe, He expressed a wish for exchange, strategic feedback, or mentoring.

Start-up 5: *"I missed access to people who have really brought hardware products to the masses. In our case especially, because we are not the classic B2B product, which only happens in small quantities and we are rather close to consumers and still have the problem with the whole regulation, so we are a particularly difficult case. It would be good to find a connection to people who have really scaled this on a European level, an exchange or strategic feedback, or professional mentoring from this niche would be very interesting."*

This challenging situation in the ecosystem was underlined by Stakeholder 1, as he expressed the problem of differentiating between good, helpful support and inadequate support that is rather time-consuming and can negatively influence the venture. Based on this observation, the stakeholder stated that he would not say that there is a need for more support for the start-ups. He claimed that the start-ups are in a position where they cannot see and evaluate the available offerings by the existing institutions.

Stakeholder 1: *"The difficult thing for start-ups is actually to recognise what is good support and what is bad. This is especially important as time is actually the only currency a start-up has."*

On the other hand, the stakeholder also underlined that this is a part of the growth process. Start-ups must go through this phase and learn rather quickly to differentiate good partners from the bad ones and act quickly to avoid losing time with non-productive cooperation. He expressed that this is something he would give to the start-up representatives as learning instead of complaining about the ecosystem's situation.

The interview partner from Start-up 7 showed another point of view on the networking programmes in the ecosystem. In his opinion, the actual program is often less

important than the people who are attending it. He highlighted the possibilities to exchange and network with other entrepreneurs and the benefit of these contacts. This expression could be interpreted as a sign of the ecosystem's lower quality in existing supportive measures than expected.

Another topic that was present in all the interviews with Start-ups and the stakeholders was the acceptance of longer development cycles and the overall time-to-market duration by ecosystem stakeholders. Especially because hardware development cycles are usually longer if compared to business models that are based exclusively on software solutions. The interviewed hardware Start-up representatives expressed their experience with the ecosystem that does not really consider the longer duration of development leading to a disadvantage for their businesses. Moreover, some of the interviews showed, that a strong focus of the ecosystem towards software is perceived by the respondents.

Start-up 7: *"So the structures are developing, as I see it at the moment, more and more in the direction of digital and software tech start-ups […] where the money and time requirements are much lower, that is out of the question, but in the long run it is not possible to have more hardware start-ups if the responsible people simply continue this trend and ignore the hardware start-ups."*

The interviewee from Start-up 3 described his experience in an accelerator for Start-ups; he described that the whole program and the talks with the investors were strongly focused on B2B business models, especially on the area of software as a service.

Start-up 3: *"[…] it became apparent relatively quickly that especially investors want pure B2B SAAS models. They don't dare to go with hardware because they don't understand it."*

This statement was also confirmed by the interviewed venture capital manager (Stakeholder 1). On the other hand, Stakeholder 2, an angel capital investor in the US and Europe, expressed that the different treatment of hardware start-ups and searching for differences is too abstract. In his opinion, a separate treatment is superfluous; after all, from an investor's point of view, similar parameters apply to both sectors.

4.4.2 Feedback Culture

Another ecosystem-related challenge identified during the interview sessions is the feedback culture. The insights shared in the interviews were less about the feedback from customers, which is widely described known frameworks such as "The Lean Start-up" (Ries, 2011). Instead, the topics focused on feedback from potential investors, partners, and other stakeholders, which were perceived as a major challenge by the representatives and stakeholders. The venture capital representative (Stakeholder 1)

expressed the problems with getting honest and valuable feedback from relevant stakeholders in the ecosystem. The first identified difficulty was that the start-ups are often refused instantly by the venture capital and receive a generic answer. He expressed a wish for establishing a culture of constructive feedback, so the start-ups can further develop.

Stakeholder 1: *"What is often the problem is that the start-ups are rejected immediately or get a generic answer from the VCs. That means they can't learn. I would like to see constructive feedback on rejections."*

The same stakeholder described a typical situation he experienced at various events for start-ups, acting as a judge for pitch presentations, with those organising and responsible for said events giving him advice not to be too hard in giving feedback, as they are afraid of discouraging the entrepreneurs.

The interviewed representative of Start-up 2 described that the feedback of an investor or another stakeholder is often expressed very positively, so the vis-à-vis does not close his or her doors in case the business is interesting for them in a later phase. After operating in the scene for several years, he claimed that he developed an instinct for such fake interests to avoid wasting time by following up and investing resources into the relationship.

However, Stakeholder 1 showed an understanding of the behaviour of not giving honest feedback from the institution's representatives as he claimed that by giving honest feedback, the person runs into the danger of being overwhelmed by messages from the start-ups in the future. Because the start-ups argue that they have improved in the areas which were identified as weak points and fulfilled the requirements.

Stakeholder 1*: "So if I tell the start-up that we are not investing for such and such reasons, I give them the ammunition to be able to permanently harangue us on these 5 points. So, there are also these start-ups that don't understand when we say no."*

The VC manager also mentioned that many of the start-ups that get honest feedback from him show much gratitude and often come back to get honest feedback to see if they have developed in the right direction. It was also discussed that this behaviour links to culture, and there is more openness regarding feedback in a business context outside of the DACH region.

4.5 Business-related challenges

4.5.1 Strategy

As hardware start-ups have much higher needs for working capital than start-ups from the software sector, their overall business strategy is crucial for successfully applying

for investments and market penetration. The strategy development of start-up ventures consists of diverse areas, including the analysis of own value propositions, identifying a target market, as well as the customer, and the monitoring of progress.

The targeted markets were a recurring topic in the interviews. Especially the representatives of companies that had a very sophisticated technology, which they tried to integrate into a product, had a long phase of identifying the pilot market. For example, one of the interviewed start-up representatives claimed, that the team had a precise idea of the targeted market, with the goal of serving suppliers of original equipment manufacturers (OEM). However, this strategy had to be changed as the target group had shown no interest in their product. After pivoting the targeted market toward OEMs and selling first products to them, the Tier 1 supplier showed interest as the product was now attractive for them to increase their revenues by suppling it to the end customer.

Stakeholder 1 commented on the common issue of missing exchange with potential customers while developing a business plan. This was also represented in the fact that 6 of 7 start-ups interviewed had to significantly change their strategy and the targeted market during the development of the product.

Regarding Stakeholder 1, another crucial point of the strategy is how the final relationship between a start-up, its customer and how the overall corporate structure will look like, this being essential to make it clear to investors how the venture will be financed. He stressed that it is unrealistic to assume that one investor will finance the entire production. Ideally, the entrepreneurs should set up a financing strategy that combines advance payments, debt capital and equity investments. The challenge is to find a strategic financing model that balances the instruments so that the company can serve the market. He expressed that these skills are missing in most high-tech ventures and are crucial for success.

Moreover, the stakeholder claimed that the original business plan with which the companies enter the VC is considered as the first concept, it takes several months of working together as a VC together with the start-up to get a business plan that is substantial. The stakeholder expressed the issue with distinguishing between fussy assumptions and assumptions that are based on reality, especially in the topics of the targeted market and the overall plans of the entrepreneurs. A dialogue with customers is perceived as essential for this part. The stakeholder described several examples where companies came to the VC with relatively vague plans of how the customer relationship should work, and these were changed during the collaboration between the VC and the start-up. Often the companies do not think about the possibilities of selling via asset financing, which is becoming increasingly popular in the B2B sector, or the possibilities of advance payments by the clients. In his view, a sensible strategy is of enormous importance here.

4.5.2 Team and HR

Team and HR Challenges are one of the biggest sub-categories of the examined challenges. It consists of statements, that are related to the onboarding of founding members as well as to the availability of qualified personnel that can be hired. The availability can on the one hand depend on the availability of human capital in the country, and on the other hand on the willingness of the workforce to work for a start-up.

In all the interviews conducted in the course of this work, the multidisciplinary of the team played an important role, corresponding with the existing literature that already identified a positive correlation between team multifunctionality and successfully bringing a product on a market. Technical resources and skills are needed to boost product differentiation, while marketing skills are required to take the differentiated product to market successfully in order to reach performance objectives (Lisa Z. Song, 2010). Accordingly, the most prevalent topic addressed by the stakeholders in the ecosystem-related category was finding team colleagues that have know-how in areas outside of the core competencies of the original idea. Three of seven interviewed start-up representatives claimed that they see themselves as experts in the technology which their business idea is based on and consider themselves as engineers or scientists. Two of them explicitly expressed the struggle with finding business developers with entrepreneurial know-how which they consider to be crucial for their businesses. These interviewed stakeholders see themselves as interim business developers until they acquire a new team member with corresponding skills.

Start-up 7: *“I have already trained myself so that I can first take over the business part until we find or have found someone who can then take over, so to speak, and we then started relatively early to find someone for the company set-up, business set-up, for the team, i.e., someone who really wants to then co found.”*

The related challenges of homogenous teams were expressed by the stakeholder of Start-up 4; he described a very scientific composition of his team and the resistance of the current team for hiring a new team member coming from another field of expertise.

Start-up 4*: “I also increasingly have the discussion that some of my colleagues would like us to hire another employee who should be recruited from the research area, and I would like this new employee to be someone who can bring a new perspective to the company.”*

This statement shows an internal dimension of acquiring entrepreneurial know-how in a technologically focused company, whereas some individuals show resistance towards different mindsets. The interviewee attributed this to the fact that his employees feel more comfortable in their familiar surroundings. He also mentioned the challenge of working with an exclusively scientific team that focuses on proving their

hypothesis and the corresponding technology and not on creating a product that is ready for production and for a customer.

Start-up 4: *"When scientists are involved, they think, for example, a product is developed when they have shown with one prototype that the technology works. They don't understand that you must scale it up and produce a significant amount. That's all unimportant to them, university scientists usually come from a different world."*

On the other hand, three of seven interviewed start-ups showed a mix of technological and entrepreneurial know-how in their teams. The stakeholder of Start-up 2 underlined the benefits of this heterogeneous collaboration, and the CEO of Start-up 5, an experienced entrepreneur with a management know-how, was hired by the founders of the university spin-off to accelerate the time-to-market.

Coming from a venture capital company, Stakeholder 1 underlined that hardware start-ups in which they invest and collaborate usually have a person on board, which has a business development-related education or background. Furthermore, both stakeholders interviewed underlined the importance of the team composition and skills for the investment decision.

Besides the challenge of hiring personnel with business know-how, just one explicit issue with hiring special skills came up during the interviews. The stakeholder of Start-up 1 struggled to find an expert for programming the software part of their business model while founding the venture. After a long period of time, the team managed to find a programmer who got shares in the company. The problem with the lack of skilled workers for IT positions is a well-known one and is not only challenging for start-ups. Major companies are willing to shower appropriately trained employees with benefits and thus pose a major competition for small companies.

A general statement that referred to the overall position of start-ups searching for new employees was related to the fact that hardware start-ups are struggling to find qualified employees, as the jobs in a small and fast evolving company are perceived as insecure. The stakeholder of Start-up 5 outlined the change of the reservedness of potential employees towards their company after their product had a successful introduction on the market. As the product is B2C and targets the healthcare sector, the employees express their happiness about the fact, that they are part of a company with a meaningful impact.

A further problem of the growth phase was described by the representative of Start-up 6. When the company grows rapidly, new challenges arise in the culture and communication that the management is confronted with.

Start-up 4: *"What was challenging, but I think it is the same with all companies, was the process of growing beyond 10-12 people. At 5 or 8, everyone still knows everything*

about the company. As soon as a certain size is exceeded, it is no longer possible without a well-established structure, meeting culture, communication channels, communication processes and all that."

The costs for the workers were an explicit topic in one interview. Start-up 1 representative mentioned that he was not able to hire any employees at the beginning of the venture as the financial situation was too unsecure. The only possibility was to give shares for the company and acquire team members. Moreover, he underlined the costs, that are connected to changing the owner structure for several times when giving shares on a Star-up to investors and Co-Founders.

Start-up 1: *"The costs for the workers are very high, you either have to give shares in the company or alternative contracts, otherwise you can't afford it at the beginning. […] These company register and notary fees, the whole thing is expensive."*

4.5.3 Partner Collaboration

One of the dominant challenges of hardware-start-ups that distinguish them from other ventures is the dependence on external influences. In addition to the usual start-up hurdles, entrepreneurs who work on a physical product business model face additional hurdle, which are explicitly addressed in this thesis. The respondents pointed out that collaborations with partners can target these external issues, and these collaborations often go beyond traditional financing.

A rather usual collaboration between a start-up and a corporate was described in 3 of the start-up interviews. This alignment with a corporate is usually based on the sharing of the corporates existing distribution channels to get the products to the customer. In return, the corporates receive commission and maintains his customers by offering them a novel product; some of the corporates are even ready to invest small amounts in the start-up for supporting development. A similar strategy was described by Start-ups 3, 4 and 5. According to the study of KPMG (New Horizons 2014), this is also the primary motivation of start-ups for cooperating with corporates, as 90% state that the goal of these partnerships is market access.

2 of 7 representatives mentioned negotiations with potential partners interested in a deeper collaboration, namely an equity investment or a joint venture company. Both representatives mentioned a concern that one of the targets of corporates in such a collaboration is to quickly buy complementary technology or capabilities to solve their problems and enter new markets. This behaviour corresponds with existing publications on that field (T. Weiblen, 2015) and (Lermer, 2013). However, the concern of losing control of the product and the technology was outweighed by the benefits that were mainly seen in market penetration and production know-how. Moreover, the representatives saw potential in penetrating one market together with one partner to

establish a production and then further develop the products and serve different markets on their own.

A different form of collaboration was explained by another representative, who claimed that the whole certification process of their product was carried out in a project with a certification company. The certification company was interested in the cooperation to get know-how in the field and had no intention of making money directly from the product.

One of the representatives described a fruitful collaboration with a manufacturer of a substantial part of the product, which was very beneficial in the product development phase. However, after penetrating the market, the start-up found itself in a vendor lock-in situation. The supplier started to increase the prices and a supplier change would be costly and technologically challenging, as the whole system (software and hardware) was built around the manufacturers product.

Also, the cooperation with other SMEs and start-ups in shared office spaces and buildings was pointed out by several representatives in the interviews.

Start-up 2: *"Our neighbours in the technology and start-up centre also supported us. This was an advantage for us because the companies there are very diverse, e.g., an electrical company, a construction engineer who builds containers. There is give and take here. The design engineer, for example, always looked at the CAD products of our students because he naturally has more know-how. My colleague is building PCs and he could always support the neighbours. It's not on a monetary level, it's mutual help. You can get expertise through this "neighbourhood" without it costing a lot of money."*

4.5.4 Time-to-Market

Time-to-Market describes the period in a product life cycle in which the product generates costs without generating any revenues and it ends with the market-readiness of the developed product. The respondents consistently agreed that developing physical products takes longer than developing pure software solutions and services. This fact has to do with the longer iteration cycles, the multidisciplinarity and the dependence on external factors and was described in existing literature (Berg, 2020) and (Anh Nguyen-Duc, 2018). This phenomenon was present in several interviews and is further described in the product development challenges. All companies participating in the qualitative study agreed that time is one of the most significant problems in HW entrepreneurship. Many described the issue as the so-called Valley of Dead, a term used by to indicate the phase in which capital is burnt, and no revenue is generated. In this phase, companies are depending only on equity and subsidies. The company's goal is to bridge this phase with the initial investments

and grants. Generally speaking, the longer the valley of death, the higher the company's risk of failing This risk challenges the entrepreneurs, as well as the investors, that are reserved towards the investments in hardware companies. Another dimension of the problem is linked to the limitation of supporting programs and measures.

Start-up 5: *"What is very important, is that all instruments are typically limited to 6 years, so you are no longer a start-up after 6 years. Now, of course, it is very painful for hardware start-ups, because maybe we were able to get things done a bit faster, but de facto it took us 6 years to reach the market. Then you're on the market and it's not done, you're still a start-up for several more years. I'd say 2-3 years, and you quickly reach a time of 10 years to even become halfway profitable. That means you lose many opportunities after 6 years due to the industry and not on your own responsibility. This is already an issue for hardware start-ups and medical start-ups that need even longer. The challenge is that everyone wants to see revenues, which is also quickly feasible with software, but no one wants to finance it without, that is the Valley of Dead."*

The dependency on external factors comes with the necessity of sourcing components, services, and materials from third parties. It extends the time-to-market as start-ups usually have a disadvantage due to the small order quantities that suppliers do not prioritise (see chapter "Technology-related").

Start-up 6: *"What was very problematic were the iteration cycles that you have with hardware. […] It's not like software, that you just roll it out. We really have to buy materials and components"*

Start-up 7: *"The time you need is usually longer because you have a physical product. You always have to work with the potential customer in an interplay so that you don't bypass the market, but of course it's even more difficult with a physical product, which is very complex, so everything is more time-consuming, and yes, I think those are the two main points, i.e., you need more money, and you need more time."*

Both interviewed ecosystem stakeholders agreed on the longer time needed for product development in hardware start-ups. However, Stakeholder 1 pointed out the better ability of successful hardware entrepreneurs to think systematically in iteration steps, which benefits structured product improvements. He also mentioned that this prevents them from a widespread mistake of software venture, where the entrepreneurs get lost very quickly in features that are not important for the customer, and they are not forced to think about additional costs of the product, because usually the changes can be made just by the workforce and an update of the product.

Stakeholder 1: *"One thing is the time horizon, which is much shorter for software than for hardware. This is given by nature. But, for example, one of the hardware companies in our VC is already planning with 3 generations and knows when they will change*

what and where. At the same time, they have designed the final product in such a way that they still have a certain flexibility for the customer feedback that comes in after the first and second generation. But they can't deliver the third generation faster than in 14 months. These are things that can't be done faster in terms of the supply chain. This means that there is a natural cycle for this iteration […] On the software side, you very quickly get lost in features, saying that the customer wants this and that. Then you have something perfectly adapted for the customer. But after just one month, it is no longer useful for this customer. Because the company continues to develop. On the hardware side, you know that every additional screw costs so and so many euros and accordingly you think twice about whether you implement it or not."

4.5.5 Marketing & Sales

As far as the end customer is concerned, all possible business models were considered in the sample. There were three consumer market companies with one venture aiming to serve business customers as well in the future; the remaining four start-ups were serving or aiming to serve B2B markets. The products of Start-up 1, Start-up 5 and Start-up 6 were already available on the market when the study was conducted. The remaining ventures have not yet reached the customers.

