M.Sc. Management of Technology

An Integral Framework for the Customer Discovery Phase

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Type of report : Master Thesis
Date : 12 July 2023

TU Delft Delft University of Technology

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Thesis
MOT2910

An Integral and Practical Framework for the Customer Discovery Phase

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A thesis presented for the M.Sc. Management of Technology at the Delft Centre for Entrepreneurship. To be defended publicly on July 17 2023 at the faculty TPM of the Delft University of Technology.

July 13, 2023

Acknowledgement

Running a start-up is supposed to be hard. At first I thought it was just hard work and late hours that defined it as hard. However, it is the confusion and uncertainty that makes it hard. Still, with several tools, mentors and a team supporting you, this hardship can be reduced. I am grateful for those who paved the way, the patriarchs of entrepreneurship. But also for the people surrounding me.
First and foremost I want to thank my co-founder Thijs Bieling. We started this adventure together and I appreciate everything you do for our mission during this shared adventure. Although in my thesis I refer to the literature a lot, many steps were performed based on feedback by my start-up coaches Aleksandar Giga and Erik van Gangelen. Aleks and Erik helped me during the customer discovery by providing almost weekly advice and to say they were of great value is an understatement. I want to thank them for helping us with not only advice, but inspiration as well. As stated by Blank, "Being a great entrepreneur means finding the path through the fog, confusion and myriad of choices." Although we must find the path ourselves, our coaches helped us by providing metaphorical lanterns. Finally, I want to thank my supervisors Dap Hartmann and Sander Smit for providing feedback along the way, nudging me in the right direction, and for being patient with me.

July 12, 2023

Berend Bart de Klerk

Abstract

Much research has been conducted regarding which steps to take to enhance the likelihood of entrepreneurial success. However, entrepreneurs often turn to practical books for insights on what steps to take, resulting in a research-practitioner gap. This thesis aimed at combining different models and methods into one integral yet simple framework that is practically applicable for start-up founders in the early phase: customer discovery. The scientific literature for these models and methods was included. The framework included the Customer Development Model, Diffusion of Innovations Model, Technology Acceptance Model, the Mom Test method and the Lean method. This framework was then tested on a practical use-case to test the applicability of the different aspects in a real-life scenario. This use-case was the company Plense Technologies, a start-up I recently co-founded and still in the customer discovery phase. The metric of learnings and insights was used to assess the framework during this phase. Although the initial framework proved to be insightful, some additions were made. These four additions were (1) the distinction between directive- and non-directive interviews at the different phases of the customer development insight cycle, (2) interviewing suppliers, (3) the benefit of start-up coaches and (4) doing an internship to get a better understanding of the customer. With these additions, the resulting framework proved to be integral and simple to apply in a practical context. Entrepreneurs can use the models and methods in the framework to rapidly iterate and improve the business model, ultimately increasing the chances of entrepreneurial success. Factors mentioned that may influence how the framework can best be applied are the financial climate, regulatory environment, culture, market segment, market type, product type, role of the customer and the relevance of deep tech. These should be further assessed in future research to validate its applicability in different contexts.

Contents

1 Introduction

How do you get from an invention to a sustainable business? For starting entrepreneurs, this question rises when spinning off from university with a technology. In today's dynamic and competitive business landscape, the success of start-ups heavily rely on their ability to navigate a multitude of challenges and make informed decisions. What steps should you take, how should take them and why are these steps the right steps? With various papers, books and coaching programs, the amount of information available from different sources may be overwhelming. Furthermore, in for example the Startup Owners Manual from Blank [1], a great overview is given of which steps to take, but it lacks specifics on how to apply this. Moreover, current methods such as The Mom Test [2] are widely adopted in the start-up community, but lack evidence from the scientific community. These last two issues result in a research-practice gap: entrepreneurs not paying attention to academic research [3, 4] and researchers neglecting practice when formulating research questions [5, 6]. The thesis largely builds upon the framework developed by Shepherd et al. [7] who wrote a framework to bridge this gap specifically for the Lean Startup Framework (see Subsection 2.1.3 for an explanation of the Lean Startup). Although this research already makes significant steps in bridging the research-practice gap, this area can still benefit from more research from a practical perspective. In their work, Shepherd et al. suggest several opportunities for future research, such as investigating what activities entrepreneurs use throughout adapting and refining business models, or what factors and conditions influence the use and outcomes of the framework. Furthermore, they suggest to delve into a more detailed analysis of the individual contributions of each building block of their framework and investigate the effects of each building block. They defined the building block as follows:

1. Finding and prioritizing market opportunities
2. Designing business models
3. Validated learning
4. Building minimum viable products
5. Persevere or pivot with course of action

This thesis continues with the research of Shepherd et al. [7] and zooms in on the second and third building block, which correspond to 'customer discovery' (see Section 1.3 for a detailed explanation of the scope). By doing so, this thesis aims at assessing the literature and bridging the research-practice gap further for the building blocks mentioned. This will result in a simple but integral framework for implementing and combining the existing methods based on the currently available scientific literature. This new framework is thus a descriptive framework that describes the relevant methods and models. The new framework is then applied to a case-study, which is a start-up committed to bring ultrasound plant sensing technology to the market (see Appendix D.4). By doing so, the new framework will be tested in a practical environment and improved where necessary. This is done with the goal to bridge the practice-research gap and to delve deeper into the specific practicalities that entrepreneurs face, while linking this to the academic world. The resulting framework will help future entrepreneurs in their endeavors to bring a product to market with their business hypothesis. According to Schrage, "[...] a business hypothesis is a testable belief about future value creation" [8]. The resulting framework is thus a prescriptive framework suggested to use for future entrepreneurs.

1.1 Research Objective

The objective of this thesis is to provide an integral framework and to evaluate the practical implementation of the framework as a guide for starting entrepreneurs with a business hypothesis. The framework is developed by first by identifying the key components of the framework, then assessing its applicability to real-world scenarios, and finally examining the factors influencing its implementation. The resulting framework can be used by entrepreneurs to get guidance in the first phase of their journey and allow entrepreneurs to gain a deeper understanding how theories and principles presented in the literature apply in a real-world start-up setting. At the same time, it could help identify any gaps where the theories may not be integral or fully applicable. By adopting an evidence-based and systematic approach, entrepreneurs can leverage the scientific insights to enhance their decision-making, minimizes risks, and maximizes their potential for growth.

1.2 Research Questions

Given the research objective, the main theoretical research questions that follow are:

1. Which scientific models and methods result in an integral but comprehensive framework for entrepreneurs in the customer discovery phase and how can they best be applied?