Start-up 1 focuses on a market niche in a B2C hobby music segment; the sales channels are an online shop, phone order and direct sales. However, the CEO revealed that the plan is to have primarily digital distribution in the future. This decision was motivated by the COVID-19 pandemic that was ongoing during the writing of this thesis. The product consists of hardware parts that must be bought individually, and a software solution paid in a subscription model.

Operating in the automation of production processes and human-machine collaboration, the interviewee from Start-up 6 described a difficult path to convince the production planning companies and intermediaries to market their technology. He said it was necessary to first contact the end customer segment and create a market pull. The Start-up 6 could not attract the actual targeted sector in the supply chain as the companies were not interested in increasing the complexity of their business and collaborating with a start-up, while the sales numbers of them were good.

Start-up 6: *"We actually cracked the first direct customer by bringing an end customer to them. So, we wrote to all sorts of people, and the reaction was usually: you are a start-up, what do you want? However, as soon as we dropped an end customer name who was interested in a specific robot and we dropped the name at a meeting with the robot manufacturer, it worked."*

Start-up 1 and Start-up 6 underlined the importance of thematic fairs, where they could showcase their product to end customers. Both companies were disadvantaged by the

current pandemic situation as business events were largely cancelled due to the contact reducing measures.

Start-up 5 focuses on online sales via their distribution channel for the German and Austrian market and an exclusive distribution partner for the Swiss market. Moreover, the company cooperates with non-exclusive dealers that focus on stationary retail. As the product is relatively expensive and needs much explanation, the Start-up focuses on PR to get a media presence for free and influencer marketing.

Start-up 5: "*Influencer are an important channel for products that need so much explanation and to create this 360° overview."*

The marketing strategy of Start-up 2 was to target a B2B segment in the entertainment industry; the company was prior to the market entry phase during the interview. However, there were already precise plans and collaborations with several distribution partners. The CEO expressed the challenge of intensive support and training of the distributors. As the product is novel and radically innovative, the distributor must describe it well to sell it successfully. He expressed concerns about the dealers' ability to market the product.

Start-up 2: *"However, it remains to be seen how the distribution partners can sell this complex solution and whether they can communicate which problems our solution solves."*

In contrast to Start-up 6, the representative of Start-up 2 said that the distributors are interested in the idea. They see it as a new communication pretext for contacting their customers and maintaining their relationship with them.

Start-up 3 operates in B2B health wearables segment and handed over the exclusivity to a distribution partner. Distribution was not seen as a core competence of the company's managing directors.

The Stakeholder interviews revealed a common issue with entrepreneurs having unrealistic expectations about the targeted market.

Stakeholder 1: *"Very often it happens with us that the founder describes a market like LED and then says their solution will serve 5% of this market. But there is usually nothing behind that assumption. There is often much work to be done because the founders' skills are simply lacking."*

4.5.6 Market fit

According to the reference works of today's start-up scene, the determination of the target customer and the Go-to-Market (GTM) is essential for entrepreneurial success (Ries, 2011). Furthermore, business coaches, mentors and other stakeholders of the

start-up ecosystem warn entrepreneurs from focusing just on a technically superior product and not having the proper access to the market[6] and recommend a well-planned GTM strategy[7].

Stakeholder 1 described a typical situation during pitch presentation where the start-ups describe different possibilities of the technology but do not have a precise definition of their target market yet. He expressed how the optimal start-up mindset and followingly the pitch presentation should look like to attract investors.

Stakeholder 1: *"The start-ups should give us a simple story from A to Z, what exactly they want to do, where the money will go in and what the chances are. They should show us this story. Very precisely, show us a customer and say he would buy it for this and this reasons, we have already had talks with them, we need you as an investor to implement this and that, and besides this one customer others have the same need for action, and it can be scaled accordingly. That is what we are looking for, so to speak."*

He also expressed an estimate about the product-market fit being the most significant reason for a failure of a venture; he estimates that it is the reason for around 70% of the failures. His explanation for this phenomenon was that hardware start-ups are usually technology-driven, resulting in a strong focus on perfect technology and not being sensible about the customer needs. From the author's interpretation of the start-up interviews, this phenomenon was observable in several of the cases. The start-ups that already managed a successful market penetration have shown that the team was able to be very flexible and find a pilot market by adapting their product; on the other hand, several interviewees showed a strong focus on the product itself but struggled to find a go-to-market. Stakeholder 2 stated that the technology can usually remain the same, but it is essential to understand the customer's needs and what influences his decision to buy the product. The product development must be versatile and adaptable.

A low-threshold method that is applied by Stakeholder 1 to support the start-ups in finding their go to market and creating a product that meets potential customers' needs is to invite the responsible technicians to the talks with the customers.

Stakeholder 1: *"We always want the technicians to be on-site with the salespeople at the customer and that they experience the first conversations. So that they also understand what the customer is looking for. And typically, the technician is more result-neutral, which means he doesn't hear "they want to buy it". Rather he hears, "they don't like this, they don't like that, they don't like this". And this soberness, which*

[6]Jasna Klemenc Puntar, „Why a Killer Go-to-Market Always Wins over a Great Product", https://medium.com/omneechannel/go-to-market-strategy-framework-and-deep-dive-a0a77f5474e8, last accessed December 09,2021

[7] Zen Liu, „Go to Market (GTM) from a PM ", https://medium.com/agileinsider/go-to-market-gtm-as-a-pm-7fc1df7db993, last accessed December 09,2021

is very pronounced in German culture, helps gain an objective picture. And they can then analyse it together as a team and make changes."

The stakeholder also pointed out that the people involved in technological development are usually not willing to attend these meetings.

4.5.7 Financing

This sub-category covers both types of financing: equity financing and debt financing and is distinguished from subsidies. Considering the overall investment volume, 2021 seemed to be an excellent year for start-ups in the DACH region. Looking at Austria in particular, the investment volume in July 2021 was twice as high as in the whole year 2020. However, a detailed analysis reveals that this volume does not represent the whole ecosystem, as it was mainly driven by two extraordinary ventures. The overall number of ventures that attracted investors decreased by 17 per cent, and without the two outliers, the medium investment volume went from 2.5 to 1.7 million Euros[8]. A similar development can be observed in all countries. The venture capitalists are targeting rapid growth, which was described as blitz scaling, and tend to invest massive amounts of capital into a relatively small number of enterprises (Donald F. Kuratko, 2020).

A challenge that occurred in all the conducted interviews is attracting investors for investing in hardware companies. Due to the overall situation on the market that is described above, these statements could be misleading if considering just the start-up representatives, as the assumption is that other entrepreneurs would subjectively rate their possibilities to get equity investments as low. However, after analysing the interviews with the ecosystem stakeholders, it was proven that this issue is linked to several characteristics of a hardware venture. Both interviewed stakeholders, and a third one (VC manager) consulted before the actual start of the thesis concluded that investors are reluctant to invest in hardware ventures.

Stakeholder 1: *"There are areas where all investors agree and where they say it makes sense to invest in this area. Beautifully scalable, everything is feasible, and hardware is usually left out of the equation. Hardware is more complex because there are additional with delivery, with implementation, with financing, with the procurement of parts, especially in the area of microelectronics and not to forget, the scarcity of resources."*

A prevalent hurdle was the financing of the development and setting up the production. As covered in the sub-category of time-to-market, developing a physical product is more time consuming and depends on many external factors. Also, the fact that the

[8] EY Start-up-Barometer Europa, https://www.ey.com/de_at/news/2021/07/ey-start-up-barometer-austria-1-2021, last accessed December 30, 2021

hardware ventures are often rather technology driven plays a role in searching for customers. All the interviewees agreed on the need of significant investments for creating a minimum viable product or a production ready prototype that can be used to attract customers. The need for working capital is very high, whereas the working capital of software companies is sometimes even negative because they can sell (beta) test versions of their software before even entering the market.

Start-up 4*: "There are additional financial resources needed for technology development, which are usually much lower in case of software ventures. That means you are much more limited because there are not so many programmes where you can still get funding […] you also must explain to someone that, at a VC for example, that it takes significantly longer until they get their money back."*

One way of counteracting this financing problem was described by 2 of the start-ups active in the field of B2B high-tech products. Both companies found potential customers who participated in the development of the product. In both cases, the partners were companies that were open to innovation and willing to co-finance the development to reap the benefits later as early adopters.

Start-up 4: *"From the market side, as far as investors and customers are concerned, it is more difficult. Some customers are relatively simple; they just want to see the demonstration and are happy to support the development in the lab. Investors, on the other hand, are difficult, the majority says, that they don't understand anything about the technology and that their area of interest is digitalisation and IT".*

The interviewed start-up representatives agreed on the issue of not being able to get investments because they cannot present a production-ready product in the early phase of the venture. This phenomenon is connected to the cost intensity of the product development and leads to a problematic situation. Customers and investors want to see the ability of the team to produce the product; on the one hand, the start-up seeking for investment to be able to set up the production on the other hand. This issue was present in 6 of 7 of the start-up representative's interviews. Moreover, 3 of the interviewed start-ups claimed, that most of the investors are not interested in and cannot understand hardware start-up business models or technologies. Start-up 5 sketched the problem of showing credibility towards investors, especially about the capability of bringing the product on the market.

Start-up 5: *"It's hard to have the credibility that you're actually going to bring something to market and that it's actually going to work".*

All interviewed start-ups that already managed to secure investments claimed that they could get to this point mainly through grants and that the transit from a subsidies carried venture was challenging. One of them pointed out that searching for investors became easier when the first market penetration succeeded. Another interviewee expressed a

possible solution to attract more investors into hardware by enabling governmentally backed equity guarantees.

Start-up 5: *"Of course, it would not be uninteresting to say that Europe would want hardware to continue to be developed or produced here, and to consider whether certain equity guarantees could be given to investors."*

Stakeholder 1 highlighted the challenge of getting capital for bringing the product on the market on point and went deeper into how his VC is trying to support the entrepreneurs to overcome it.

Stakeholder 1: *"So what we see very clearly is that hardware companies always have the question of how the pre-financing should work. […] Now, the classic problem is that we, as investors, basically don't want to shoulder the hardware on our own. We want to see how the company manages the asset financing with its clientele or in combination with a bank."*

The stakeholder also claimed that usually, there is a lack in financing know-how in the hardware start-ups.

Stakeholder 1: *"They usually have businesspeople on board, but they pay much more attention to the business model situation and the effective finances, so to speak, but they hardly ever have this financial intelligence to think about loans and holistic financial strategies […] and our VC tries to teach its hardware start-ups, we believe that this is actually much more important for a hardware venture than for a software start-up, because the software input is primarily in manpower, i.e. employees, and not in direct expenditure. That means you are positioned quite differently, so the strategic level is much more important for hardware start-ups than it is for software start-ups. Of course, fintech is an exception."*

4.5.8 Grants

The DACH Region, and Austria in particular, is internationally known for a very good subsidy system[9]. According to the "Austrian Startup Monitor", more than 50% of start-ups in Austria have made use of national funding (Leitner & M., 2019), in Germany, this share is at 44% (Tobias Kollmann, 2020). These statistics also show that the most prominent funding recipients are founders with an academic career background. A close interpretation of this phenomenon is that it is because of the know-how of the

[9] Alison Coleman, Why Vienna Is The Best Place To Start A Business https://www.forbes.com/sites/alisoncoleman/2019/09/10/why-vienna-is-the-best-place-to-start-a-business/?sh=215169c04f29, last accessed December 09,2021

grant system and in writing proposals gained at university, which was confirmed during the interviews.

Start-up 4: *"So the application process itself was less of a problem because the know-how is available at the university."*

Other interviewees highlighted the collaboration with service companies that support the application process and writing. Two of the companies interviewed have used such services several times.

All the companies in the qualitative study have received grants, and those that have succeeded in entering the market stated that it would not have been possible without grants. However, several shortages were identified by the interviewed start-up stakeholders regarding the subsidy system of the EU and, more specifically, in their region. 2 of 7 entrepreneurs (both located in Germany) pointed out that the subsidies volumes for start-ups are not laid out for radical innovations and that it is not possible for them to reach the grants for high-tech development because these focus on established companies and research institutions.

Start-up 2: *"The problem is that the significant grants that go to research activities are not well adapted to start-ups. We talk about funding in the hundreds of thousands of euros or millions, which we are currently aiming for because of our innovative technology. I also spoke to a grant provider who was enthusiastic about the technology but said that the funding is oriented towards established companies and research institutions. The granting institution wants to have particular security, that the receiving body can carry the project."*

On the other hand, all Austrian start-ups interviewed and Stakeholder 1 coming from an international operating VC, highlighted the Austrian subsidy system's opportunities and the possibility of receiving even high-volume grants for ventures. This observation corresponds with the research outcomes of the Austrian platform addendum:

"The role of the state as a provider of capital is disproportionately larger in Austria than in other European countries. In exceptional years like 2014, state agencies accounted for 76 percent of the available private equity funds. That is 9.5 times as much as the European average."[10]

Despite the availability of capital in the DACH region, other problems with subsidies and grants were identified during the interviews. Start-up 1 interviewee said that notwithstanding the amount of money available, start-ups that are not coming from academia struggle to find proper grants and apply successfully. Another representative described his most significant challenge that is linked to grants: Working in project

[10] Woher das Geld für österreichische Startups kommt, https://www.addendum.org/startups/staat-foerderungen/, last accessed December 10,2021

consortia. Many partners do not take the project's actual goal seriously and focus just on the reporting and applying part. He highlighted a project where a good manager was in charge and expressed a wish for more commitment in such projects. (For ethical reasons, the citation is not attributed to a Start-up)

"I worked in a project where there was a manager who really made sure that the consortium partners did what was agreed beforehand or what was planned. With the aim of achieving the objectives. On the other hand, there were also projects where before the reports were handed in, the consortia partners just quickly looked for something to write in. It is important that there really is a regular exchange, I have also experienced that for some partners regular meetings every two weeks, where progress and goals are discussed, are perceived as too much. For me, the commitment of consortia partners is a major challenge in cooperation projects."

Another issue described by 2 of the interviewed start-ups was the flexibility of the existing subsidies regarding company development. One of the entrepreneurs concerned said that the company's foundation was delayed because of the subsidy, with the aim not to lose the right to receive money, as the grant was conditional on not having founded a company. Another university spin-off located in Germany stated that it is difficult to finance the transition from a university research project to a company founding and that there are not enough suitable subsidies for this in the German ecosystem.

4.6 Technology-related challenges

4.6.1 Product Development

Challenges associated with technological development were very individual among the investigated start-ups, depending on the complexity and nature of the product. In Start-up 1, a physical product was an integral part of the business model, but the complexity was minor since a ready-made part from a supplier was used, and only simple additional parts had to be produced. This venture focused more on software development, which represented a significant effort. The other interviewed start-up representatives had to go through intensive physical product development work with related challenges.

The main challenge identified by the start-ups and the stakeholders was the time and the resources needed for product development in the start-up. Since the entire product development period was a topic during the interviews, the approximate development period of the products has been determined for 4 of the 7 respondents, i.e., the time between the founding of the company until the product is ready for production. The average duration is 3.75 years in the sample. However, only three start-ups have sold actual products to the customer at the time the interview was held; the other two only stated that they would have products ready for production in a few months. To put this number into perspective, the supporting organisations targeting (hardware) start-ups show different requirements for the maximum age of the companies to be perceived as start-ups:

- 3 years German High-Tech Gründerfonds[11]:
- 5 years at the Austrian AWS[12]
- 7 years at the European EIT Manufacturing[13]

Yet, the actual time needed from the first idea to the production ready product has generally been longer. All interviewees stated that there was preparatory work on the product's technology at university or as a leisure activity - many of them spent several years or even a decade before starting the business-oriented project. Most of the respondents have invested much time and other resources before starting a new company or spin-off. This was also described by the interviewees, see above.

All the start-ups described an iterative process with related challenges. The Book “The Hardware Startup” (DiResta, 2015), which intends to be a guide for entrepreneurs and

[11] https://www.htgf.de/de/gruender/, last accessed December 13,2021
[12] https://www.aws.at/fileadmin/user_upload/Downloads/ergaenzende_Information/Definition_Start-up.pdf, last accessed December 13,2021
[13] https://www.eitmanufacturing.eu/what-we-do/calls-and-opportunities/, last accessed December 13,2021

follows the principles of “Lean Startup” (Ries, 2011), describes the developments in rapid prototyping that enabled design iterations and low-resolution prototypes before bringing the product on the market. The ease of iteration is considered key for successful product development.

3 of 7 ventures showed a radical change of the product on which the business model is based during the prototype development phase. After this change in an early phase, these companies showed a strong focus, and the interviews revealed that the time to market for them was shorter than in the two ventures, which showed significant pivoting of the product in rather later stages. This behaviour led to additional time and, subsequently, to additional cost effort as the costs of changes in product development are increasing the closer the product is to the production readiness stage (Steffens, 2007). The remaining two start-ups showed no changes during the technological development of the physical product. In the author's opinion, in one case, it was because the initial idea was not technology-based; it focused on customer needs, and the novelty was instead in the provided service, being a combination of several existing technologies. The remaining start-up used a novel technology from university research for a product that served as a first market penetration possibility. The product was chosen with a marketing strategy focus, and the plan worked out very well as the venture showed the shortest time-to-market and got a powerful media presence, selling a B2C product. This initial success is essential for future products.

An omnipresent topic was the product development's complexity and the multidisciplinary nature of a hardware venture. 6 of the 7 start-ups faced challenges with developing functioning electronics, complex software, and technical design.

Start-up 2: *“We need the hardware; it is not enough to just program the software. For example, it is not enough to have one sensor to detect this movement in space. [...] We need to fuse the sensor data and combine LIDAR, infrared sensor, camera, and other data. [...] We have developed boards ourselves. I would say that is the holistic approach, if we want to have it the way we think of it, then the command control and everything has to flow together and that's why we have a central hardware unit where all the calculation and everything comes together.”*

The path from a prototype to a product that is scalable and can be showcased to a potential customer is rather long and expensive. This was identified as a major difference between hardware and non-hardware ventures. As described above the go-to strategy which is in the standard frameworks for entrepreneurs is to create a minimum viable product (MVP) that represent the first functioning iteration of the product. In the case of a software-based business model without any hardware components this can be done relatively easily by creating a front-end mock-up that demonstrates the functionality. The resources needed for this representation are merely the workforce with respective know-how and creative ideas. Many investors are

ready to invest in software-focused ventures based on this rather easy produced MVP. On the other hand, hardware start-ups need a very advanced prototype to be perceived as a potential investment opportunity. This phenomenon is related to the fact that investors question the ability of small ventures to develop the product into a production readiness stage. Moreover, the respondents claimed that most potential investors are not able to understand a hardware product or reject it in principle because of the high risk and instead focus on software solutions. The complexity of innovative hardware products was described in several statements of the entrepreneurs interviewed.

Start-up 3: *"The way from the first idea to the proof of concept is considerably longer if compared to a software venture. The feedback loop takes much longer; the development and testing of a printed circuit board, for example, takes two months. Of course, that is insane compared to software. […] On the other hand, many more competencies are needed that must be acquired. With hardware, there is the need for know-how in embedded hardware, embedded software, mechanics and so on."*

This complexity leads to a high dependency on external factors and difficulties related to the sourcing of components; moreover, as described before, it leads to long iteration cycles.

Start-up 3: *"So clearly the challenges are the issue of development times and external factors that influence you. Whether it's the delivery situation or that you need a manufacturer, you might need external partners who don't have a huge focus on your product and are more focused on other customers."*

The investigation of long development times was included in the quantitative part of this study.

Start-up 6 described a challenging phase of developing a new way of additive manufacturing, where the technicians had to work together with a company and completely disassemble and adapt an existing 3D Printer to be able to produce the needed parts. The representative also expressed the problem with European prototype suppliers. Namely an injection mould prototype that was extremely expensive in Europe and took several weeks in production, whereas the Chinese suppliers were able to deliver a prototype within days with significant less costs. This agility is essential for the development of products, as the company can act very quickly and boost the iteration times.

Start-up 7 described the challenge of letting a B2C customer test their products for possible adaption. As a functioning prototype is very costly and takes a long time to produce, the team decided to create one and let just a few companies try it and created a video of the UX and usability to collect more feedback from other potential customers.

Despite these hurdles, Stakeholder 1 highlighted the ability of hardware teams to counteract with thinking in generations and in development stages. This strategy leads to a well-structured and planned development of a product and to a more conceptional approach on deciding which changes are necessary to meet the customer needs. Another key success factor of a complex hardware product that was mentioned is the ability to design the product in a modular way, so new functions can be added when the basic product is on the market.

Stakeholder 1: *"What I meant before was that hardware companies are a bit better in development because hardware entrepreneurs understand more than software ones that they depend on external influences and think in iteration cycles. […] Many start-ups leave room for further improvements in their hardware products from the beginning. They can add features later and it doesn't cost them anything today. Because they have thought about the fact that the customers might have other demands that can be met with this adaptability or modularity in the future."*

Three of the companies interviewed stated that they had used development services in Asia. The clear advantage mentioned by the companies was the speed with which the development centres work, which is in line with the literature, as (DiResta, 2015) also emphasises the growing Shenzhen´s manufacturing ecosystem for producing prototypes and the increasing ease of sourcing through Chinese online shops. However, in contrast, there was a clear reluctance to outsource production, which is described below.

4.6.2 Certification

Among the investigated start-ups, the author found that start-ups have different points of view on certification depending on the area they are operating in and on their maturity. Especially Start-up 5 working in the health sector and Start-up 6 as a manufacturing supplier, both domains where the market regulations and standards infer strict guidelines for the development and production of the product, showed a strong focus on quality management and certification. The interviewees said that a significant part of the resources must be invested to ensure that all the necessary standards are fulfilled and documented. Certification requires developing and integrating a complex process, which is highly challenging for a young company. Start-up 5 underlined the benefits of developing their own quality management department and having this in-house know-how.

Start-up 5: *"Our company has a medical quality management system certification according to which we work. The product itself is currently still on the market as a consumer product, but we have already passed all the tests that we need for a medical device, which means that we will be obtaining a declaration as a medical device class*

1 in the foreseeable future to be able to map further use cases. […] We preferred to build up our quality manager. Which then had the lead, and others who had prior knowledge helped. We then made it through certification after the first attempt."

The company decided to enter the market with a CE consumer good certification to generate revenues and postponed the certification for medical products which is costly.

As mentioned above, the Start-up 6 underlined the collaboration with a certification company and was the only stakeholder who positively expressed about working together with certification companies. 3 of 7 interviewees rated these institutions as too costly and non-cooperative.

Another possible interpretation of the progress in certification of these two companies would be that these were beyond the phase of serving pilot customers and with the increased number of customers, quality and certification of the product becomes more important. This assumption is indicated by the fact that other respondents gave significantly less weight to the topic and underestimated the effort required. If compared to the companies that had already gone through.

Striking is the direct comparison between two interviewed start-ups active in the medical sector. Both companies are engaged in a very similar market, however the approach of the respondent that is still before market entry and production seems to underestimate the certification challenges. The stakeholder of the less mature company mentioned that they have no certifications until now, although the production start was planned in two months after the conducted the interview. He claimed that the company already had one try for the certification required for network devices but failed. However, he was confident that the following check by the certificating organisation would be sufficient.

Coming from elementary research, the interviewed CEO of Start-up 4 expressed that the certification is not a pressing topic for them as it depends on the market they will target, which was still not clear at the time of the interview. Start-up 1 said that the main component from the supplier is CE certified and that other certifications are not necessary for the system. The representative of Start-up 2 said that partly they count on the fact that the main component of their product, which comes from the supplier, is already certified. The technicians plan to reduce the functionality (speed) of the system to avoid the necessity of certification, which is mandatory for the specific product.

4.6.3 Intellectual Property – Patents

A patent allows the inventor or the company exclusive rights to the invention, which could be a design, process, improvement, or physical invention. The primary purpose of a patent is to protect intellectual property and prevent competitors from copying the

technology. In small enterprises, patents are perceived as an essential signal for external investors, as they reduce the asymmetry of information between a start-up and a potential investor (Conti & Thursby, 2013). The interviewee from Start-up 2 pointed out that there are many ideas for a patent in their technology. The decision about what will be patented in the pre-market phase was based on the attractiveness of the patent towards investors and the expected application duration. This statement corresponds with the signalling function of patents.

Start-up 2: "*We do not lack ideas for patents because we have a large system (complex product) where a lot is possible. However, we must always look at what the benefits of the patents are in this phase? The one patent we have was chosen mainly because it goes down well with investors; it wasn't the most glorious one, but it was something that could be implemented quickly and that we could sell quickly as our patent.*"

A majority (6 out of 7) of the start-ups surveyed were applying for patents or have already registered patents. Striking in this context was that the challenge of managing intellectual property and applying for a patent was perceived with very different degrees of difficulty among the respondents. The interviewees with patent experience agreed on the challenge of navigating in the existing patent landscape and conducting a cost benefit analysis to identify a good IP strategy. One of the challenges was the formulation of a patent that does not collide with existing ones.

Start-up 6: *"The search in the patent jungle was a challenge. The idea is written down quickly but formulating the whole thing in a patentable way and finding out if it doesn't touch anything out there eats up time. The first national patent was written by us. […] We soon hired a patent attorney, who also costs money, but it was clear that as soon as we filed an international application, we couldn't do it ourselves."*

All the interviewed companies used external support of patent lawyers at some point during their process. In the German, as well as in the Austrian ecosystem, subsidies exclusively for patent applications exist and were used by 3 of the start-ups interviewed. The spin-offs used their connection to universities and the existing patent offices of their institutions. Start-up 3 started an application for a patent but cancelled the application during the process as the patent had to be very precise and fear of revealing the know-how prevailed the benefits of a patent.

Start-up 3*: "We also filed an application, and then we would have had to go into too much detail, and we said it is not worth it. The issue of patenting software is that you always need a hardware component, and then you must go into so much detail about this software that it's just ridiculous, so you might as well disclose your code. Besides, it costs a lot of money and time, and then we said, let us leave it."*

The respondent from Start-up 5 described the decision-making process of IP management. The company serves a B2C market and had to find a balance between

costs of the patent nationalisation in different countries and avoiding copies from competitors. In the end, the representatives decided to focus on larger markets as they assumed that copying the technology for the remaining markets would be too costly for a competitor. This decision has proven to be correct up to the interview date. However, the interviewee mentioned that retrospectively he would have applied for a patent in Asia which had no priority back then. Another factor pointed out was that the decision about protection must be done in a phase where nobody can guess if the product will make it to the market, which can lead to high losses.

Coming from a university spin off, one interviewee expressed the issue in university spin-offs, where researchers tend to publish findings and data in scientific literature and he as a CEO must counteract to avoid losing valuable know-how of the technology.

4.6.4 Production

The production of physical goods specifically concerns hardware ventures and distinguishes them from software or fintech companies. Setting up production is a very costly matter and is a significant challenge even for established firms. The expenditures connected with the design of a production-ready product and the production are one of the main challenges of businesses based on physical products.

The interviewed companies have had different production strategies and thus very diverse problems. Three of the companies already had products in production and had different degrees of outsourcing of production. Start-up 6 has produced mainly on its own; Start-up 1 has worked with a finished product and has equipped it with a relatively simple extension, which required some manual assembly work. Start-up 5 completely outsourced the production of their B2C electronic device to an electronic manufacturing services provider.

The representatives of the producing companies underlined the benefits of additive manufacturing that became accessible in the past decade. The usage of 3D printing goes beyond prototyping and is used as a production for smaller batches method. Being very flexible it can reduce the iteration times and enable changes on products that are already in production. However, two interviewees mentioned the high cost and production times for medium and large batches compared to injection moulding production. One of them expressed the plan to change the production process entirely:

Start-up 1: *“A major challenge is the price of the 3D printed parts, you are very flexible with 3D printing and can also produce small quantities, which is also great for us, but of course, the price is relatively high compared to injection moulding, and we are also considering going in the direction of injection moulding here.”*

This decision can be associated with the fact that the products are standardised without a significant variety. On the other hand, Start-up 5 had two processes running in parallel as the company has different batch sizes for every product type.

Start-up 5: *"For this reason, we have two processes. One is 3D printing; the other is selective laser sintering for individual pieces and small batches. That was also an advantage during development because the process is very flexible. For higher quantities, we have another process that we developed ourselves in cooperation with partners. Here we produce injection moulds."*

Creating a radically innovative deep-tech product, the interviewed CEO of Start-up 4 sketched the challenging way from prototypes into production. While parts of the production can be designed with existing machines with slight modification, a significant part of the production process must be developed from scratch. The production line cost was estimated at millions of euros for the pilot production and tens of millions of euros for actual production. This phenomenon is a significant issue for the company, as investors see an extremely high risk with an uncertain outcome. On the other hand, without setting up a production and subsequently having goods to sell or showcase, the company cannot acquire a significant number of customers, which would lead to a better negotiation position with investors. The representative described a strategy of focusing on a small niche market in the first place to start the first production. As the company aims to produce a material that can be used for various applications, the niche market would serve as a possibility to design first products together with the producers and subsequently attract new investors and customers when significant production volumes are possible. Setting up production was by far the biggest hurdle for this company. Without production and a scalable product, the entrepreneurs cannot bring products to customers and thus find investors.

Start-up 4: *"We rather first target a market that is small and special and for which there has been no investment in this technology so far. In other markets that use similar technology, there are already companies that have been working on their product for decades, and we simply can't keep up with the prices or the volumes. In my opinion, this is the better way for the company, but of course, it brings the problem of scalability. The investors then say that if there is no multi-billion market behind it, it is not interesting for them. […] It is no use trying to get potential customers now, I will be at a large trade fair the week after next, but the special challenge there will be to raise people's interest and to make it clear to them that they cannot order 50 pieces of the product now."*

To a smaller extent but a very similar problem was described by 6 of 7 start-ups and by both Stakeholders. The investors usually do not believe that the start-ups will set up a production and be able to bring the product to the customer. Partly this issue is based on a wrong financing strategy which is further described in the "Business-related

challenges" subsection under the caption "Financing". Regarding to Stakeholder 1 the investors do not want to finance the entire production costs with extra working capital, they want to see, that the company is able to get debt financing or pre-payments for setting up the production. This strategy was not present in any of the interviewees with the start-ups.

Although, as described above, some product development was outsourced to Asia, all companies wanted to produce in Europe and were searching for European contract manufacturers. Only one of the interviewed companies considered a production outside of Europe, however the representative said that it would be a second choice after a European company.

4.6.5 Sourcing

All interview partners stated that their venture is dependent on external suppliers. The purchased goods ranged from individual parts to complete modules to finished products from suppliers. In addition, some companies also outsourced the development of hardware and software as described above.

One issue that was raised by all the companies interviewed was the one of order volumes. Five of the respondents had difficulties finding a supplier who could deliver relatively small quantities at an acceptable price.

Start-up 1: *"[…] Of course, we also looked at other options, such as ordering from China, but you have to order 10,000 units and of course you don't have the money at the beginning."*

Medium-sized and large suppliers are used to producing large quantities and are often not willing to work with start-ups or rank their orders at the back because the revenues of such collaboration are not attractive at the beginning. Future collaboration is unsure, and much more exchange is needed than with established companies with more know-how in product development.

Moreover, suppliers often offer products with a minimum order quantity and force the purchaser to buy a significant number of parts or products. The start-ups are forced to pre-finance these parts, leading to higher demand for capital in the pre-production phase.

Start-up 2: *"So the company that supplied us with the part was a bigger one and of course that was not easy because they are used to producing larger quantities and are not designed for start-ups that need a lot of communication and iteration."*

However, Start-up 5 expressed an opposite problem of regional suppliers and electronic manufacturing services in a later stage of the product life cycle. After the company reached a certain maturity level and overcame the problem described above, a new challenge occurred. The CEO described the struggle of cooperating with regional suppliers on large batch sizes. As these companies usually operate in a niche with special products, there is a lack of competencies in sourcing and processing large batch size medical consumer products.

Start-up 5: *"From a certain stage of the product, where the company is dealing with significant quantities, it is difficult to find partners who are used to doing this in the consumer medical sector in Austria and Germany, because it simply requires a proper purchasing competence or international sourcing competence. […] Because these partners are often active in special products, where the batch sizes are in the hundreds. If the company starts to go into higher quantities, which is necessary for consumer products, then the partners simply don't have the competence to scale this."*

The interviewee of Start-up 3 expressed a problem with datasheets for electronic components which were sourced for the product. The parameters that were quoted have often proved to be wrong. This is a well-known problem in the sector: on the one hand, different manufacturers use the same names for products with different performance figures. On the other hand, it is reported that the first pages often have more of a marketing effect and should not be trusted in case of doubt. In addition, the data sheets are written by employees of the producer who can make mistakes.[14] These inconsistencies in datasheets lead to a significant delay in product development and to additional costs.

Another recurring problem in the interviews was the supply chain crisis caused by the COVID-19 pandemic. Getting the electronic parts was very complicated for most of the respondents. Again, the company's size played a significant role; the suppliers prioritised companies with larger and constant order volumes.

Start-up 5: *"At the moment, it is tough to source good and affordable components at all. Especially as a small company because the major companies, especially in the automotive industry, are fighting over the chips. We are certainly not the first in the food chain, and we are struggling to bring products to the market."*

The respondents indicated that the search for suppliers is a very complex matter. Not only must the costs and quality be weighed, but it is also necessary to find components that are state of the art and that are available on the market for as long as possible.

[14] "Hardware-Designtipps des Monats: Datenblätter" https://www.mikrocontroller.net/topic/430170, https://medium.com/zebras-unite/zebrasfix-c467e55f9d96 last accessed January 03,2022

Start-up 5: *"You cannot overhaul the design every year because some part was cancelled or because you are no longer at the cutting edge of technology. That means it was difficult to do this with foresight and to combine it well."*

Moreover, the tense situation on the market changed the common practice of suppliers; usually, before an electronics component or another part reaches the end-of-life and is no longer produced, the manufacturer announces a last time buy. The interviewee said he was confronted twice with a situation where a company suddenly stopped production from one day to the other, leading to significant problems.

Start-up 3: *"We have had two cases where the manufacturer took the product out of the catalogue overnight, and from then on it was no longer available. That did not happen before, these are extreme situations in which we operate, and that is, of course, an external factor that we cannot influence, and that is why there is always a bit of uncertainty."*

But sourcing has not been limited to finished products and components. 5 of the 7 companies have made use of various development services. The main challenge was identified in outsourcing in such a way that the company does not give away strategic knowledge about the unique selling point to suppliers.

All companies that outsourced have stated that the regionality of the partner companies played a significant role in the decision making. However, three of them decided to cooperate with suppliers in Asia (2 China and 1 in Taiwan) after realising that the know-how in certain areas is clearly much higher than Europe and the DACH Region.

Start-up 3: *"The hotbed of wearables is Asia, especially Taiwan. We have approached huge corporations that work for big German automotive companies and asked if they can do it, and the answer was that they cannot.*

The interviewed entrepreneurs felt compelled to source parts and development services globally, in order not to compromise development speed. As mentioned above, all the company representatives interviewed stated that they sourced the final assembly and key processes as regionally as possible. This strategy was chosen mainly due to the advantages of closer cooperation, the lack of culture and language barriers, and the signal effect to potential customers of a product labelled with made in Germany or made in the EU. Another advantage of this approach is the elimination of foreign exchange and systemic risks which goes in hand with sourcing in foreign countries, as all the interviewees revealed a clear focus on the European market.

2 of 7 interviewed start-up representatives expressed a lack of alternatives for specific parts and technologies on the supplier market. This leads to the indispensability to source from a single supplier and a high dependency. In the case of one of the start-

ups, this so-called vendor-lock-in resulted in a situation where the supplier's margin is very high, and there is no willingness to reduce the prices due to the meanwhile high order volumes of the start-up. Nevertheless, as the start-up builds its entire product around the component, switching to a different supplier would lead to high costs of changing the whole system.

As far as the loss of know-how through cooperation with suppliers is concerned, the interviewees did not have any major concerns.