In this first research question, *integral* refers to a framework that considers various dimensions and factors important for starting entrepreneurs. It aims to bring together different theories, models, and methods into a cohesive whole, providing a integral approach to entrepreneurship. However, it is also the objective to keep the framework simple, as indicated with *comprehensive*. The other research questions are as follows:

2. What factors influence the use of the framework?
3. What are the limitations of the framework in a practical, real-life setting?

The second research question describes what factors, such as market type, may influence how the methods and models should be applied. The question aims to understand the contextual elements and variables that affect how the framework is adopted, implemented, and utilized by entrepreneurs. Note that this research question does not investigate which factors influence the success of a start-up. The research further involves investigating the practical applicability and potential shortcomings of the integral framework for starting entrepreneurs, given with the third research question. When examining a theoretical framework in a real-life use case, it is essential to assess its limitations and constraints. This research question aims to identify challenges that may arise when implementing the integral framework in practice. By understanding these limitations, future entrepreneurs can gain insights into the framework's feasibility and effectiveness, and make informed decisions regarding its adoption.

1.3 Scope

This research covers the customer discovery, the first step of the Customer Development Model (CDM) [1]. In Subsection 2.1.1 this CDM is further explained. Customer discovery is all about finding out who the customer is and what you can do for the customer. The customer discovery phase is a critical step for start-up entrepreneurs and is followed with the customer validation phase. Many ventures fail due to a lack of understanding of customer needs or a misalignment between the product and the target market [9]. By integrating scientific models and methods, entrepreneurs can gather reliable and actionable data to make informed decisions and pivot their strategies based on customer feedback. Although the transition from customer discovery to customer validation is not very strict, in this thesis this border is defined as follows. When assumptions are validated using interviews and talks (see Section 3.3), it is still part of the customer discovery phase. When assumptions need to be validated using prototypes, drawings or other specific things that you need to build, this is taken to be part of customer validation and therefore not included.
A step before customer discovery is market discovery. The market discovery is about analyzing different markets to select the domain that is most suitable for the business case [10]. For this element, Blank and Gruber developed the Market Opportunity Navigator (MON) that acts as a framework in this phase [11, 12]. The MON helps entrepreneurs in defining where to search further for a sustainable business case. As Shepherd et al. state: "While the Market Opportunity Navigator helps entrepreneurs in figuring out 'where to play', entrepreneurs also need to understand 'how to play' in a given setting to develop a viable new venture." [7]. The scope of this thesis is on 'how to play', so for technologies that already have a market defined. Although the funnel from market to market segments and customer segments will be discussed, this will not be the core of this thesis.
There are many subjects that entrepreneurs should become familiar with. These subjects include goal setting, legal, intellectual property, team building, story telling, funding and pitching. However, these subjects will not be discussed in this thesis.

1.4 Research Approach

To address the research question, this study employs a comprehensive review of existing literature across various disciplines, including entrepreneurship, management, and journalism. Chapter 2 examines scientific models, frameworks, and methodologies commonly used in entrepreneurial research to identify the most relevant and effective approaches for start-up entrepreneurs. Furthermore, a thorough literature study is conducted to explore the current knowledge on validating a business hypothesis in its initial stages. Additionally, a case study and empirical evidence demonstrate the practical application and impact of these models and methods in a real-world scenario, leading to further refinement of the framework. Chapter 3 outlines the research methodology employed to address the research questions, while Chapter 4 presents the results from the use-case that was applied to test the framework. This chapter highlights how the literature study's framework

aids in comprehending customers and their problems, offering valuable new insights to enhance the framework. Chapter 5 provides a comprehensive discussion of both the research process and the improved framework. It includes recommendations for future research, as well as an exploration of the limitations and benefits of the current study. Finally, Chapter 6 concludes the findings. The appendices shows a list of acronyms (A), the books referred by other start-up founders (B), an example of the business model canvas (C), background about horticulture (D) which includes the background information of the start-up used as use-case, an overview of several sub-steps of the CDM (E), example interview questions for growers (F), the different customer segments (G), a list of companies I interviewed (H), and finally the mentimeter results from Delphy showing the response of growers on questions about sensors (I).

2 Literature and Background

To get an overview of the full road towards a sustainable enterprise, several books and papers about entrepreneurial models and methods are available which provide great insights in what to do and what not to do in general. These include the CDM and lean method as mentioned in the introduction. However, next tot the methods and models mentioned by Shepherd et al. [7], several other methods and models are available.
Section 2.1 describes different relevant models and methods. The difference between *methods*, *models* and *frameworks* should first be explained. In general, a method is a specific technique or approach used to solve a particular problem or achieve a certain goal. A model, on the other hand, is a simplified representation of a complex system or phenomenon that is used to understand, predict, or control its behavior. A model therefore can be used to explain *what* to do, and a method explains *how* to do this. A framework is a higher-level abstraction to provide guidelines for applying models and methods. For the models and methods from non-scientific books, the underlying scientific principles are explained as well. In Figure 1 the models and methods are combined into one integral framework.

2.1 Scientific models and methods

As stated in the introduction, this theory builds upon the research of Shepherd et al. [7]. Where Shepherd et al. mainly used the CDM and lean method, here several other aspects are added. These additions are the the Mom-test method, the Diffusion of Innovation Model and the Technology Acceptance Model. Together, these methods and models answer different important questions: *what* to do, *why* do you need to do that and *how* do you do that. This forms an integral framework for starting entrepreneurs, as these methods and models were advised by start-up coaches, my supervisor and other start-up founders after being asked about books they found most useful in the early phase of their start-up (see Appendix B). From all the recommended books, a selection has been made to further evaluate the scientific models behind them.

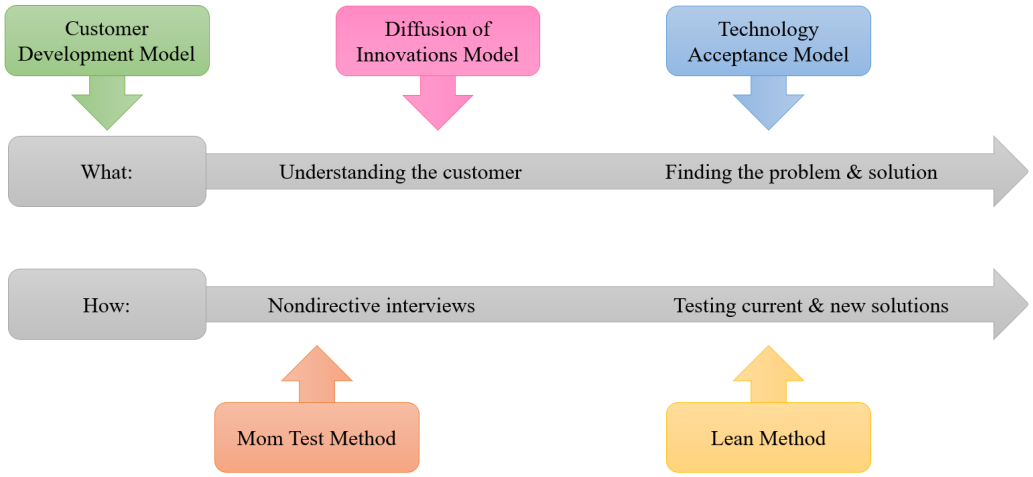

Figure 1: What to do during customer discovery and how to do this, depicted in grey. The colored blocks indicate the existing models and methods that give guidance in these aspects. The arrows indicate at what moment in time the method or model is most relevant.