4.6.6 Scaling

The vision of profits attracts investors to invest in potentially disruptive technology start-ups and fund them to advance their speed of growth. Especially in the Silicon Valley model, the goal is to aggressively scale and seek enormous returns for investors. This leads to a prioritisation of speed over efficiency in an uncertain environment and subsequently to compromising of quality, market fit or even ethics. The companies must reach a certain level of growth before they run out of capital, which reduces the time for the release of a product. (Donald F. Kuratko, 2020) These businesses typically depend on network effects; the company that gets to scale first will usually stay on top. Due to the cheap capital availability on the markets, the investors can push companies towards success. Examples for such practice are the companies Lyft and Uber, that spend 55% of its revenue on driver incentives, passenger discounts, sales, and marketing to acquire passengers and drivers faster than others. The competition has been taken down with the flood of investments. "*Investors anointed the winners rather than letting the market decide who should succeed and who should fail.*"[15]

This market situation poses significant challenges for hardware start-ups, as scaling hardware needs a well-developed product, proper sourcing strategy and a production that can produce the needed quantity at a quality expected by the customer. A question of principle is if a so-called unicorn start-up desires a typical entrepreneur operating in the examined sector of hardware start-ups in the DACH region. After interviewing the start-up representatives, the author got the impression that the typical entrepreneur tends to have goals on healthy and sustainable growth rather than a radical, exponential one. This paradigm was formulated in the idea of a zebra start-up by Jennifer Brandel, Mara Zepeda, Astrid Scholz & Aniyia Williams[16]:

"The current technology and venture capital structure is broken. It rewards quantity over quality, consumption over creation, quick exits over sustainable growth, and

[15] "The fundamental problem with Silicon Valley's favourite growth strategy" https://qz.com/1540608/the-problem-with-silicon-valleys-obsession-with-blitzscaling-growth/ last accessed December 29,2021
[16] "Zebras Fix What Unicorns Break", https://medium.com/zebras-unite/zebrasfix-c467e55f9d96 last accessed December 29,2021

shareholder profit over shared prosperity. It chases after "unicorn" companies bent on "disruption" rather than supporting businesses that repair, cultivate, and connect."

Stakeholder 1 expressed the focus of his VC to focus on business models where cash flow from operations can fund the company rather than speculations on radical growth and exits. His VC provides coaching and support to the start-up and focuses on technological innovation rather than on the so called "blitz scaling".

4.6.7 Design

The product's design was not a topic in any of the interviews with start-ups, despite the fact, that many of the entrepreneurs interviewed operate in segments where appearance and practicality play a significant role. Stakeholder 1 has emphasised that the entrepreneurs usually pay less attention to the designing work and that the product often lacks on designed. He mentioned a considerable difference in mentality compared to the Anglo-Saxon ventures, where the appearance is critical, and a lot of time is invested into improving it. While often, the technology underneath the exterior is considered as not essential. In his opinion, it would make sense for the companies that manufacture physical products to devote more resources to design and thus create a balance between technical maturity and appearance.

5 Quantitative Part and Results

5.1 Summary of Quantitative Results

The quantitative study revealed that the most significant challenge perceived by the entrepreneurs is financing the entire process of a product from prototype to production. The subsequent part was designed to go deeper into the topic and evaluate the underlying hurdles of financing and hardware development-related challenges.

The challenges identified during the qualitative interviews were evaluated with a [Likert] scale and divided into the more significant and less significant ones. The survey results can be seen in the table:

More significant challenges	Less significant challenges
production of the products	working with a contract manufacturing company outside of Europe
finding suitable employees for your start-up	finding suitable suppliers within Europe
prototyping/product development	gathering relevant feedback from (potential) investors
finding suitable suppliers outside Europe	submitting grant applications
supplier management	working with a contract manufacturing company in Europe

Table 3 Breakdown of the examined challenges

The most significant problem that the entrepreneurs face is the production of the product, followed by the hurdle of finding suitable employees for the start-up. The next most problematic area was the production of the products, followed by prototyping, finding suitable suppliers outside of Europe and the overall supplier management. On the other hand, the respondents find the challenges connected with collaboration with contract manufacturers, submitting grants, gathering feedback from investors, and finding suppliers within Europe less significant.

The gaps in the examined ecosystems were analysed to assess the unique needs of start-ups operating in hardware and analyse the challenges from the perspective of the support measures and physical infrastructure. A multiple choice question was used to examine the relevant gaps. In this context, it is striking that even though the financing was perceived as the most relevant challenge in the overall perception, the most significant gap was identified in the support for the certification of products, being a specific topic relevant for hardware entrepreneurship. Furthermore, Production, Supplier Management and Exchange with Experienced Entrepreneurs, were perceived as gaps in the ecosystem.

The following classification of the significant gaps identified in the qualitative part was made:

Big Gaps	Small Gaps
Certification	Patent Registration
Searching for Investors	Strategy
Production	Marketing & Sales
Supplier Management	Product Development/Prototyping
Exchange with experienced entrepreneurs	Subsidies

Table 4 Breakdown of the examined ecosystem gaps

5.2 Discussion Quantitative Part

The quantitative survey evaluates the relevance of the identified challenges of hardware start-ups and hardware entrepreneurs. Moreover, the evaluation of perceived shortages in the supportive measures for entrepreneurs available in the ecosystem enabled a more detailed analysis of the challenges and how these can be tackled in the future. The author's hypothesis was confirmed that financing is perceived as a major problem by the entrepreneurs. Nevertheless, the most significant gap identified in the ecosystem was around the topic of certification. This striking discrepancy illustrates that the hypothesis about specific challenges of hardware entrepreneurs is correct and that the start-ups investigated have many challenges that are unique to their business models.

Moreover, the significant gaps in the ecosystem identified were predominantly in the areas which are typical for hardware ventures and are connected to their physical product. Offers for entrepreneurs are still problematic as the certification bodies focus on established companies and business models. Besides the area of certification, the entrepreneurs are missing support in the field of production and supplier management. Areas that are similar regardless of the business model, such as strategy, marketing & sales, and subsidies, were perceived as well covered by different ecosystem-supporting entities. Against the author's expectations, Product Development and Prototyping turned out to be an area which does not represent a gap in the ecosystem. Even though it was perceived as one of the more significant challenges, the close interpretation of this result shows that the possibilities for rapid prototyping, which evolved in the past years, and the growing offerings of maker spaces and other facilities cover the entrepreneurs' needs. The missing machines and services that were identified were typically particular, depending on the area of operation and the final product.

The detailed examination of the different phases of product development has proved the assumption that the deviation from the planned development time of a prototype is smaller than the deviation while transforming a prototype into a finished product. The reason for these deviations is the lack of know-how and problems with outsourcing

activities that are not part of the critical know-how of the company. Entrepreneurs are cautious and avoid outsourcing due to the financial situation. Moreover, the conservative mindset of the companies offering development and certification services is often causing entrepreneurs to avoid external support.

Regarding the outsourcing and cooperation with suppliers, the study showed that in contrast to start-ups in general, where the development is done in-house and the outsourcing is used in the sales phase (Steinbruch, Fernandes, Nascimento, & Zawislak, 2022), hardware ventures are often forced to outsource from a very early stage. This early dependence on other firms leads to the need for good supplier management and the ability to cooperate with suppliers. The collaboration in Europe was perceived as less challenging than the collaboration with other regions.

Similar results apply to the cooperation with contract manufacturers. Also, the collaboration with the European partners was perceived as less challenging than those based outside of Europe. However, as the qualitative part of this thesis shows, in a later phase of a venture, especially around consumer goods, outsourcing within Europe can be problematic as not many suppliers can scale to big volumes.

Overall, cooperation with European partners is perceived as less challenging and consequently more attractive than cooperating with foreign countries. An apparent explanation would be the more comfortable communication due to cultural, political and economic proximity, making the collaboration easier. Moreover, the current literature describes a growing trend of de-globalisation, which is ignited by the reduced rentability of global supply chains due to current international events, such as the world wide pandemic (Marin, 2021) or the war in Ukraine.

The quantitative study confirmed the high dependency of hardware enterprises on external entities. This manifests in different areas, such as certification and fulfilment of norms that must be done by certification bodies and product development know-how. This applies especially for a more complex product where different areas outside of the core development must be covered or scaling the business collaboration with manufacturing service companies. This high dependency on external factors leads to a high reliance on working capital from very early phases.

The study confirmed the exceptional offer of public funding in the examined region for which both countries are well known (Karl-Heinz Leitner, 2019) (Kwiotkowska, 2019) (Max Marmer, 2011). The share of companies that received grants was extraordinarily high and striking compared to those that received money from investors. This result shows a significant disproportion between public and private money spent on start-ups in the region and can be attributed to various causes. The immediate interpretation, especially considering the interviews in the qualitative part, is investors' aversion toward hardware ventures, based on the high capital intensity that was described

above. However, as described in the qualitative part, the aversion is also based on the lack of financing strategy of the entrepreneurs when pitching their business plans. All in all, the stakeholders agree that investors are more interested in other forms of ventures. This phenomenon is also reflected in the discrepancy between the perceived availability of capital in the region and the question of investor interest in hardware companies.

To evaluate the statements from the interviews, the ecosystem strengths are analysed in the quantitative part. The overall possibilities to exchange with stakeholders are considered positive; however, the possibility of exchanging with experienced entrepreneurs is perceived as a significant gap. Moreover, the entrepreneurs rated the practical relevance of the programmes offered (coaching, accelerator, incubator, etc.) as less practically relevant. This confirms the statements from the qualitative part criticising a lack of practical mentoring. The entrepreneurs described very general programmes that do not consider the individual needs of a hardware venture.

The study reveals that the labour force shortage is the biggest challenge for hardware entrepreneurs. Regarding the Eupropean Commission paper „ Analysis of shortage and surplus occupations based on national and Eurostat Labour Force Survey data“ (McGrath, 2019), the problem with skilled workers is well known in the examined area. Specifically, the shortages are associated with relatively high levels of formal education qualifications and specific technical vocational qualifications. Start-ups are affected by this phenomenon on two levels. On the one hand, the entrepreneurs lack skilled workers in specific technological areas; on the other hand, there is a lack of strategic and financial management skills in the team. Arguably the ventures see themselves in a difficult position competing for workers with established companies that have often significantly better financial possibilities and offer more secure jobs.

5.3 Demographic Analysis

The quantitative survey was conducted between 28.11.2021 and 10.01.2022 using the online survey platform Respeak. This novel tool combines the functionality of a traditional survey with AI technology that makes it possible to ask further questions and estimate the quality of the answer. Especially the open questions are monitored and answers which are not answered are repeated. This strongly enables the elimination of unanswered questions by the surveyed person. On the other hand, a deep dive into some problems can be done by setting up special reactions for concrete key words. In the context of this thesis the function was used to determine detailed information about certain topics depending on the answer given by the user.

Table 5 illustrates which branches were served by the start-ups represented in the survey:

Start-up	Absolute Number	Percentage
Mechanical Engineering/Plant Engineering	10	29%
Mobility	5	14%
Chemistry	2	6%
Electronics	5	14%
Recycling	1	3%
Aviation	1	3%
Health	3	9%
Sensors/IoT	3	9%
Robotics	1	3%
Other	5	11%

Table 5 Branches represented in the study

The survey covered the regions of Austria and Germany. 19 respondents indicated that their start-ups were founded in Germany, and 17 were founded in Austria. This results in 53% German start-ups and 47% Austrian start-ups. The question of the orientation of the business model revealed that 69% of start-ups serve B2B, 11% of them B2C and 19% both segments. 89% of the surveyed start-up representatives stated that hardware is a significant part of their business model. Regarding the age of the surveyed start-up companies - counted since the founding year - the median value was 3,5 years. The oldest company in the sample was 11 years old and was perceived as an outlier.

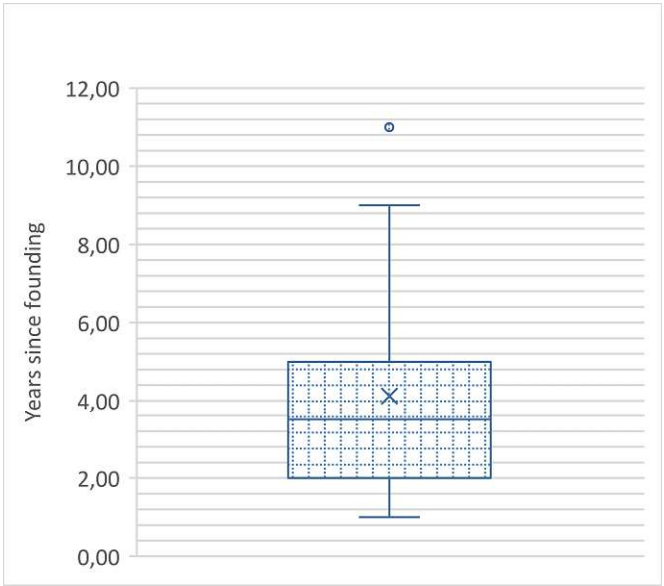

Figure 3 Maturity of the surveyed companies [n=36]

The highest level of education completed by the respondents was university or a university of applied sciences for 87%, secondary school for 10% and apprenticeship for 3%. The survey targeted founders and employees at the C-level; the following participants from start-up companies took part in the survey:

Position	Absolute Number	Percentage
CEO	26	72%
CFO	6	16%
COO	2	6%
CTO	1	3%
Business Development	1	3%

Table 6 Respondent's roles in their companies

Thanks to stakeholder research and statistics from the ecosystem (Gauthier, Penzel, Keuster, Morelix, & Rozynek, 2020) (Karl-Heinz Leitner, 2019), the author estimates 4000 hardware start-ups to exist in the Austrian and German ecosystems. Consequently, around 1% of the existing hardware start-ups are represented in the online survey.

5.4 General Challenges and gaps in supportive measures

The first part of the questionnaire focused on the general areas connected to a hardware venture, intending to start in a broad way and focus on specific topics in a later phase of the survey. This approach was chosen to avoid the influence of specific questions on the general point of view. The opening question examined which general aspects of product development are perceived as challenging, with the target of examining unique challenges for hardware ventures. Multiple entries were allowed in this question. The results are displayed in Figure 4 Major challenges in entrepreneurial activities. Three-quarters of the respondents identified the financing of their project as the major hurdle, followed by product development and prototyping; the production phase was selected by one-quarter of the respondents. In the "other" category, most respondents identified challenges in finding suitable employees and team members, followed by marketing and issues with certification, bureaucracy, and legal hurdles. The option "other "was chosen by 22% of the star-up representatives. The answers to the following open question included HR challenges, legal uncertainty regarding CE conformity, and problems with distribution.

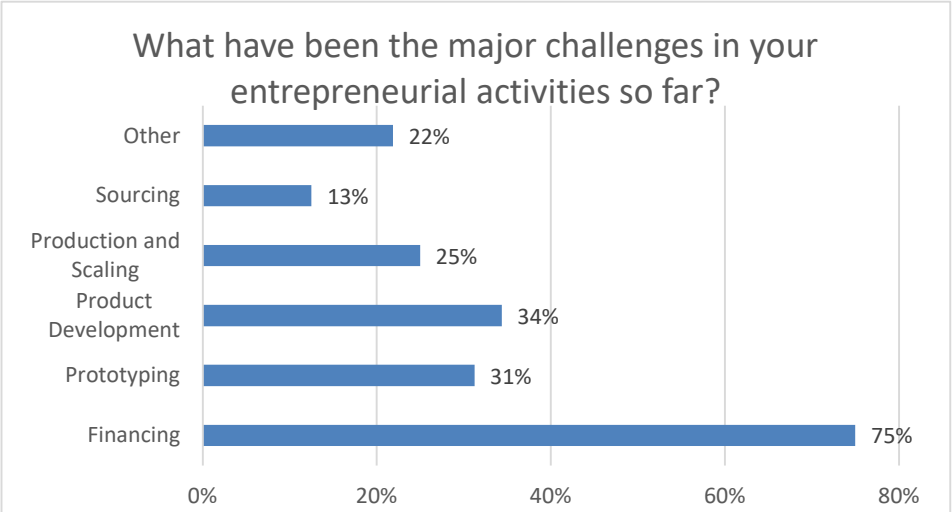

Figure 4 Major challenges in entrepreneurial activities [n=32]

Subsequently, the possibility of getting support on the challenges identified in the qualitative part was analysed via a multiple-choice question in the survey. More than 50% of the respondents identified gaps in getting advice on certification of products, respectively to the previous question the second-biggest gap was identified in searching for investors, with 48% choosing this answer. This observation is interesting as financing was by far the biggest problem in the previous question. A gap in the area of production was chosen by one-third of the respondents, followed by supplier management with 27% and exchange with experienced entrepreneurs, which was chosen by 24%. To consider the difference between companies which reached the production phase and the ones in a less mature phase, the data was filtered and compared to the data set. The biggest differences were in the perception of prototyping as a challenge. Only 4% of the companies which already reached the production phase considered it as one of the major challenges. Financing, and Production and Scaling was perceived as major challenge by 38% and 85% of the respondents which is significantly more than in the companies that did not reached the production phase.

The higher significance and lowers significance topics regarding the level support within the ecosystem are:

Big Gaps	Small Gaps
Certification	Patent Registration
Searching for Investors	Strategy
Production	Marketing & Sales
Supplier Management	Product Development/Prototyping
Exchange with experienced entrepreneurs	Subsidies

Table 7 Breakdown of the examined ecosystem gaps

The supportive measures in product development and prototyping were perceived as rather good when directly compared to other topics. This result is striking as certification represents a major part of a product development process, especially in the examined region.

5.5 Examination specific challenges

The challenges identified in the qualitative part were rated on a Likert scale (Likert, 1932) with 4 possible answers. The questions were for every challenge “How do you rate the challenge of …”. The answer possibilities were:

Likert Answer	Numeric Value
Very high	4
High	3
Low	2
Very low	1

Table 8 Numeric representation of the Likert Answers

The examined challenges focused on the period between building a prototype and having a production-ready product that can be sold to the customer. This part of a hardware start-up lifecycle shows significant differences compared to ventures not dealing with hardware development. The following table shows the performance of the challenges, split into the more significant ones and the less significant:

More significant challenges [weighting]	**Less significant challenges** [weighting]
production of the products **[3,20]**	working with a contract manufacturing company outside of Europe **[2,80]**
finding suitable employees for your start-up **[3,11]**	finding suitable suppliers within Europe **[2,77]**
Prototyping/product development **[3,03]**	gathering relevant feedback from (potential) investors **[2,74]**
finding suitable suppliers outside Europe **[2,96]**	submitting grant applications **[2,68]**
supplier management **[2,88]**	working with a contract manufacturing company in Europe **[2,47]**

Table 9 Breakdown of the examined challenges

The answer possibilities were transformed into a numeric value to enable a numerical analysis. The resulting median value of the challenges was at 2.84 and was used as dividing value for the classification. Challenges that were rated higher, are perceived as more significant and challenges with lower rating as less significant.