Figure 1 combines five methods and models into one framework. The arrows indicate at what moment in the journey they are most relevant. The Customer Development Model (CDM) forms the basis on what to do: understanding the customer, finding his/her problem and finding the hypothetical solution for this problem. The Mom Test method shows you how to conduct non-directive interviews in this early stage and by doing so objectively understand the customer. The Diffusion of Innovation Model (DoIM) can be used to map the innovative character of different customers you interview. This can be used later with testing your solution, as the innovators of the DoIM usually are open to test non-finished solutions. The Lean method shows how you can test certain solutions for the customer problem and why an iterative process is paramount. Current solutions to the customer problem can be structured using the Technology Acceptance Model (TAM), which shows which aspects of the current or new solutions limit the adoption of using this solution.
By integrating these methods and models, the framework benefits from an integral approach that combines principles of lean experimentation, customer-centricity, innovation adoption, effective customer interviews, and technology acceptance. It enables researchers and entrepreneurs to validate ideas, refine value propositions,

understand customer needs, target specific user segments, learn from competitors and facilitate the successful adoption of technology within their ventures. The iterative nature of the framework allows for continuous learning, adaptation, and optimization throughout the entrepreneurial journey. In the next subsections, each method and model is further elaborated.

2.1.1 The Customer Development Model (CDM)

Since the work of Drucker in 1954, emphasis for managers has been on creating value for the customer instead of emphasis on the product [13]. This so-called customer-oriented approach is about using customer-supplied information about desires, perceptions and needs as basis to deliver products or services [14]. It is the opposite of the product-oriented approach, where an initial product forms the basis of the business hypothesis. A similar approach to the customer-oriented approach is market-orientation [15] where a general customer group is subject. Both are opposite to entrepreneurial orientation [16] where the enterprise itself is subject and defines the new entry. This approach was used until the 1960s. These two opposite approaches can also be characterized by the terminology *market-pull* and *technology push* [17]. Concepts similar to the customer-oriented approach, such as human-centered design, user-centered design or service design, all focus on building solutions with strong emphasis on the needs and preferences of the end-user.
In the start-up community, the model for the customer-oriented approach is called the Customer Development Model (CDM). This model is extensively explained by Blank in The Startup Owners Manual [1] and the earlier version Four Steps to the Epiphany [18]. The CDM from these two books answers the question: *what* to do. The CDM is a systematic approach to building and validating the business model by focusing on the customer. The model emphasizes the importance of actively engaging with customers and iterating on product development and market strategy based on customer feedback and insights. In the Startup Owners Manual, Blank goes deep into the different kind of products [1]. More specifically, he shows a framework for both physical and digital products that can be sold physically and digitally as well. Furthermore, the focus in The Startup Owners Manual is on the first two steps of the CDM (Figure 2): customer discovery and customer validation.

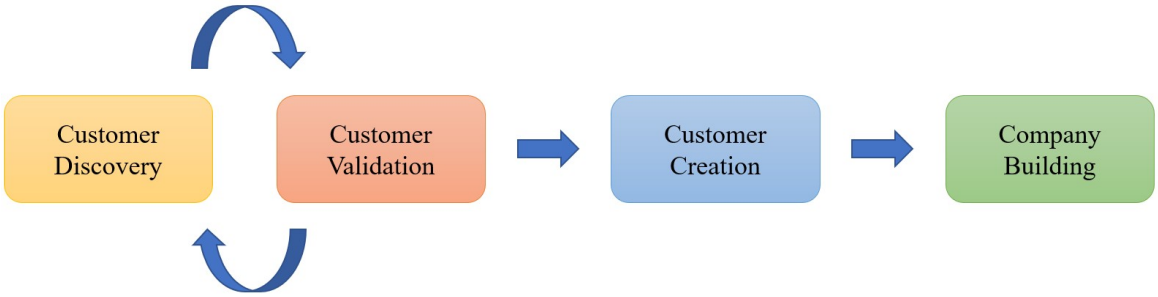

Figure 2: The Customer Development Model [1]

In this thesis, the focus is on customer discovery. In this phase, entrepreneurs engage in a process of identifying and validating their target customers and their needs. The goal is to gain a deep understanding of the customers, their pain points, and the problem the start-up aims to solve. The emphasis is on conducting market research, customer interviews, and collecting data to gather insights and validate assumptions. Figure 27 in Appendix E shows the subphases that customer discovery entails. In the customer validation phase, the aim is to validate the business hypothesis by testing and refining the product or service concept with target customers. The goal is to collect data and evidence that demonstrates customer demand, viability, and willingness to pay for the proposed solution. Next, in the customer creation phase, the focus shifts to acquiring and expanding the customer base. Entrepreneurs aim to develop effective marketing and sales strategies to attract early adopters and generate initial traction for their offering. The final phase, called company building, involves scaling the business and establishing a sustainable organization.
Customer discovery corresponds to the first 7 steps of Aulet's Disciplined Entrepreneurship [19]. Customer discovery is divided into four phases shown below. These four phases can be further divided into several sub-phases. However, the overarching method is clear: get out of the building and talk to customers.

1. State your Hypothesis
2. Test the Problem
3. Test the Solution

4. Verify

In Disciplined Entrepreneurship [19], Aulet's goal is "to provide guidance in a messy and sometimes confusing process where you, the entrepreneur, are attempting to do something that has never been done before". In his book, he refers the work of Blank as great material, but he argues that the Four Steps to the Epiphany focuses too in depth on a few key points without providing the more fulsome roadmap. Indeed, Disciplined Entrepreneurship provides a structured framework for what steps to take. To some extend, it builds upon the CDM of Blank. However, due to its structure and rigor, it loses both flexibility and in-depth knowledge on specific topics. Considering the fact that the focus of the thesis is on the customer discovery phase, the two books complement one another and the message from both is clear: in this first phase of a start-up, emphasis should be on understanding the customer.

2.1.2 The Mom Test Method

The mom test method refers to the book The Mom Test written by Rob Fitzpatrick [2] and has some very valuable insights as it comes to customer interviews. This book came out in 2013. In his book, Fitzpatrick explains *how* you should conduct interviews and talk to potential customers. The title refers to the fact that if you propose something to your parents (or any other relation for that matter, such as a potential customer), they have the tendency to respect your feelings, thereby reacting more positively than they actually are. This results in non genuine interest in your proposition but without you knowing it. After reading the book, you will know how to conduct interviews that result in objective answers and facts instead of words meant to propitiate you. The book emphasizes the importance of asking open-ended questions, avoiding leading questions, and focusing on the customer's experience and behavior rather than their opinions or hypothetical responses. According to Batova et al. little to no research is available on how to conduct interviews during the customer development [20]. One paper that highlights customer interviews is from Camuffo et al. and uses the case study of Inkdome [21]. In this paper, a quasiethnographic method for customer interviews is given. They base their research on the work of Littman called The Ten Faces of Innovation [22]. Once again, this is not an academic book. One paper that mentions The Mom Test is from York [23]. In this paper, York provides effective questioning and interviewing techniques. Specific questions that one could use during interviews come directly from The Mom Test, but the paper falls short on extensive references.
After contacting a few professors from the social sciences, it became apparent that the Mom Test is not a common method in this field of study. However, dr A. Pleijter, expert in online journalism from the University of Leiden, wrote in an email exchange about the Mom Test that "the same principle is very common in qualitative interviews: asking open, non-directive questions in order to get to know people's world or experience". Although indeed an explicit link to The Mom Test is not made, several scientific papers about qualitative interview methods for applied business research questions suggest a method that is very similar to The Mom Test called 'nondirective interviewing'. This method was developed by Rogers around the 1940s [24]. This method comes from therapeutic studies and is also referred to as the 'client-centered technique'. A similar technique, often referred to as 'indirect interviewing' emerged separately from a different field of study, but is very similar to the nondirective interviewing technique. This technique originates from the Hawthorne studies between 1924 and 1932 and was intended to generate, not verify, hypotheses [25]. One can imagine, that during customer discovery, generating hypotheses should be the core business instead of validating hypotheses. Kelly et al. gives examples of how directive and nondirective interviewing styles can be used effectively in different research contexts [26]. In directive interviews, it states, the interviewer takes a more active role and guides the interviewee towards specific questions and answers. This an be useful in situations where the interviewer wants specific information. However, this approach can also limit the interviewee in expressing its own thoughts, experiences and nuances. The contrary of directive interviews are nondirective interviews that are more unstructured and open-ended. Kelly et al. mention that this approach can be useful in situations where the interviewer wants to gain a deeper understanding of the interviewees experiences or perspectives. The Mom Test advocates the nondirective approach. In the 1960s and 1970s, the nondirective interviewing method became increasingly popular in qualitative research in the social sciences. However, this method has been criticized as well. Critics argued that it was overly time-consuming, lacked rigor, and failed to provide sufficient structure for research interviews [27].

2.1.3 The Lean Method

In the bestseller The Lean Startup, Eric Ries explains *why* it is so important to do do extensive customer analysis and validated learning [28]. It is all about learning to see the irrelevant features in your hypothetical product and then systematically eliminating this waste (Figure 3). In the figure, the lines represent time (and therefore

money) that is needed for e.g. building a specific feature. By knowing beforehand which parts are irrelevant (the red crosses), you can faster build towards the solution for your customer. To elaborate: to build something for months and learn it does not align with the customers demand, is waste of time. A better approach is to show for example a sketch of what you want to build and see the customer reaction. This might already provide valuable feedback, thereby saving months of building in vain. As stated by Ries, "success is not delivering a feature; success is learning how to solve the customer's problem." It shows how and why validated learning by performing targeted experiments is a great way to go about your start-up. Moreover, it shows why failing fast, as also advocated by e.g. McGrath et al. [29], is a good way of building products. Pivotting, meaning changing to a new strategic hypothesis, is often necessary after learning that initial hypotheses are wrong. In Figure 3, the pivots are indicated with the junctions.

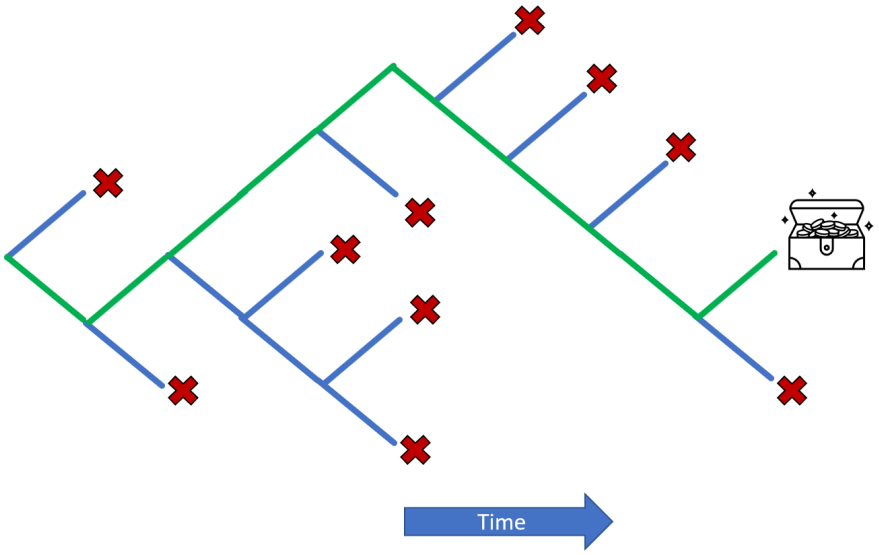

Figure 3: Personal visualization of the Lean Startup [28]. The start-up journey is full of dead-ends and by faster testing these dead-ends, you can make good choices leading a sustainable business faster. Testing assumptions that might lead to dead-ends can help you avoid costly and timely mistakes.

The lean method both has garnered a lot of support from both academia and practitioners, thereby decreasing the research-practice gap [7]. Bortolini et al. wrote a comprehensive historical review on the lean startup movement where they showed many scientific, academic and professional papers that preceded, supported and complemented the main concept of Ries [30]. The central principles of the lean startup builds upon the lean philosophy. Ohno [31] and Deming [32] were the first to write about this philosophy. The philosophy highlights the removal of waste as key factor to improve performance. The lean philosophy is used by Toyota where waste is limited by reduction of cycle times and resource usage [33], but can be used for any manufacturing process of for small- and medium sized enterprises [34]. Ries related the theory to startups, where the waste mentioned is mainly in the form of building products that do not align with demand of customers. Testing assumptions is the way to reduce this waste of time (and therefore money). Frederiksen, who analyzed the academic merits and characteristics with empirical evidence in the scientific literature, found considerable backing of the methodology [35]. Silva et al. even made a scientific framework for entrepreneurs they called the 'staircase roadmap' to apply the Lean Startup in practice [36].