5.6 Detailed examination of the challenges.

5.6.1 Prototyping (From the idea to a Minimum Viable Product) & Product Development

The vast majority (88%) of the surveyed start-ups had already developed a minimum viable product at the time of the survey. The Minimum Valuable Product is defined as *"a prototype that is a functional iteration of a product and that allows testing and enables gathering user feedback"* (Crismond DP, 2012) to avoid misunderstandings and distinguish it from a production-ready product that needs to be scalable. Prototyping reached a value of 3,03 and was the third most significant challenge in this study.

The deviation of the planned development time was examined to determine the impact on the time factor, which plays a significant role in a start-up's success chance. This question revealed that the deviation was over 1 year for 21 per cent and 6-12 months

for 28 per cent of the companies. The majority achieved the deviation of 1-6 months, and just 7% had no deviation with less than one month.

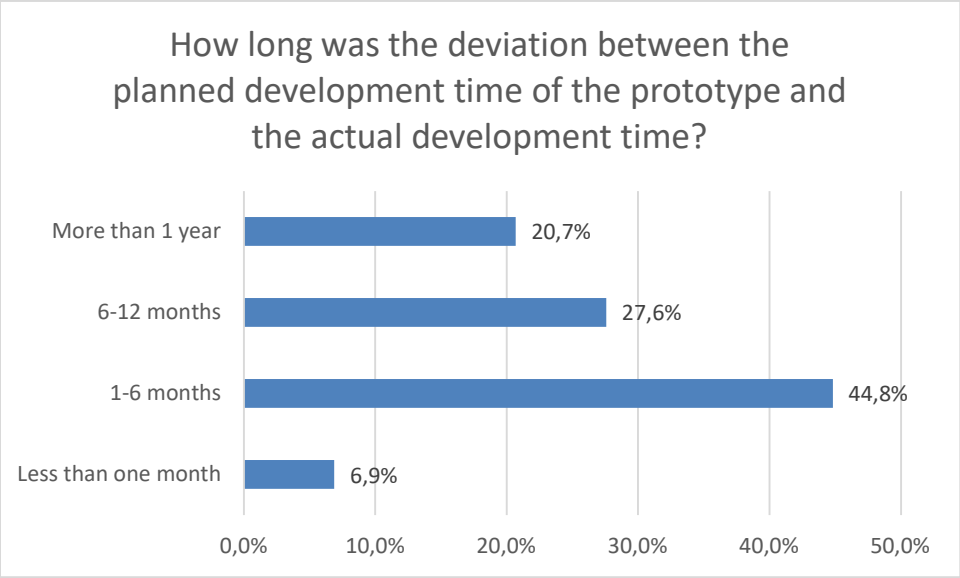

Figure 5 Deviation in prototyping [n=32]

Different data emerged from the question about the development of a product that is ready for production. Only 41% of the start-ups surveyed developed a production ready product. As only these respondents could provide relevant numbers, they were asked about the deviation between the planned development time of the production-ready product and the actual development time. The Figure 6 show no companies that managed to make the development in time and only 23% that were able to keep the deviation between 1-6 months. The vast majority needed 6 months or even longer than one year to reach the production readiness level.

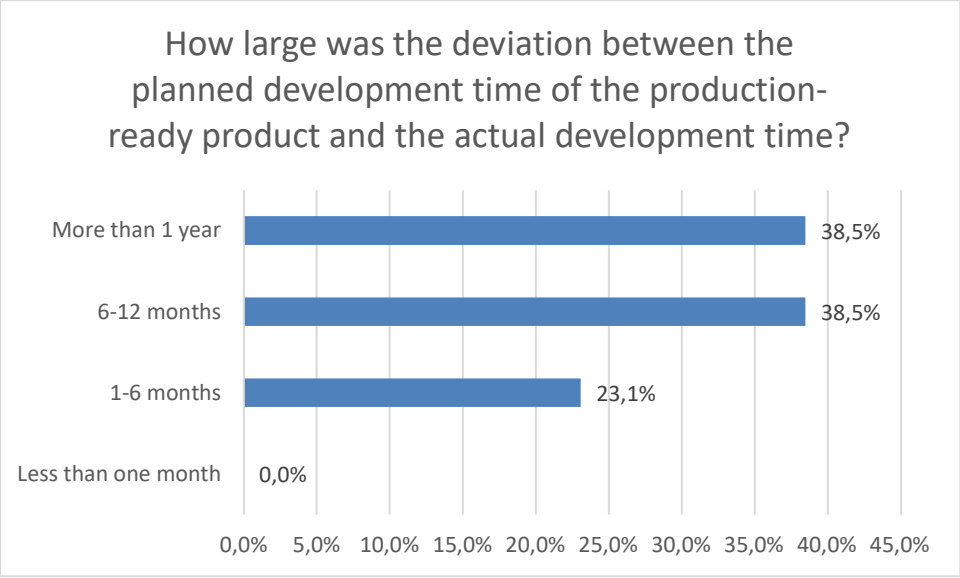

Figure 6 Deviation in product development [N=13]

Additionally, the author of this study used an open question to examine what the biggest challenges were in the context of prototyping. Most of the answers were connected to HR and the resulting lack of know-how and manpower. Other answers touched financing issues and supplier problems. Some of the surveyed stakeholders mentioned rather mindset related issues in cooperation with different stakeholders; there were several answers regarding the somewhat conservative mindset of experts, potential customers, and the certification bodies, which are reticent when it comes to new innovative technology. Three entrepreneurs mentioned problems related to the lack of knowledge at the beginning of the development and having unrealistic expectations or waiting too long with outsourcing of work packages that are not crucial know-how but hard to learn or manage by start-ups in this context.

A question that targeted the identification of the most challenging phase of a hardware venture shows that three quarters of the start-ups perceive the phase between the prototype to a production-ready product as the most challenging. This value makes it the most challenging phase, as only 15% rates the prototyping, and 10% the scaling as the most challenging phase. This result correspondents with the comparison of the two questions that targeted the deviation between the planned and actual time needed for product and prototype development. Moreover, it also confirms the qualitative results, where the financing and planning of production was an omnipresent topic.

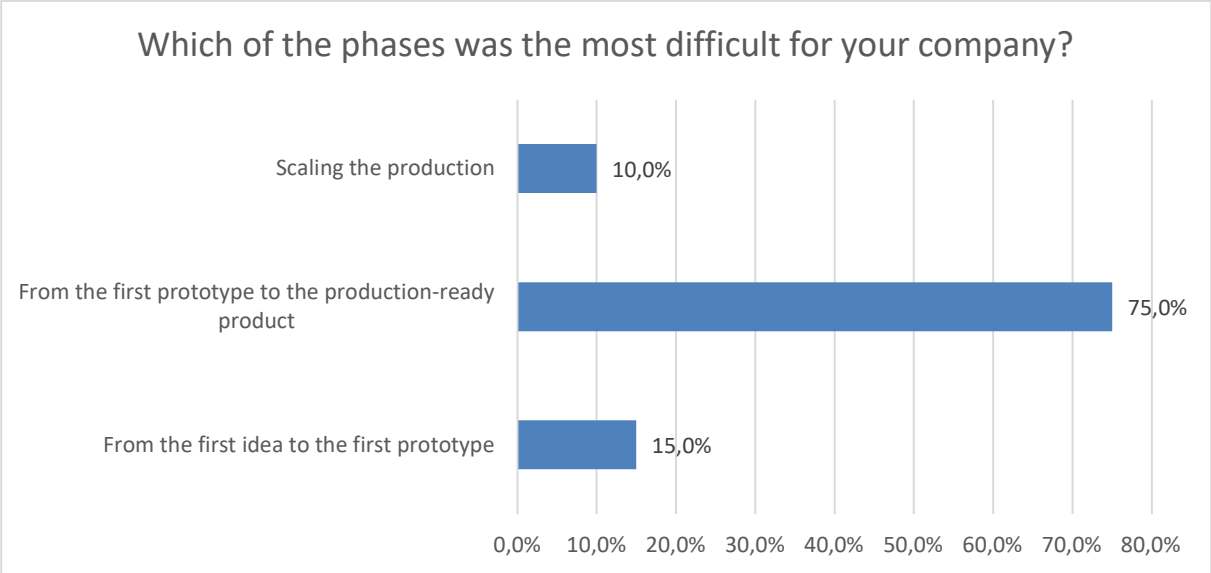

Figure 7 Most difficult phase of your company [n=20]

To assess the influence of growing facilities that allows prototyping (for Example Hackspaces, Makerspaces, Learning- and Teaching factories, …) on the perceived availability of infrastructure, the questions of availability of possibilities to produce a prototype was included in the survey. The statistics of this question show that the companies appreciate and welcome this offer, as 62% assessed the availability as

good or very good. However, just over a third of respondents still indicated that they were not completely satisfied with the availability of such infrastructure.

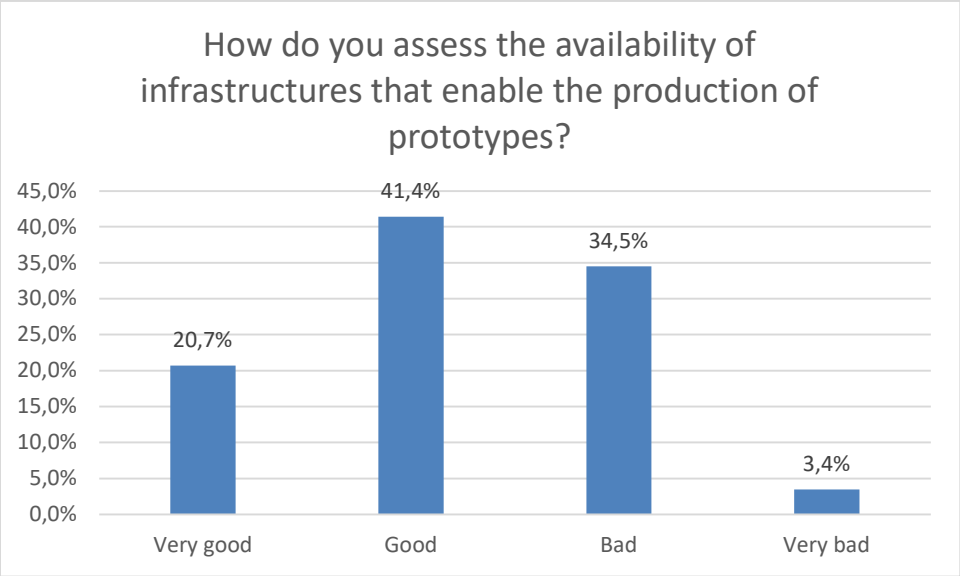

Figure 8 Availability of infrastructures [n=33]

Regarding physical facilities, the entrepreneurs lacked access possibilities to laboratories and machines. The entrepreneurs missed very specific facilities: test sides for optical sensors, electronics, recycling, injection moulding machines and the possibility of certification of different technologies. The need depends strongly on the product which the start-up is developing. Universities were mentioned several times because of a wide variety of equipment. However, the stakeholders complained about the missing accessibility for non-scientific personnel.

5.6.2 Production

As described in the qualitative part, producing a physical product is a cost-intensive matter that requires pre-financing and distinguishes hardware start-ups from other forms of entrepreneurship. Two-thirds of the surveyed start-ups have indicated that they already are close to production or are producing the product. The challenge of managing to produce a product came off the survey as the second major one, behind the HR-related challenges and reached the value of 3,20. Only 10% of the respondents rated this challenge as low; the remaining 90% rated it as very high or high.

The possibilities of production in Europe were examined in the subsequent question and showed that most of the ventures see the potential of producing a physical product in Europe as “good” (40%) or “very good” (35%). The remaining quarter of the respondents has chosen the answer possibility “bad”. 85% of the respondents stated that a contract manufacturing company is used to produce the product. This is not surprising, as outsourcing production is more profitable than investing in an own production facility and know how. As described in section4, only entrepreneurs with a

unique product with a novel production method are forced to set up an own production. This corresponds with the results in this part of the study as only 15% of the entrepreneurs whose product is already in production stated that they are not using contract manufacturing services.

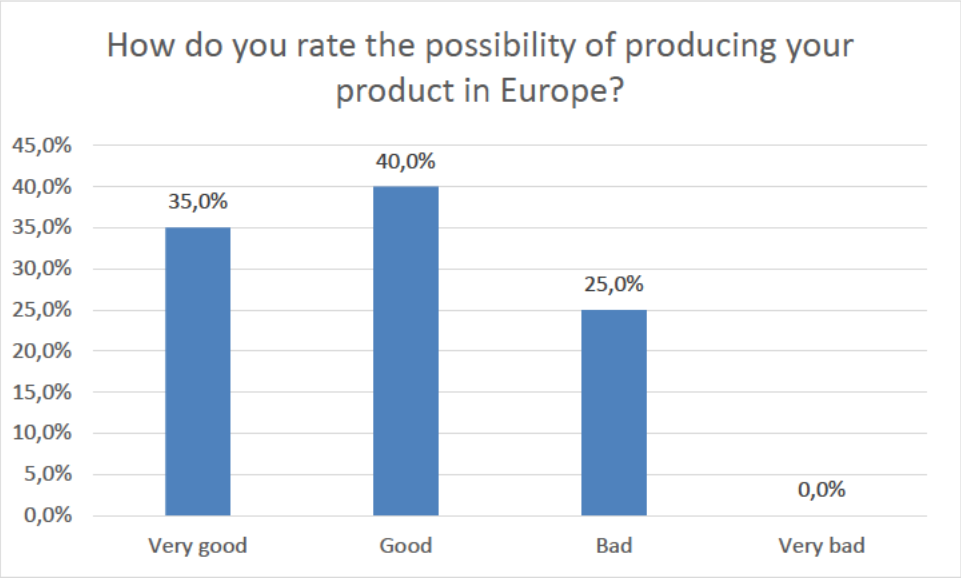

Figure 9 Producing in Europe [20]

The comparison between outsourcing to contract manufacturers outside of Europe and the European ones revealed that outsourcing to non-European countries is perceived as significantly more challenging. This is reflected in the figures as shown in Figure 10.

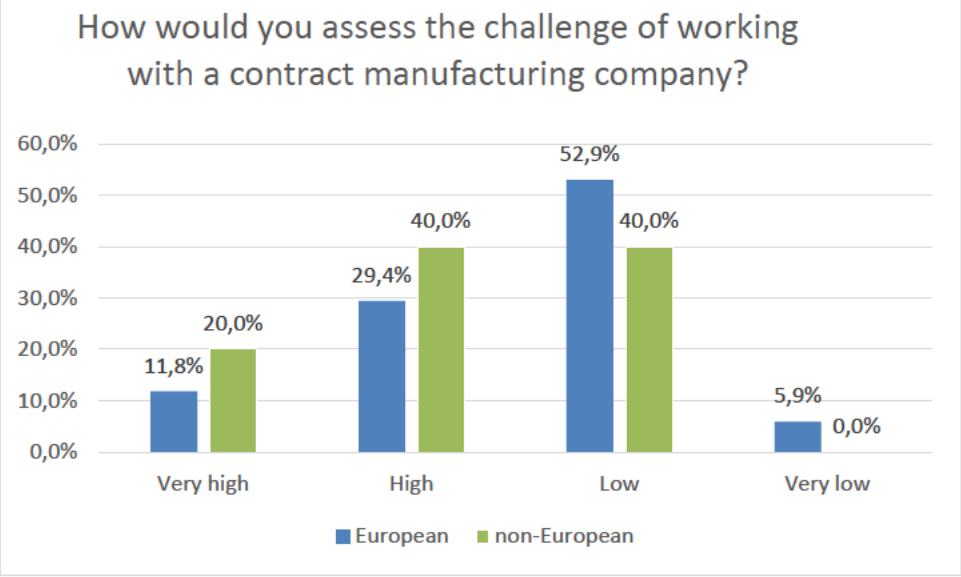

Figure 10 Cooperation with contract manufacturers

The production related challenges were examined in an open question. The answers again showed a significant dependency on external influences. Again, the challenge of

financing was present in the context. A common topic were problems with finding suitable contract manufacturing companies. On the one hand, the challenge is to find ones that are on the technical level that is needed by the entrepreneurs. On the other hand, many contract manufacturers prefer established companies over start-ups due to the unsecure future. Several stakeholders felt that they are perceived as unattractive customers during the search for manufacturers. Another point was the lack of flexibility which is typical for traditional companies in contract manufacturing but also on the supplier side.

5.6.3 Supplier

The already often discussed dependency on external stakeholders also manifests through the reliance on suppliers. Hardware entrepreneurship requires intensive supplier management. Due to the increasing importance of sustainability and social responsibility, supplier management is perceived as a growing challenge even for established companies (Zimmer, Fröhling, & Schultmann, 2016). Accordingly, small companies see themselves confronted with this challenge too. Moreover, interviews in the qualitative part of this thesis revealed that small, young companies have more significant problems with suppliers, as these suppliers tend to focus on established companies that promise higher revenues. The challenge was considered through a general question about assessing the challenges of supplier management.

The question's score was slightly over the median value of all identified challenges with 2,88, and therefore is perceived as a significant issue. The then following question targeted the difference between sourcing from European and non-European suppliers, such as the case of contract manufacturing. The answers show a less challenging collaboration with European companies. It has to be considered here that the questionnaire was conducted during the COVID pandemic. The overall situation was influenced by extreme supply chain issues, which could have affected the current evaluation of the entrepreneurs. Accordingly, the significantly better performance of the European suppliers can be affected by this fact. However, the difference is so substantial that the author assumes it would be similar under "usual" conditions. Moreover, current studies show that companies are re-thinking their supply-chain strategy and try to reduce the sourcing risks by having more suppliers, and some of them even consider the focus on regional suppliers (Patsch, Kames, Mayrhofer, & Schlund, 2021). This means that the financial benefits of non-European suppliers are getting outweighed by risks connected to outsourcing to non-European countries (for example, foreign exchange risk, third party risk,…). Yet, as described in the qualitative part of this study, financial benefits are not always the main driver of outsourcing to non-European countries. Respondent were highlighting the higher speed of development of new electronics as well as injection moulding parts if compared to Europe. Some of the interviewed entrepreneurs claimed that the time for product

development was significantly reduced by collaborating with Chinese or Taiwanese companies.

According to the results of the survey, the companies assess the challenges of finding suitable suppliers in non-European countries as higher, than in the European ones.

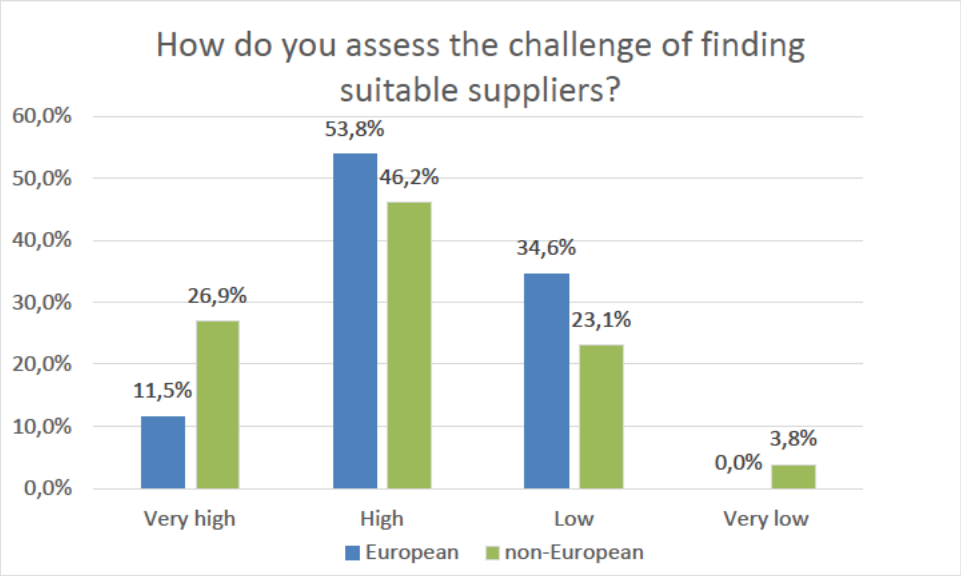

Figure 11 Finding suppliers

Nevertheless, the willingness of suppliers to work with start-ups seems to be a problem in the Austrian and German ecosystem as 46% of the respondents claim that the willingness of suppliers, whether European or non-European, to work together with a start-up is low or very low. The respondents were asked for the major challenges in the subsequent multiple-choice question to reveal the origin of this lack of motivation for working together with start-ups. The main issue identified is the order quantity; 69% see it as one of the major challenges. This result seems to be connected to the second largest answer, which was the delivery time with 54% of respondents. Due to the low attractiveness of customers with low production volumes and relatively insecure future, the suppliers tend to line their orders behind larger volume contracts from known customers. Moreover, the fact that start-ups act very quickly in comparison to SMEs and large corporates could be the cause of this observation. More than one third of the respondents (35%) see the dependence on one supplier as a major challenge. Quality related problems, customer service and sudden changes in the product range were not identified as a significant problem, as they reached less than 16% of the answers.

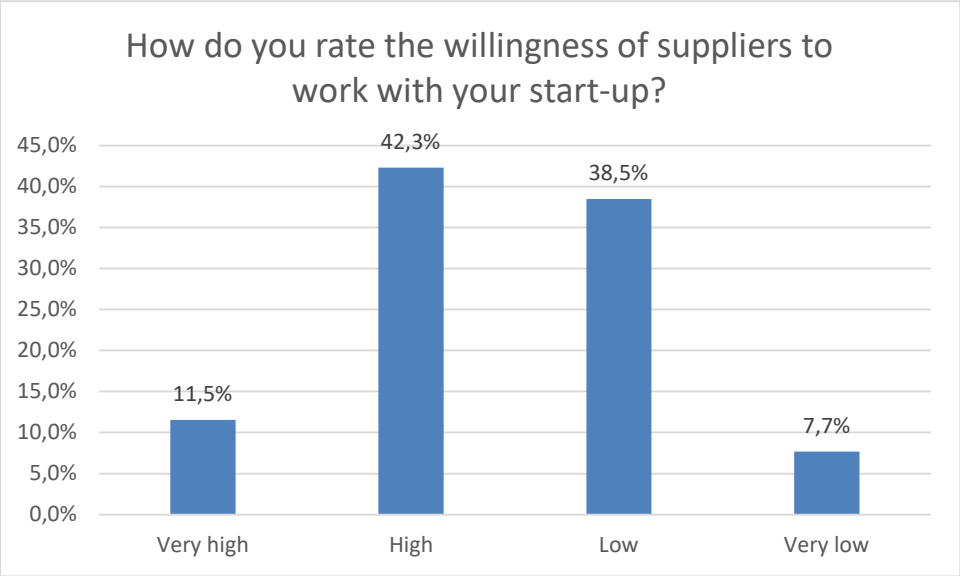

Figure 12 Willingness of suppliers to work with start-ups[N=26]

5.6.4 Grants

A significant part (87%) of the surveyed start-ups made use of subsidies, and this number underlines the availability of grants in the Austrian and German regions described in the previous part of this thesis. Moreover, the hurdle of submitting grant applications was the second least challenging part of hardware start-up existence identified in this thesis, with a score of 2,68.

Contrary to expectations after the qualitative part and literature research, the quantitative method revealed that hardware-based start-ups in the Austrian and German region do not see a significant problem in the availability of funding instruments that are suitable for their business models, as 82% of the respondents rated the availability of subsidises as good or very good, 11% as bad and only 7% as very bad. These results show the subsidies system's strengths, which is a crucial

aspect of the success of these start-up regions and results in a high entrepreneurship movement in this region.

The problems expressed in the succeeding open question targeted mainly the bureaucratic hurdles of the process and the time-consuming process of writing a proposal. Moreover, some respondents mentioned the long waiting times until funding is granted. Another issue mentioned, was the lack of technical understanding of the product or the understanding of the business model by the person(s) in charge of

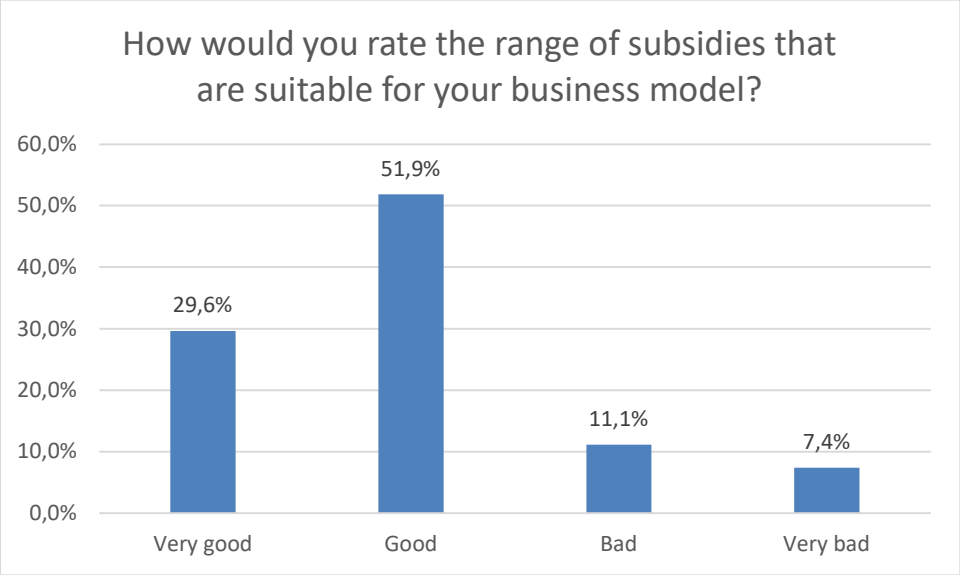

Figure 13 Range of subsidies [n=31]

permitting grants. However, the targeted region is well known for the wide variety of grants available, which was already covered above.

5.6.5 Financing

Financing was identified as one of the major challenges of hardware start-ups and was separated from grants as the assumption was made that the availability of grants is significantly higher than the availability of risk capital. As described in the qualitative section of this thesis, the main issue of start-ups that develop a physical product is the high capital intensity ratio as the business is more capital intensive and less labour-intensive compared to fintech or software start-ups. The availability of incentives in public grants allows bridging the early phase of a start-up. However, at some point, another form of financing is necessary to be able to enter the market. The representatives in the survey were asked to answer a multiple-choice question about their financing sources. Grants, with 87%, were the second most used form of capital behind own resources (94%), the third most common source of money were loans with 32%. Followed by “family, friends, and fools”, with 26%. Striking in this context is that

business angel provided capital to only 19% and venture capital just 13% of the start-ups.

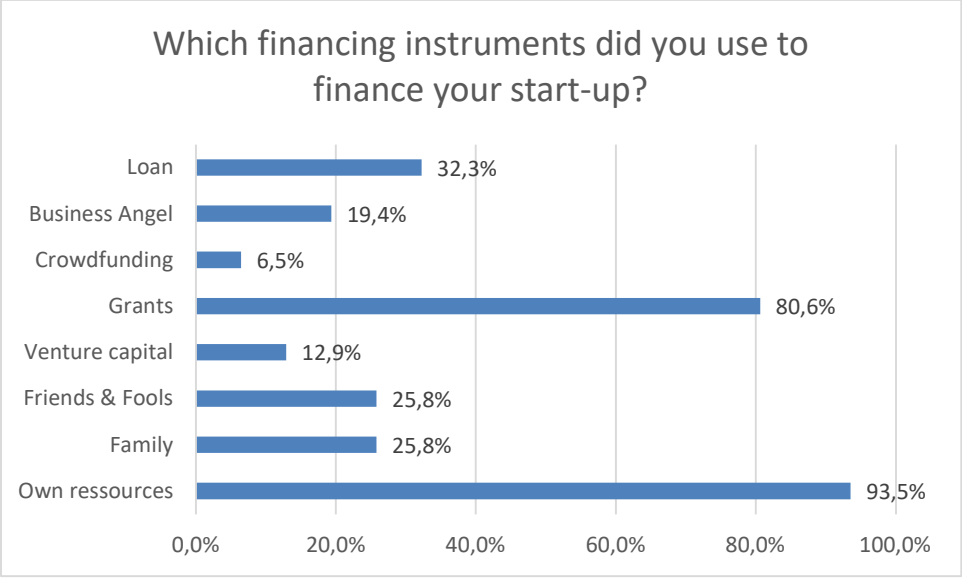

Figure 15 Financing Instruments [n=31]

The problem of investors that are interested in investing in hardware start-ups was one of the major topics in the qualitative part of this study. Correspondingly, this phenomenon was also visible in the results of the quantitative survey, where only 17% assessed the interest of investors to finance a hardware start-up as high. On the other hand, 38% see the interest as low and a vast majority of 45% as very low.

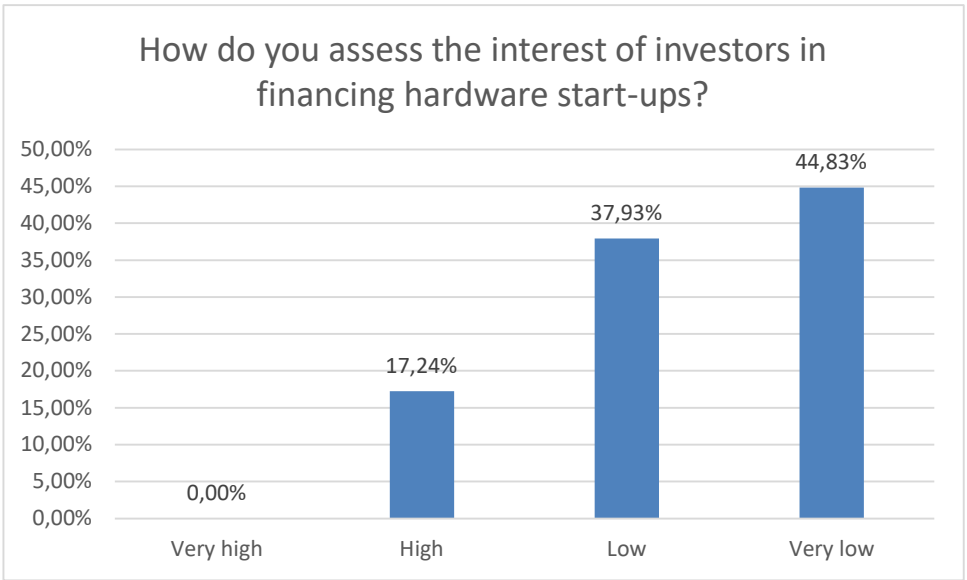

Figure 14 Interest of investors [n=29]

Comparing this result with the question that targets the overall availability of venture capital in the region shows a discrepancy. The surveyed representatives perceive the availability of venture capital significantly better than the interest in financing hardware start-ups. With 42% rating the availability of venture capital as “good” and 3 % as very

good, 55% rate it negative, which is a high percentage, however still a better performance than the previous question.

The next open question supports the theory that investors prefer software-based companies because they are better scalable than hardware and are reticent if it comes to investing in hardware. One-half of the respondents described said challenge, and the high capital intensity and difficult scalability were quoted as explanations. Two respondents claimed that a few venture capital companies are operating in the region, which is a problem if searching for capital. One of them expressed his opinion of start-ups relying on subsidies, which contrasts the USA and China, where business angels and venture capital companies carry the start-up development.

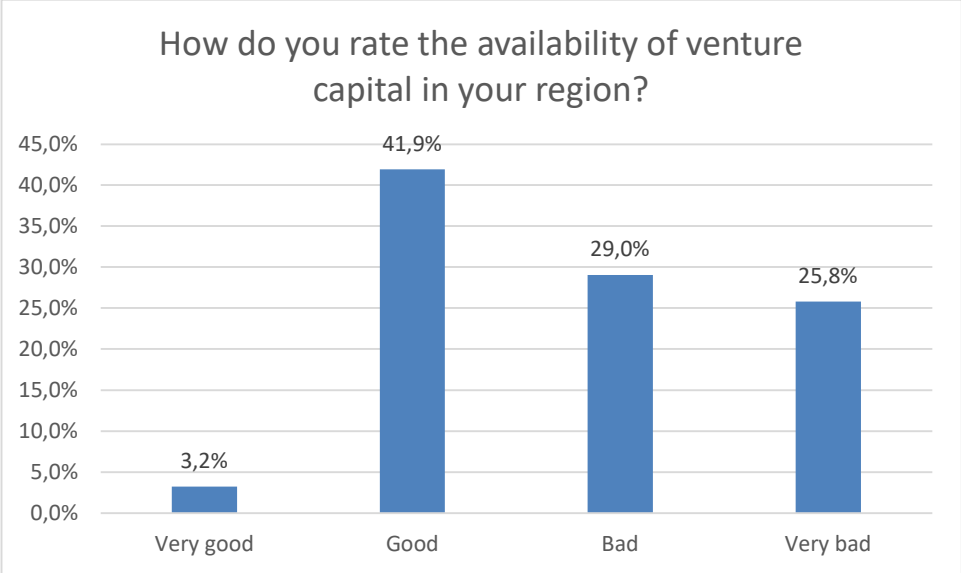

Figure 16 Availability of Venture Capital [n=31]

Besides the apparent reasons for the high relevance of financing challenges, the qualitative part of this thesis detected a challenge in getting valuable feedback from investors. As the exchange with customers and investors is precious and essential for start-ups in general, and in particular for hardware start-ups, the identified lack of feedback had to be investigated in the quantitative part of the study. The relevance of this question was underpinned by the statements of the Venture Capital and Angel Investor stakeholders that both highlighted the importance of a sound financing strategy.

The results of the quantitative study showed that this challenge is not perceived as one of the most relevant ones by the entrepreneurs; it reached the score of 2,74, which

puts it among the less relevant challenges. Still, just under two-thirds of the surveyed companies rated the challenge of getting feedback from investors as very high or high.

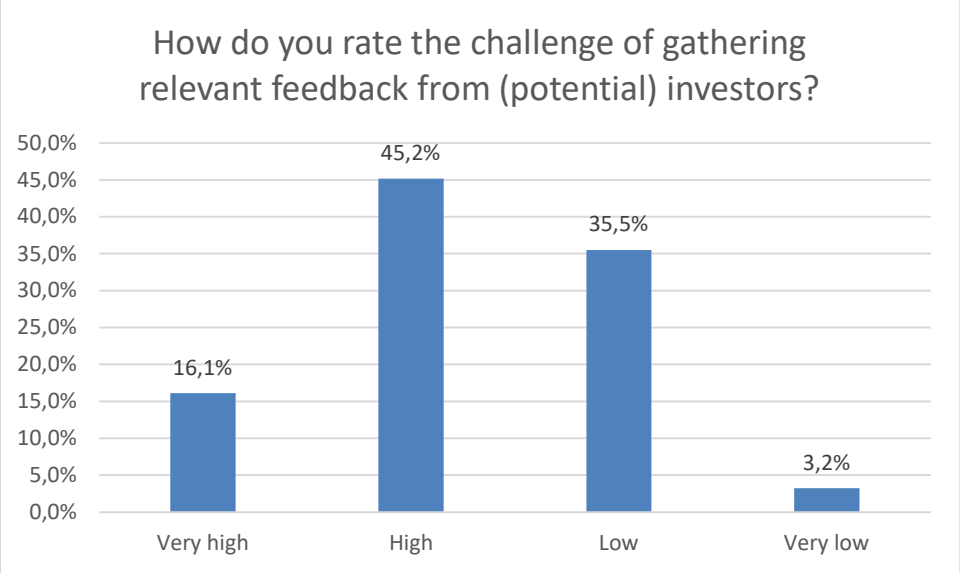

Figure 17 Getting relevant feedback [n=31]

5.6.6 Ecosystem

The qualitative interviews revealed several weak points of the hardware entrepreneurship ecosystem. One of the recurring topics was the lack of possibilities to exchange with experienced entrepreneurs that already managed to establish a hardware accompany. The entrepreneurs were seeking some mentoring that is backed by real-business experience, some of them mentioning too theoretical trainings in the existing programmes, accelerators, and incubators, that are usually held by people without a significant business experience. Some of the interviewed representatives missed an ecosystem and stated that there is no hardware specific one in the region.

The questions of the quantitative part targeted the overall possibility of exchange with stakeholders from the ecosystem. Around one third of the representatives rated these as negative and around 64% as positive.