2.1.4 Diffusion of Innovation Model (DoIM)

The diffusion of innovation model (DoIM) is often represented by the bell-curve (Figure 4), described first by Rogers [37]. This graph shows the adoption of innovation, divided by certain adoption groups. The innovators, followed by early adopters are the group of people that initially are open to innovation and invest in new technologies. According to Moore [38], the way to sell to the majority is by first selling to the innovators and early adopters. The early adopters form a flywheel, which is suggested to be a necessary condition before targeting the majority. Innovators, or lead users as advocated by Urban and von Hippel [39], display two characteristics, they face a need before other customers do, and they benefit more to obtain a solution compared to regular users.

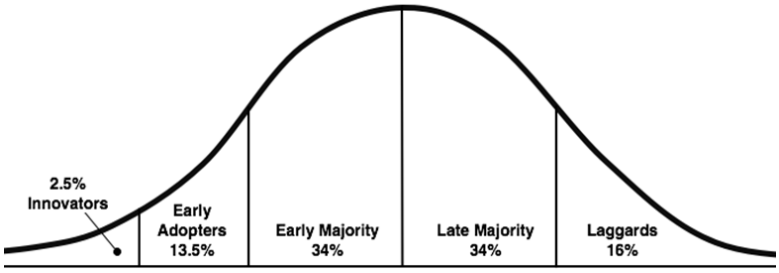

Figure 4: The diffusion of innovations [37]. The curve represents the successive groups of consumers that are adopting new technology during time.

The theory can be used in primary market research, marketing, technology adoption and social change efforts. During customer discovery, it should be used to spot the innovators, as these are the first that adopt your solution and allow bulky prototypes. This can be used to learn from your solution from a customer perspective.

2.1.5 Technology Acceptance Model (TAM)

A more specific way to asses the adoption of technology is by using the Technology Acceptance Model (TAM) [40]. In this model, Davis claims that the two main determinants for adoption are perceived usefulness and perceived ease of use. The model also includes a number of external factors that can influence users' perceptions, such as social norms, training, and support. Perceived usefulness refers to the degree to which a user believes that a technology will enhance their performance or productivity, while perceived ease of use refers to the degree to which a user believes that a technology is easy to use. This model can be used to explain user acceptance and adoption of new technologies. It can be used to better understand potential customers' perceptions and attitudes towards new- or existing products.
In most literature about entrepreneurship, the focus is on the customer and its problem. However, learning from current solutions can already provide great insights. In research about adoption, emphasis is usually put on the perspective of the receiver, not the technology [41]. In their work, Munguia et al. analyzed the determinants for adoption of technology in agriculture, and suggest that research often mainly looks at the adoption from a customer perspective, rather than from a product perspective. It might be somewhat unorthodox to interview your potential competitor and they might not want to share their thoughts. However, it can be beneficial in two ways: first to learn how they solve the customer problem and see why they took certain steps (learn from them). Second: to refrain from making something similar. If you know a company is specialized in developing sap flow sensors and they already have customers, it would be advisable to develop something else as the customer problem is already being solved.

3 Methodology

This chapter provides an overview of the methodology employed in this study to address the research questions and achieve the study's objectives. This methodology is divided in the theoretical- and practical research. In the latter, I applied the framework in practice and conducted the field work that is needed when starting a start-up company. In the former, the methodology is given to conduct and asses the practical work and relate it to the research questions.

3.1 Theoretical research

For the primary research question, the literature described in Chapter 2 was employed and the framework from Figure 1 was used. Next to the written literature, I was coached by start-up coaches Aleksandar Giga and Erik van Gangelen via the Impact Studio. The Impact Studio is the pre-incubator of the TU Delft, aiming at providing guidance for researchers to take the first steps in bringing a technology to market. Aleksandar teaches entrepreneurial finance and technology startup development at the TU Delft and Erik is an experienced entrepreneur. These coaches are very well aware of the models and methods explained in Chapter 2 and provide coaching almost weekly. After applying the framework in a practical setting as explained in the next section, the results were used to evaluate the framework. Thereafter, the framework was improved where necessary and related to specifics of the use case.
During the research, it is important to note what makes certain steps or interviews successful or beneficial. According to Ries: "[...] the right way to think about productivity in a startup [is] not in terms of how much stuff we are building but in terms of how much validated learning we're getting for our efforts." Therefore, the metric of insights/validated lessons are used to assess the framework during the time of the research. This can be related to Figure 3: the sooner red crosses are found, strategic pivots are made and the path towards problem-solution and product-market is enlightened, the less time is spend on building the wrong solution. Insights/lessons are arbitrary and therefore hard to quantify. Considering Figure 3, when do you observe a red cross and how do you quantify how many green parts you have identified? In the results of Chapter 4, each subsection ends with a small section about the validated lessons which will be referred to as new insights. This links the findings to the framework proposed in Figure 1 and its different models and methods.

3.2 Practical research: the case study

The framework from Figure 1 was applied to the start-up Plense Technologies, a spin-off from the TU Delft that develops plant-sensing technology of which I am co-founder. In Appendix D.4, more information and background about the start-up is given. The following research questions are developed using the toolbox from Disciplined Entrepreneurship of Bill Aulet [19]. As stated in Subsection 2.1.1, this toolbox aligns largely with the CDM and the framework developed by Shepherd et al. [7]. The following questions for the start-up were tested using the framework:

1. Who is the potential customer for plant sensing technology?
2. What problems can plant sensors solve for the customer?
3. How have other parties tried to solve these problems?

The results from Chapter 4 are also structured based on these questions. These practical research questions provide the structure and are referred to as *practical research*, whereas the research questions stated in Section 1.2 together form the *theoretical research*. The practical research investigated both the customer and sensor suppliers. On the one hand, I investigated the demand for plant sensors: what are the challenges of people in agri- and horticulture and how have they tried to tackle these. What are their fears and drivers that result in demand. On the other hand I researched the supply: what technical solutions currently exist that solve the problems of the customer. This part is often overseen in literature, as mentioned in the work of Munguia et al. [41]. The answers on the practical questions are given in the next section (Chapter 4) and are used as a result for the theoretical research questions.
The practical research to test the framework consisted of two parts (Figure 5): interviews and an internship. Both were conducted to find out more about the potential customers and their challenges. The parties being interviewed, adding up to roughly one hundred, came from the internet, recommendations from interviews themselves and from influencers such as the AgTech institute or HortiHeroes and are shown in Appendix H.