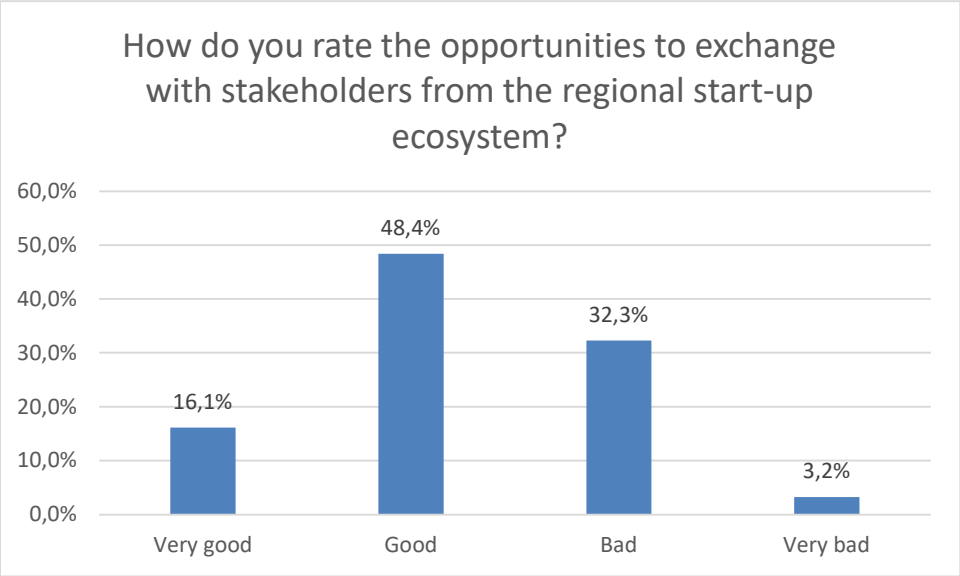

Figure 18 Exchange with stakeholders [n=31]

The subsequent question targeted the practical relevance of the programmes which are offered in the ecosystem. This indicator performed poorly with 39% rating it as low and 13% as very low. Slightly over a third of the respondents saw the offerings of high relevance and 13% of very high relevance. The results show a very split experience by the start-ups. This corresponds with the statement of Stakeholder 1 in the quantitative interview, who identified the difficulty of finding good support, more significant than the lack of existing supportive programmes.

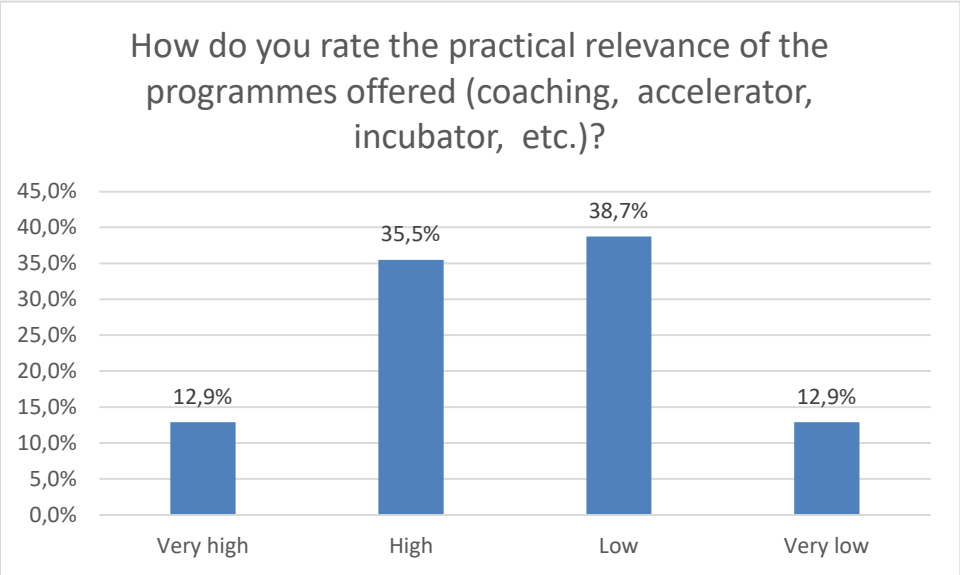

Figure 19 Practical relevance of programmes [n=31]

The percentage of companies that participated in an accelerator or incubator programme was 74% which is a high share. To test the influence of start-ups that had no previous experience with an incubator or accelerator, the author filtered out the companies that stated that they were not participating in any of the aforementioned

programmes. This categorisation led to a slightly better performance; however it still remained the second worst performing indicator after the availability of venture capital in the region.

To understand this performance, two subsequent open questions examined the positive and negative aspects of participating in such a programme. The prevalent answers on the positive side referred to the networking possibility, which was also mentioned during the qualitative part of the study. Only a few start-ups mentioned content relevant topics and the contacts to relevant subsidiary entities and investors. The negative aspects were very diverse; several stakeholders mentioned the lack of contact with relevant customers and investors, and the time consumption of such a programme was also a recurring answer. Moreover, the stakeholders identified the theoretical orientation and support by people with no real-live experience with bringing a product on the market or running a business as a problem. One stakeholder identified the issue of *"trying to make a businessman out of a technician"*, which is counterproductive and takes time. They suggested a model where business-oriented people are "lent" on an interim basis to the start-up, and the technicians can focus on the technical product development.

5.6.7 Human Resources

The survey revealed that the challenge of finding suitable employees for a start-up was the second most challenging aspect, with a total numeric value of 3,11 of maximum of 4. Moreover, the open questions in the quantitative part often named the problem of the availability of personnel that is either skilled in a specific technical domain or that is business oriented. The qualitative part identified the origin of this issue in the fact that often hardware start-ups are very technology driven and the founder(s) are usually rather technology oriented. For such a homogenous team it is often a struggle to find a member from a completely different area of expertise. A possible reason would be that business-oriented employees which could be suitable as candidates for hardware ventures, tend to work for software or fintech ventures; for the same reason as investors. Namely because hardware is capital intensive and hard to scale.

One third of the respondents rated the challenge of finding suitable employees for their venture as very high and 46% as high which is a clear indicator for a challenge.

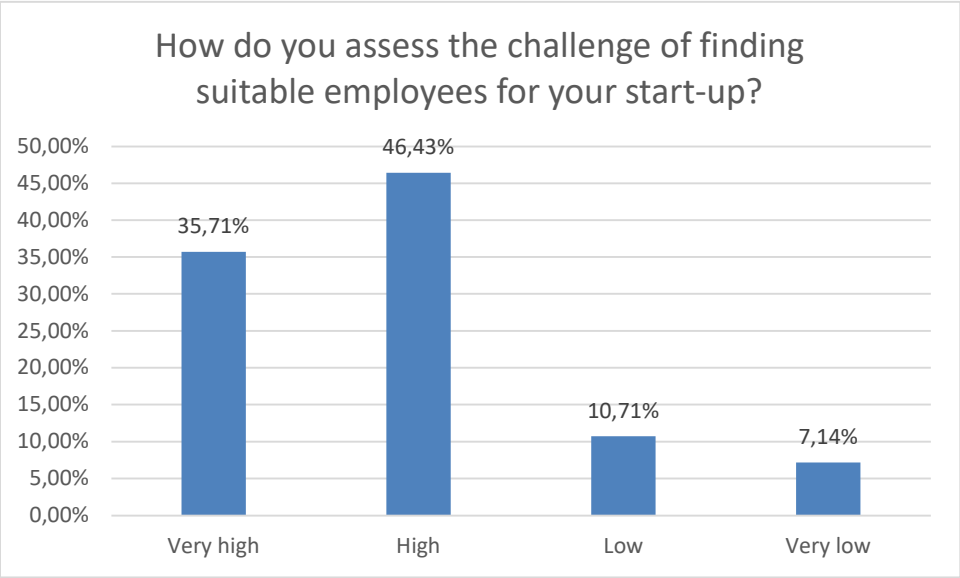

Figure 20 Finding suitable employees [n=26]

6 Conclusion

This work aims to identify relevant challenges hardware start-ups face and examines the internal and external impact that cause these challenges. Due to their cultural, linguistic and economic proximity, the geographical regions this study focuses on are Germany and Austria. The focus lies on the general overview of the challenges, as well as on hardware start-up specific tasks in product development, quality assurance, certification, patenting, supplier management, testing, capital expenditure and team composition.

Given the existing research landscape regarding this topic, the decision fell on a mixed-method approach, combining semi-structured qualitative interviews with a quantitative study. The semi-structured interviews were analysed with the inductive category creation to get a systematic overview of challenges faced by hardware entrepreneurs. Subsequently, the quantitative online survey helped assess the relevance of the examined challenges and shortages in the ecosystem.

6.1 Findings

The results of the research questions are presented in turn:

- What are the main challenges that hardware start-ups from Austria and Germany face in their life cycle?

The interviewed experts expressed a diverse spectrum of problems entrepreneurs face in their ventures. In general, the high multi-disciplinarity leads to a dependency on external companies and a high demand for skilled workers. These two overreaching topics prevail throughout the different challenge categories identified; the technological dependency on external companies is summarised in the second research question.

The quantitative study demonstrates the relevance of challenges linked with the business domain of human resources. Especially the areas of expertise not directly linked to the technological aspects of the venture turned out to be problematic for the team composition. Business strategy and finance tasks, both of which are primarily of interest to investors, are often tackled on the side by the founders, who usually lack the necessary skill set. This leads to problems and discrepancies in expectations between investors and entrepreneurs. This challenge is not only caused by the overall situation in the labour market, as the group dynamic and psychological aspects seem to play a role as well. The study identified an aversion against non-technological hires by team members with a technological background. This phenomenon was described during several interviews with start-up representatives.

Furthermore, financing with private equity turned out to be a significant issue for hardware start-ups. The background of the aversion of Venture Capitalists, Business

Angels and other investors is based on the lack of acceptance of a long development cycle and the high capital intensity. However, the cooperation with investors reveals tension on both sides. Investors are indeed more interested in more easily scalable business models such as software as a service, while hardware entrepreneurs typically have very naive ideas about how to finance their start-ups.

- What are the unique problems that distinguish hardware start-ups from other ventures?

A challenge that distinguishes software-based start-us from hardware ones is the needed capital. The capital intensity of a hardware venture is very high due to the needed sourcing of components and services on the one hand and due to the production of physical products on the other hand. The high capital required in hardware start-ups can also be attributed to the high multi-disciplinarity and can be linked with the dependency on external companies and the demand for skilled workers described above.

Entrepreneurs often expect a single investment to finance their entire production and development work, while investors expect a clear strategy in which their investment is only one part of the plan. The requirements for the hardware companies are therefore extremely high, especially regarding the fact that customers only want to pay in advance when there is a product or when they have a specific guarantee. Not having a resilient guarantee for orders is the case for start-ups, as they usually neither have any production-ready products nor the production possibility during the cost-intensive phase between a prototype and a developed product. A usual escape from this situation is a collaboration with an established company, acting as a pilot customer or selling partner.

As described above, the overreaching challenge of entrepreneurs is to handle the variety of tasks in a hardware venture. The existing start-up ecosystem and infrastructure is typically well prepared for ventures in the areas of software and fintech. However, a typical hardware business model requires an interplay of software development activities with the diversity of physical product development.

The biggest identified challenge in the examined field, is connected to the development of a production-ready product and its scaling. The quantitative survey illustrates that the main deviations leading to a long time to market are between the first prototype and a production-ready product. Ventures need to successfully combine various soft and hard skills to pass this stage. This forces the entrepreneurs into multiple make or buy decisions and the question of crucial know-how and outsourcing.

- What are hurdles related to the development phase between the first physical prototype and the mass production?

The hypothesis about the relevance of this development phase in the hardware start-up lifecycle was confirmed by the fact, that it is the source of major deviations from the planned time-to-market. Accordingly, the challenges from this phase are crucial for success.

Closely connected to the previous research question's answer (make or buy decisions) is the challenge of supplier management. In contrast to other ventures, hardware start-ups are forced to outsource from a very early stage. This early dependence on other firms leads to the need for good supplier management and the ability to cooperate with those. However, the collaboration with suppliers is often problematic as they prefer to work with established companies and often lack agility. In supplier management, sourcing parts brings about the problem of minimum order quantities and quantity discounts that are not reachable for a small batch producing start-up. Moreover, sourcing parts and materials has to be done in a strategic way to avoid downtimes due to changes in the suppliers' product range. This problem intensified during the pandemic, as suppliers cancelled product groups without announcement.

Additionally, the certification of a product to fulfil normative standards was identified as a major issue in most of the ventures. The study's results show that a significant part of available resources must be invested to ensure that all the necessary standards are fulfilled and documented. Certification requires developing and integrating a complex process, which is highly challenging for a young company.

- What demand do hardware start-ups have in terms of infrastructure to be able to master the identified challenges?

Overall, the infrastructure demand of the examined start-ups is aligned with the significant challenges described above. The most dominant gap in the ecosystem is in certification. Certification is a part of the critical phase of a venture, namely the transformation of the first prototype into a production-ready product and thus represents another part of the business which is highly dependent on external influences. The stakeholders missed the availability of testing facilities as well as the possibility of getting information on the development of standard-compliant products. Although some cooperation between certification bodies and start-ups are already in place, the overall perception in the quantitative study was, that there are not enough possibilities to get a product ready for certification.

In addition, the availability of supporting institutions such as accelerators, incubators and similar offerings was not perceived as problematic. However, the support programmes available are usually very theoretical and are not designed to develop physical products. Entrepreneurs need to quickly identify which support is good and which does not help them to further develop. Additionally, a lack of networking opportunities with a hardware thematic focus was identified. Formal mentoring

possibilities with successful hardware entrepreneurs could provide a good way of supporting upcoming entrepreneurs.

6.2 Limitation of the Study

This study examines the challenges of hardware start-ups in the Austrian and German area, respectively the created categories cannot be applied for other geographical regions. Especially considering the unique ecosystem of subsidies in both countries. However, the author expects the areas of product development and business development to be similar in other regions.

The mentioned aspects of multidisciplinary orientation and its influence on the start-up's success are especially considering hardware entrepreneurship from the business and technological development perspective, it is not covering the psychological aspects of individuals of this phenomenon.

Human resources were identified as one of the major issues in this study, however the sampling of the study was limited to stakeholders from the ecosystem and entrepreneurs, a perspective of potential employees in general and employees with a certain know-how and their motivation to work for a hardware start-up is a possible topic for subsequent studies.

The relationships between different stakeholders were obtained only from the perspective of start-up entrepreneurs and investors. The study did not examine the interactions with start-ups from the perspective of manufacturing companies or suppliers, this perspective could indicate the differences between the stakeholders in a subsequent work.

The influence of the global pandemic has to be considered especially in regard to the topic of sourcing. The global supply chain situation was extremely strained during the study; this consequently led to a rather negative perception of the overall situation. The long-term perception could differ from the results in this thesis.

The share of B2B was significantly higher than the share of B2C Start-ups, this fact influences the results especially in regards to marketing strategy.

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8 List of figures

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10 Appendix

10.1 Qualitative Part

10.1.1 Start-up questionnaire

Section 1 (Introduction)

1) Briefly describe your company, where are you standing now, what is your product or service?
2) What is your role in your company
3) How many employees does your company have?
4) When did you start your company?

Section 2 (Main part)

5) What have been the major challenges in your entrepreneurial activities?
6) What challenges do you have or have had that you think other start-ups that do not develop physical products have not had?
7) What were the challenges in product development?
8) How did you fare in sourcing components in terms of suppliers?
9) Have you certified your product?
    a. What were the challenges in the certification process?
10) Have you already produced your product?
    a. Did you take over or outsource the production?
    b. What were the challenges in terms of production?
    c. What batch sizes were produced and what was the impact on
11) Have you patented your product?
    a. What were the challenges in the patenting process?

12) What were the challenges in relation to the team and the HR management?
13) What were the challenges in finding investors?
14) What were the challenges in funding with grants?
15) How do you distribute your product and what challenges do you face in sales?
16) How does the customer service work?
17) Were there any problems with a vendor lock in?

Section 3 (Closing)

18) What would you have liked to see in the German and/or Austrian start-up scene that would help you overcome the hurdles mentioned?
19) Do you have any further comments on the subject?

10.1.2 Stakeholder Questionnaire

Section 1 (Introduction)

1) Briefly describe your position in the Austrian (German) start-up ecosystem.
2) Which hardware start-ups, i.e. those that develop a physical product, have you already worked with or got to know?

Section 2 (Main part)

3) What do you think are challenges hardware start-ups face that differentiate them from other entrepreneurs?
4) In your opinion, what is the typical reason for the failure of a hardware start-up in Austria and Germany?
5) What support are hardware start-ups typically looking for?
6) What factors are decisive for you when you evaluate a HW start-up or when you think about potential cooperation?
7) Are there typical mistakes that are made by entrepreneurs or people in charge in the hardware start-up scene and what are they?

Section 3 (Closing)

8) Which services or which facilities would favour successful hardware start-ups in Austria/Germany?
9) Do you know of institutions or programmes from abroad that support hardware start-ups that are lacking in the Austrian or German scene?