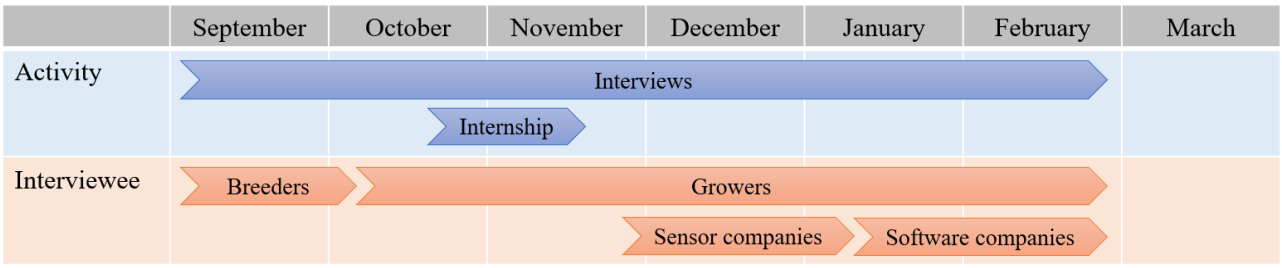

Figure 5: Timeline of practical research.

3.2.1 Interviews

Chapter 2 shows that the initial steps for the CDM are 'going out of the building' and talking to customers using non-directive interviewing techniques as described in the Mom Test. This technique is rather chaotic, but encourages the interviewee to freely express their thoughts, feelings, and experiences. The interview questions were open-ended and does not follow a pre-determined set of questions, although some questions were asked in most interviews. The list of questions altered as new information came to light, which changed the questions for a next interview as well. In Appendix F, some questions used to interview growers are shown. Note that these questions are different from questions asked to e.g. software companies. These questions were combined with the 5-why method: asking 'why' five times after getting an answer. This is used to get to the root of a problem. As the questions changed after each interview, the interviews are not coded or quantified. It is important to have an open mind and listen closely. Each interview should start without assumptions to ensure room for new insights, but findings from previous interviews should be assessed at new interviews as well, to get a better understanding of the quantity of a certain problem. This is also advocated by the Mom Test method. Fitzpatrick also mentioned that you should never push your product to consumers, but listen to the needs of the consumer to learn their needs. Only if you understand them, you can sell to them [2]. As the use case was a business to business (B2B) start-up, we were limited in the number of datapoints. To wit, there are only 100 tomato cultivation companies in the Netherlands. This means that thorough interviews were more relevant than e.g. a questionnaire you send out to any grower, because of the simple fact that there are not that many growers. A business to customer (B2C) start-up could explore different ways to get more information from potential customers, because usually there are many potential customers. The interviews were preferably conducted face to face. With physical interaction, it is easier to observe facial expressions and detect hidden messages. Moreover, this allows for a closer look in their work, the interaction with colleagues and sometimes even resulted in a guided tour through the greenhouse facilities. However, if needed, the interview could be conducted online as well. For some companies several interviews took place. One example is Syngenta. After I visited their open day, I had interviews with different people (one of which was based in Basel, Switzerland). This was done to get a more wholesome view of this large organization and to speak to multiple relevant people. Figure 6 shows the interviews conducted with different market segments.

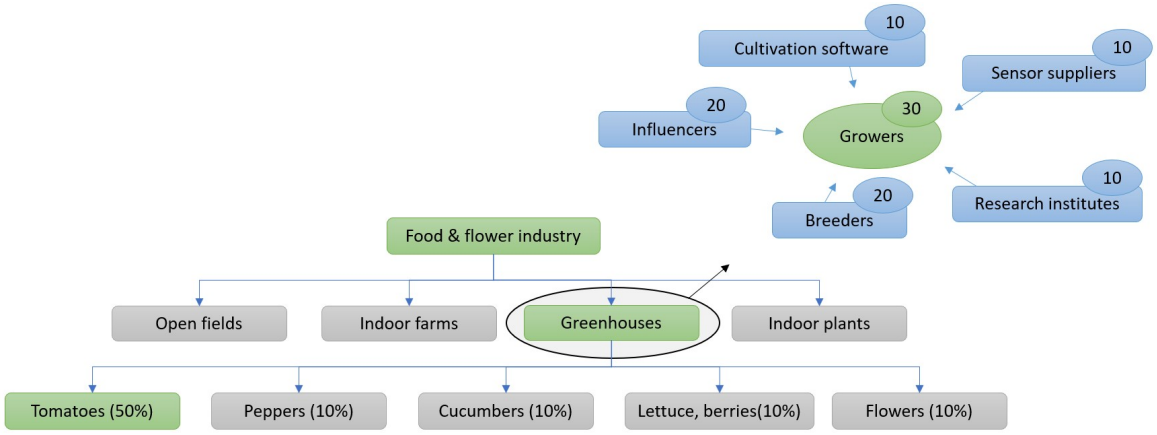

Figure 6: Market segments and interviews conducted at relevant parties (including amount of interviews). Green indicates the beachhead market.

The companies and people that were interviewed were not predetermined. The first steps are finding out who

your customer is. Only after the first interviews do you know who to interview next; it is an iterative process. New people and companies arise due to former interviews (ending by saying "who should we talk to next"), market advisors and contacting companies via the internet.

3.2.2 Internship

Mochary stated: "Remember that you are not making a product - you are solving a customer problem. It is therefore critical that you continually live that customer problem. Only then can you solve it well. To live the customer problem, you must sit with the customer, ask them about their life, and observe their daily routine, on a regular and constant basis." [42]. To do so, I volunteered at a relevant company to simulate an quasi-ethnography study. This method was proposed by the startup coaches. An ethnographic study is a strategy where a researcher "closely observes, records, and engages in the daily life of another culture [...] and then writes accounts of this culture, emphasizing descriptive detail" [43]. According to Alvarez, observing customers in their natural environment is the highest-fidelity method of customer development [44]. This research method has four advantages compared to conducting interviews. First, it gives a more wholesome view of all activities. Secondly, it lowers the threshold of asking certain questions. Furthermore, it allows for discovering problems that are not public information. Finally, it may expose problems that the person being interviewed is not even aware of. Since I didn't have the time to perform an ethnographic study for several months, I volunteered for 2 weeks at a propagation company that does breeding, propagating and growing of plants. Using the extensive network of the HortiHeroes, which is an organisation that has the mission to connect professionals and companies in the food- and flower industry (see Figure 28), I came in contact with Vreugdenhil Young Plants, where I volunteered at different locations. This company has both a breeding department and growing department, allowing me to get a sense of both activities. The goal was to get to know the customer better and find out how he or she spends his day.

3.3 Data Analysis

Of all interviews, minutes were recorded. This was done by writing down notes in a notepad during the meeting and elaborating them after the meeting. These interviews resulted in an increase of intrinsic knowledge base that influenced the interviews themselves chronologically. In other words, the results from interviews, the internship, and other talks, were used as input for new interviews. Once new information came to light that yielded new assumptions, the next interview would be conducted to test these assumptions. As stated above in Subsection 3.2.1, this resulted in different questions per interviewee. Figure 7 shows a visualisation of the influence of the chronological factor during these interviews. In the figure, assumptions turn out to be either correct or incorrect. In reality however, this may not be that determined, an assumption may be partially true. Moreover, there is a difference between testing assumptions and learnings. A learning is an insight you get during a customer interaction that you had no idea about beforehand.

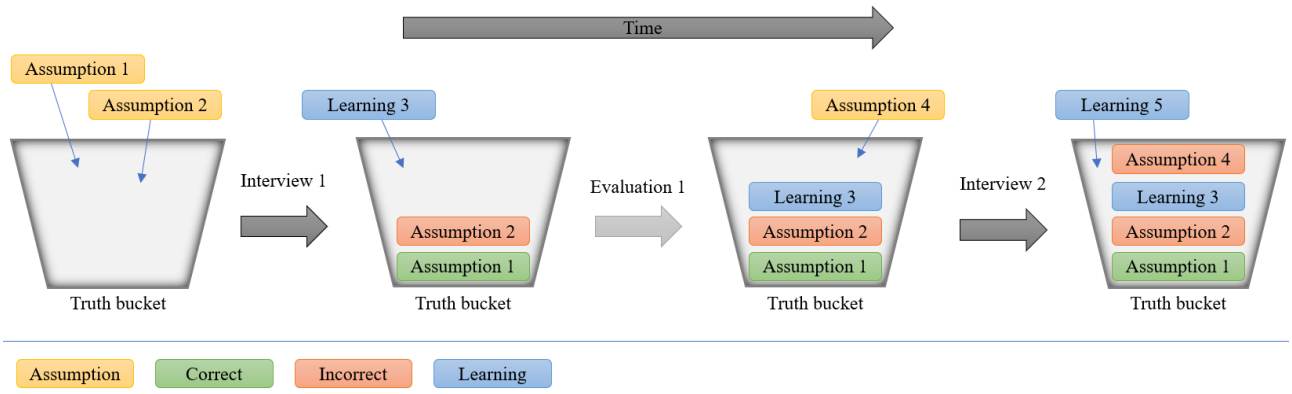

Figure 7: Visualisation of the learning process. The different colors indicate: non-tested assumption (yellow), correct assumption (green), incorrect assumption (orange) and insight/learning (blue). The truth bucket represents all the information that you have gained. Initially, you start with just assumptions. With each interview, you should learn new things and validate if the assumptions you have are correct. With this information, you can come up with new assumptions. In the next interview, you can validate these new assumptions. This is a continuous process that goes beyond customer discovery.

Assumptions that turned out to be correct or incorrect should stay in the 'truth bucket', which is a visual

representation of reality. For example: learning that a customer does not care about a certain feature is still the truth and should be taken in mind for further development. The correct assumptions from the truth bucket are translated into a framework called the Business Model Canvas (BMC) [45]. The BMC is a framework that outlines the different (validated) assumptions about the following aspects of your business:

- Key partners
- Key activities
- Key resources
- Value proposition
- Customer relationships
- Channels
- Customer segments
- Cost structure
- Revenue streams

Each interview yielded either new insights and learnings, or was used to validate the new information. In the first interviews, emphasis was put on gaining as many new insights as possible. Later in the process, the emphasis was on validating the insights. With the minutes, certain aspects or insights can be validated in hindsight. The BMC was iterated with each new insight. Figure 21 in Appendix C shows such a BMC at one point during the research.

4 Results

This chapter is written and structured based on the practical research questions explained in section 3.2. We can divide the section into three subsections: who is the customer (Section 4.1), what problem can we solve for the customer (Section 4.2), and how have other parties to solve this already (Section 4.3)? These practical questions are used as input for the theoretical research, which is presented in Section 4.5.

4.1 Who is the potential customer for plant sensing technology?

The search for a potential customer funnels in from market to market segment, and next to customer segment. The supply chain (up to traders) of crops is shown in Figure 8. The traders mainly deal with the produce of crops and not with growing crops (such as tomatoes from a tomato plant). Therefore, the traders are not included in this research. Also other parties such as packaging, processing, distributors, retail etc. are not included.

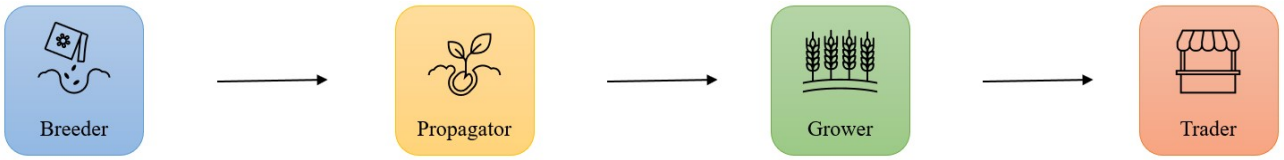

Figure 8: Simplified supply chain of crops in horticulture. Breeders create new improved varieties of crops. They then sell the seeds of these new crops propagation companies, that grow them into small plants. They sell these small plants to the grower that grow them in large quantities. The growers then sell the crops or fruits of the crops to traders such as supermarkets. In agriculture, breeders sell directly to growers.

In the following subsections, the market segments, market size and persona are explained. This method funnels in towards the specific customer.

4.1.1 Market segments and sociographic data

After initial exploratory interviews, the horticultural market was segmented as follows:

- Research Institutes
- High-tech Dutch horticultural growers
- High-tech horticultural growers abroad
- Low- and mid-tech horticultural growers abroad
- Autonomous data companies
- Breeders
- High-tech open-field farmers
- Indoor farming companies

As mentioned in Subsection 3.2.1, the interviews were used to get an understanding of different market segments and to find out whether the market segments are interesting to further investigate. Each of these market segments are elaborated: why they want sensors, how they currently use sensors and why they are fit for a beachhead market. To determine whether or not a segment is fit as beachhead market, Bill Aulet identified 7 questions that help in this determination. These questions are as follows:

- Q1: Is the target customer well-funded?
- Q2: Is the target customer readily accessible to your sales force?
- Q3: Does the target customer have a compelling reason to buy?
- Q4: Can you today, with the help of partners, deliver a whole product?
- Q5: Is there entrenched competition that could block you?