10.1.3 Participants informed consent (GER)

Sehr geehrte_r Interviewpartner_in!
Im Rahmen meines Masterstudiums Wirtschaftsingenieurwesen - Maschinenbau an der Technischen Universität Wien (in der Folge kurz als „TU Wien“ bezeichnet) arbeite ich gerade an meiner Masterarbeit.
Das Verfassen dieser wissenschaftlichen Arbeit ist mit der Erhebung und Verwendung personenbezogener Daten verbunden.
Die Verarbeitung personenbezogener Daten hat in Entsprechung der geltenden Datenschutzbestimmungen zu erfolgen, daher darf ich gemäß Art 13 Datenschutz-Grundverordnung (DSGVO) über die Datenverarbeitung informieren wie folgt:
Verantwortliche_r für die Datenverarbeitung
1. Interviewer_in, Verfasser_in der Masterarbeit und Verantwortliche_r für die Datenverarbeitung iS von Art 4 Zif 7 DSGVO

David Kames
2. Kontaktdaten

David Kames

Kaunitzgasse 35/12
1060 Wien
David.kames@eitmanufacturing.eu
Gegenstand der Masterarbeit
1. Titel der Masterarbeit

Identification and Analysis of Specific Challenges of Hardware Startups
2. Beschreibung der Masterarbeit

Ziel der Arbeit ist es, relevante Herausforderungen von Hardware-Start-ups in der deutschen und österreichischen Region sowie die internen und externen Einflüsse, die diese verursachen, zu identifizieren. Der Fokus liegt dabei auf Hardware-Startup-spezifischen Aufgaben in den Bereichen Produktdesign, Produktentwicklung, Qualitätssicherung, Zertifizierung, Patentwesen, Lieferantenmanagement, Produkttesting, Kapitaleinsatz und Teamzusammensetzung.
Art der verarbeiteten personenbezogenen Daten
Folgende personenbezogene Daten zu Ihrer Person werden im Rahmen meiner wissenschaftlichen Arbeit verarbeitet:
- berufliche Tätigkeit

Aufnahmen, nämlich
- Videoaufnahmen
- Tonaufnahmen

Zweck der Datenverarbeitung
Das qualitative Interview wird mittels der sogenannten induktiven Methode ausgewertet. Das bedeutet, dass der transkribierte Inhalt des Interviews für die Bildung von Kategorien verwendet wird. Entsprechend der Forschungsfrage werden hauptsächlich die Herausforderungen, mit denen junge Unternehmen konfrontierts werden kategorisiert. In weiterer folge werden diese Kategorien für eine quantitative Erhebung und für die Analyse der Ergebnisse verwendet.
Beschreibung der Datenverarbeitung
Das Interview wird mit einem Tonaufnahmegerät aufgezeichnet, im Falle von Online-Interviews wird die Aufnahmefunktion der jeweiligen Plattform verwendet. Im Anschluss werden die Interviews vom Interviewer transkribiert und ausgewertet. Für die weitere Auswertung der Interviewtexte werden alle Angaben, die zu einer Identifizierung der Person führen könnten, pseudonymisiert oder aus dem Text entfernt. In der Masterarbeit werden Interviews nur in Ausschnitten zitiert, um gegenüber Dritten sicherzustellen, dass der entstehende Gesamtzusammenhang von Ereignissen nicht zu einer Identifizierung der Person führen kann. Personenbezogene Kontaktdaten werden von Interviewdaten getrennt für Dritte unzugänglich aufbewahrt.
Rechtsgrundlage
Die Rechtsgrundlage zur Verarbeitung dieser personenbezogenen Daten stellt Art 6 Abs 1 lit c DSGVO in Verbindung mit § 81 für Diplomarbeiten UG dar.

Art 6 Abs 1 lit c DSGVO normiert die Verarbeitung personenbezogener Daten zur Erfüllung einer rechtlichen Verpflichtung, der die_der Verantwortliche unterliegt. §§ 80ff UG stellen die rechtliche Verpflichtung dar. Es wird je nach Art der wissenschaftlichen Arbeit unterschieden:

- • § 80 UG betrifft die Bachelorarbeit (Art 6 Abs 1 lit c DSGVO iVm § 80 UG);
- • § 81 UG betrifft Diplom- und Masterarbeiten (Art 6 Abs 1 lit c DSGVO iVm § 81 UG);
- • § 83 UG betrifft Dissertationen (Art 6 Abs 1 lit c DSGVO iVm § 83 UG)

Die datenschutzrechtliche Rechtfertigung für die Verarbeitung der Daten ist nicht die Einwilligung der Betroffenen.
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An folgende Empfänger_innen oder Kategorien von Empfänger_innen werden Ihre personenbezogenen Daten zulässigerweise übermittelt oder können übermittelt werden:
- an die betroffene Universität (TU Wien), insbesondere der/dem Betreuer_in der wissenschaftlichen Arbeit und dessen Mitarbeiterstab
- positiv beurteilte Masterarbeit an die Universitäts-Bibliothek der TU Wien, Resselgasse 4, 1040 Wien, zum Zwecke der Veröffentlichung gemäß Art 6 Abs 1 lit c DSGVO iVm § 86 Universitätsgesetz (UG)
- an die EIT Manufacturing East GmbH, Christine-Touaillon-Straße 11/29, 1220 Wien
- an EIT Manufacturing, 2 Boulevard Thomas Gobert,91120 Palaiseau, France
o Recht auf Auskunft über die betreffenden personenbezogenen Daten (Art 15 DSGVO)
o Recht auf Berichtigung (Art 16 DSGVO) oder Löschung (Art 17 DSGVO) oder auf Einschränkung der Verarbeitung (Art 18 DSGVO) unter den in den angeführten Bestimmungen beschriebenen Voraussetzungen
o Recht auf Beschwerde, welche bei der Österreichischen Datenschutzbehörde, Barichgasse 40-42, 1030 Wien, Telefon: +43 1 52 152-0, E-Mail: dsb@dsb.gv.at als zuständige Aufsichtsbehörde einzubringen ist.

Speicherdauer
Zum Nachweis der guten wissenschaftlichen Praxis sowie für die Nachprüfbarkeit der gewählten Methode und der erzielten Ergebnisse, wird die Protokollierung und die Dokumentation des wissenschaftlichen Vorgehens auf haltbaren und gesicherten Datenträgern gespeichert. Dies erfolgt datenschutz-konform und gegenüber Dritten unzugänglich. Die Datenspeicherung richtet sich nach den gesetzlichen

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Zur Geltendmachung Ihrer Rechte wenden Sie sich an mich wie folgt:
David Kames
Kaunitzgasse 35/12
1060 Wien
david.kames@eitmanufacturing.eu

10.2 Quantitative Part

10.2.1 Online Survey

	Frage
1	Was ist die Ausrichtung Ihres Geschäftsmodells?
2	Welcher Branche lässt sich Ihr Start-up zuordnen?
3	In welchem Land wurde Ihr Start-up gegründet?
4	In welchem Jahr wurde Ihr Start-up gegründet? (juristische Gründung)
5	Ist die Entwicklung eines physischen Produktes Teil des Geschäftsmodells?
6	Was waren die größten Herausforderungen in Ihrer bisherigen unternehmerischen Tätigkeit? (Mehrfachauswahl)
7	Wo sehen Sie die größten Lücken im Beratungsangebot? (Mehrfachauswahl)
8	Wie bewerten Sie die Herausforderung Förderanträge zu stellen?
9	Haben Sie Förderinstrumente in Anspruch genommen?
10	Wie bewerten Sie das Angebot an Förderungen, die für Ihr Geschäftsmodell geeignet sind?
11	Was waren die Herausforderungen bei der gesamten Inanspruchnahme des Förderinstrumentes?
12	Wie bewerten Sie die Verfügbarkeit von Risikokapital in Ihrer Region?
13	Wie bewerten Sie das Interesse von Investoren an der Finanzierung von Hardware-Start-ups?
14	Welche Finanzierungsinstrumente haben Sie für die Finanzierung Ihres Start-ups in Anspruch genommen? (Mehrfachauswahl)
15	Haben Sie bereits einen Prototyp (Minimum Valuable Product) entwickelt? (Unter Prototyp wird eine funktionsfähige Iteration eines Produktes verstanden, die es ermöglicht schnell Nutzerfeedback zu bekommen und erste Tests zu machen)

16 Wie bewerten Sie die Herausforderung bei der Prototypenentwicklung (MVP)?

17 Wie groß war die Abweichung zwischen der geplanten Entwicklungszeit des Prototypen und der tatsächlichen Entwicklungszeit?

18 Wie bewerten Sie das Angbeot von Infrastrukturen, die die Herstellung von Prototypen ermöglichen?

19 Was waren die größten Probleme bei der Prototypenentwicklung?

20 Zu welchen Infrastrukturen (Geräten) hatten Sie keinen oder nur erschwerten Zugang?

21 Haben Sie bereits ein produktionsfertiges Produkt entwickelt? (Unter produktionsfertig wird ein Produkt verstanden, das alle notwendigen Normen und Qualitätsstandards efüllt und produziert werden kann)

22 Wie groß war die Abweichung zwischen der geplanten Entwicklungszeit des produktionsfertigen Produktes und der tatsächlichen Entwicklungszeit?

23 Sind Sie kurz vor der Produktion oder produzieren Sie bereits ein physisches Produkt?

24 Wie bewerten Sie die Herausforderungen bei der Produktion der Produkte?

25 Wie bewerten Sie die Möglichkeit Ihr Produkt in Europa zu produzieren?

26 Welche der Phasen war für Ihr Unternehmen die schwierigste?

27 Wird zur Herstellung des Produktes ein Auftragsfertiger benötigt?

28 Wie bewerten Sie die Herausforderung mit einer Auftragsfertigungsfirma in Europa zu arbeiten?

29 Wie bewerten Sie die Herausforderung mit einer Auftragsfertigungsfirma außerhalb von Europa zu arbeiten?

30 Was war für Sie die größte Herausforderung in der Phase der Produktion?

31 Haben Sie mit Zulieferern zusammengearbeitet?

32 Wie bewerten Sie die Herausforderung des Lieferantenmanagements?

33 Wie bewerten Sie die Herausforderung geeignete Zulieferer außerhalb von Europa zu finden?

34 Wie bewerten Sie die Herausforderung geeignete Zulieferer innerhalb von Europa zu finden?

35 Wie bewerten Sie die Bereitschaft von Zulieferern mit Ihrem Start-up zusammenzuarbeiten?

36 Worin sehen Sie die größten Herausforderungen bei der Zusammenarbeit mit den Zulieferern?

37 Wie bewerten Sie die Möglichkeiten sich mit Stakeholdern aus dem Ökosystem auszutauschen?

38 Wie bewerten Sie die Praxisrelevanz der angebotenen Programme (Coaching, Accelerator, Inkubator, etc.)?

39 Haben Sie an einem Accelerator- oder Inkubator-Programm teilgenommen?

40 Nennen Sie die positiven Aspekte des Accelerator-/Inkubator-Programmes.

41 Nennen Sie die negativen Aspekte des Accelerator-/Inkubator-Programmes.

42 Wie bewerten Sie die Herausforderung passende Angestellte zu finden?
43 Wie bewerten Sie die Herausforderung relevantes Feedback von (potenziellen) Investoren einzuholen?

44 Was ist Ihre Position? Welche Aufgaben übernehmen Sie im Unternehmen?

10.2.2 Participants informed consent (GER)

Einwilligungserklärung gemäß Datenschutz für eine Umfrage zum Thema „Identification and Analysis of Specific Challenges of Hardware Startups“

Sehr geehrte_r Studienteilnehmer_in! Im Rahmen meines Masterstudiums Wirtschaftsingenieurwesen - Maschinenbau an der Technischen Universität Wien (in der Folge kurz als „TU Wien“ bezeichnet) arbeite ich gerade an meiner Masterarbeit.

Das Verfassen dieser wissenschaftlichen Arbeit ist mit der Erhebung und Verwendung personenbezogener Daten verbunden.

Die Verarbeitung personenbezogener Daten hat in Entsprechung der geltenden Datenschutzbestimmungen zu erfolgen, daher darf ich gemäß Art 13 Datenschutz-Grundverordnung (DSGVO) über die Datenverarbeitung informieren wie folgt:

Verantwortliche_r für die Datenverarbeitung

Verfasser der Masterarbeit und Verantwortlicher für die Datenverarbeitung iS von Art 4 Zif 7 DSGVO David Kames

Kontaktdaten: David Kames, Kaunitzgasse 35/12, 1060 Wien; david.kames@eitmanufacturing.eu

Die Befragung ist freiwillig und wird anonym durchgeführt

Gegendstand der Masterarbeit

Titel der Masterarbeit: Identification and Analysis of Specific Challenges of Hardware Startups

Beschreibung der Masterarbeit: Ziel der Arbeit ist es, relevante Herausforderungen von Hardware-Start-ups in der deutschen und österreichischen Region sowie die internen und externen Einflüsse, die diese verursachen, zu identifizieren. Der Fokus liegt dabei auf Hardware-Startup-spezifischen Aufgaben in den Bereichen Produktdesign, Produktentwicklung, Qualitätssicherung, Zertifizierung, Patentwesen, Lieferantenmanagement, Produkttesting, Kapitaleinsatz und Teamzusammensetzung.

Art der verarbeiteten personenbezogenen Daten

berufliche Tätigkeit>

Ausbildung

Zweck der Datenverarbeitung

Überprüfung der im Rahmend der bisherigen Arbeit aufgestellten Hypothesen.

Bewertung der Relevanz von einzelnen Herausforderungen für innovative Unternehmen

Rechtsgrundlage

Die Rechtsgrundlage zur Verarbeitung dieser personenbezogenen Daten stellt Art 6 Abs 1 lit c DSGVO in Verbindung mit § 81 für Diplomarbeiten UG dar.

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§ 83 UG betrifft Dissertationen (Art 6 Abs 1 lit c DSGVO iVm § 83 UG)

Die datenschutzrechtliche Rechtfertigung für die Verarbeitung der Daten ist nicht die Einwilligung der Betroffenen.

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Grundsätzlich haben nur autorisierte und zur Verschwiegenheit verpflichtete Personen im Zuge der Erarbeitung und Betreuung der Masterarbeit Zugang zu den verarbeiteten, personenbezogenen Daten, und dies nur in dem erforderlichen Umfang.</p>

An folgende Empfänger_innen oder Kategorien von Empfänger_innen werden Ihre personenbezogenen Daten zulässigerweise übermittelt oder können übermittelt werden:

an die betroffene Universität (TU Wien), insbesondere der/dem Betreuer_in der wissenschaftlichen Arbeit und dessen Mitarbeiterstab

positiv beurteilte Masterarbeit an die Universitäts-Bibliothek der TU Wien, Resselgasse 4, 1040 Wien, zum Zwecke der Veröffentlichung gemäß Art 6 Abs 1 lit c DSGVO iVm § 86 Universitätsgesetz (UG)

an die EIT Manufacturing East GmbH, Christine-Touaillon-Straße 11/29, 1220 Wien)

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Speicherdauer

Zum Nachweis der guten wissenschaftlichen Praxis sowie für die Nachprüfbarkeit der gewählten Methode und der erzielten Ergebnisse, wird die Protokollierung und die Dokumentation des wissenschaftlichen Vorgehens auf haltbaren und gesicherten Datenträgern gespeichert. Dies erfolgt datenschutz-konform und gegenüber Dritten unzugänglich. Die Datenspeicherung richtet sich nach den gesetzlichen Bestimmungen und erfolgt entsprechend § 2f Abs 3 Forschungsorganisationsgesetz (FOG) für die Dauer von maximal 30 Jahren.

Betroffenenrechte

Gemäß der DSGVO stehen Ihnen als betroffene Person folgende Rechte zu:

Recht auf Auskunft über die betreffenden personenbezogenen Daten (Art 15 DSGVO)

Recht auf Berichtigung (Art 16 DSGVO) oder Löschung (Art 17 DSGVO) oder auf Einschränkung der Verarbeitung (Art 18 DSGVO) unter den in den angeführten Bestimmungen beschriebenen Voraussetzungen

Recht auf Beschwerde, welche bei der Österreichischen Datenschutzbehörde, Barichgasse 40-42, 1030 Wien, Telefon: +43 1 52 152-0, E-Mail: dsb@dsb.gv.at als zuständige Aufsichtsbehörde einzubringen ist.

Artikel 11 DSGVO sieht zudem vor, dass eine separate Rückführbarkeit von Daten auf Personen nicht gewährleistet werden muss, nur um die Betroffenenrechte wahren zu können.

David Kames

Kaunitzgasse 35/12

1060 Wien

david.kames@eitmanufacturing.eu

Daten die während der Umfrage gespeichert werden:

Bei der Umfrage wird die IP-Adresse Ihres Endgerätes identifiziert. Es ist dabei aber ausgeschlossen, dass ein persönlicher Bezug zu Ihnen hergestellt werden kann. Es werden keine Cookies eingesetzt.

Die von Ihnen eingegebenen Daten während der Umfrage (Bewertungsskalen, Freitextantworten) werden gespeichert. Geben Sie daher keine Informationen an, die

Rückschlüsse auf Ihre Person geben könnten. Sie können jederzeit während der Befragung die gespeicherten Umfragedaten über den Reiter ‚Dialog löschen' selbständig löschen.

Neben Ihren Angaben auf dem Umfragebogen werden bei Ihrer Teilnahme folgende Metadaten zur Ermittlung von allgemeinen Kennwerten für die Auswertung erhoben: Datum der Befragungsteilnahme, Beginn der Fragebogenbearbeitung und Verweildauer pro Seite. Sie können jederzeit während der Befragung diese Daten über den Reiter ‚Dialog löschen' selbständig löschen.

Wir nutzen zudem die Local Storage Technik. Dabei werden Daten lokal im Cache Ihres Browsers gespeichert, die auch nach dem Schließen des Browser-Fensters oder dem Beenden des Programms – soweit sie den Cache nicht löschen - weiterhin bestehen und ausgelesen werden können. Local Storage ermöglicht es, dass Ihre anonymisierte Identifikation in Form eines Tokens auf Ihrem Rechner gespeichert und von Ihnen genutzt werden können, damit Sie mit dem System interagieren können. Auf die im Local Storage gespeicherten Daten können Dritte nicht zugreifen. Sie werden an Dritte nicht weitergegeben und auch nicht zu Werbezwecken verwendet. Wir verwenden diese Techniken im berechtigten Interesse um ihnen ein attraktives voll funktionsfähiges Angebot machen zu können auf Basis von Artikel 6 Abs 1 lit. f DSGVO. Wenn Sie nicht wünschen, dass Local-Storage-Funktionen eingesetzt werden, dann können Sie das in den Einstellungen Ihres jeweiligen Browsers plattformabhängig im Betriebssystem der jeweiligen App steuern.

Auch bei einer Umfrage haben Sie gemäß Datenschutz gegenüber dem Informationsträger das Recht auf Auskunft sowie Löschung Ihrer personenbezogenen Daten. Sie können diese Einwilligungserklärung jederzeit widerrufen. Nutzen Sie hierzu im Dialog den Reiter ‚Datenschutz' und drücken Sie dort auf ‚Einverständnis wiederrufen'. Nach erfolgtem Widerruf werden Ihre Daten gelöscht.

Diese Umfrage wird durch folgenden Auftragnehmer erhoben und ausgewertet: Respeak GmbH, Kaiserstrasse 89, c/o KIT IISM/KIT, 76133 Karlsruhe. Mit diesem wurde ein Vertrag zur Auftragsverarbeitung abgeschlossen. Die Umfragedaten werden auf Servern in Deutschland gespeichert.