- Q6: If you win this segment, can you leverage it to enter additional segments?
- Q7: Is the market consistent with the values, passions, and goals of the founding team?

The list of questions mentioned above was slightly extended and adapted to a more relevant context. For each segment, the following nine aspects are mentioned.

End user	Who will use your product.
Application	What will your product be used for?
Benefit	What is the value that your user would gain from using your product?
Lead customer	Who are the first customers to use your product.
Well-fundedness	Is the customer well-funded?
Accessibility	Is the customer well accessible to your sales force?
Market Characteristics	What are the characteristics in the market segment that would hinder or help with the adoption?
Partners/players	Which companies will you need to collaborate with?
Size of the market	how many customers does this market segment have?
Competition	who is making similar products?
Complementary assets required	What else does your customer need to have to get value from your product?
Current use of sensors	How are sensors currently used by the customer?

Table 1: Overview of 5 types of problems

Note that not all aspects are answered for each segment, as some segments proved not to be of interest right away. Therefore, further investigation was not needed. In Appendix G the above-mentioned aspects are answered for all market segments. From this analysis, I concluded that our beachhead market is Dutch high-tech growers (and the growers in breeding companies as lead users) of tomato crops. The main reasons for this decision is the accessibility and the compelling reason to buy. The persona will be described in Subsection 4.1.3.

4.1.2 Total Addressable Market size for the beachhead market

The next step was to calculate the Total Addressable Market (TAM), to make sure this beachhead market segment is large enough to become profitable. The TAM size for the beachhead market was calculated using a bottom-up approach. In Figure 9 the obtainable value for one average Dutch greenhouse is depicted. This value comes from reduced labour cost, reduced resource costs and improved yield. This yields a value of roughly €300.000 per greenhouse. Following advice from Aulet, we can leave 80% of this value for the customer and take 20%, giving a value of €60.000. Given the fact that there are 2.360 greenhouses in the Netherlands, all with an obtainable value of this €60.000 yields a TAM of €140 million. Aulet advises to have a beachhead TAM between 20 and 100 million euro's (note that this is for the USA). We can further limit the scope to either peppers or tomato's, accounting for roughly 20-25% of the Dutch market [46], yielding a TAM of €30 million. The fact that this market can be extended by moving to other crops, other market segments (low- and mid-tech) and other countries makes this a promising market. This shows that the market is large enough to act as beachhead market.

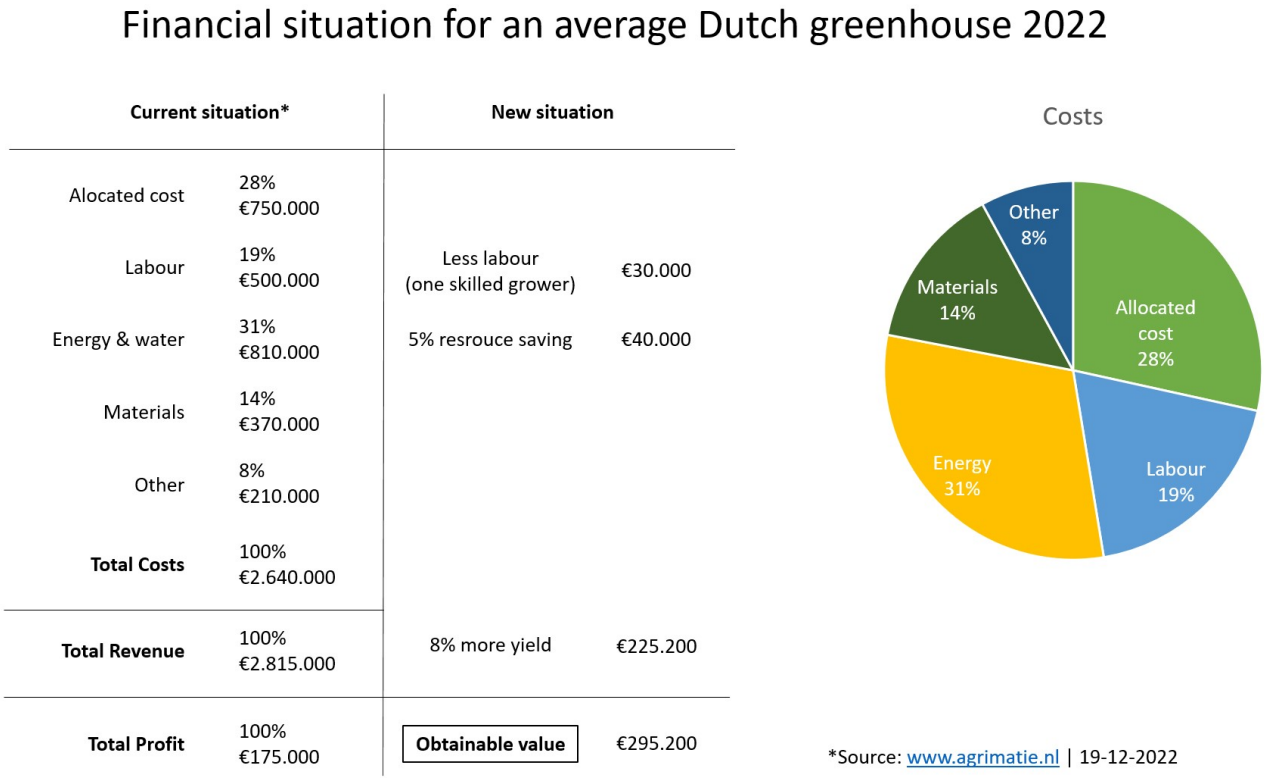

Figure 9: Obtainable value for an average Dutch high-tech greenhouse for sensor technology

In one of the interviews with growers we heard that two experienced Dutch pepper growers yielded 27.5 kg/m2 and 32.5 kg/m2 with the same facilities. This is quite a difference in yield and therefore revenue. If on average the yield was 30 kg/m2, the improvement from average to high yield is 2.5/30 kg/m2 = 8,3%. This percentage can go up to 40% for extreme cases [47]. If our system outperforms the high-yield growers, this percentage is even larger. An estimation is therefore an improvement in yield of 8%.

4.1.3 Profile the Persona

In this section, the persona is described. A persona is a composite of a person that represents your target customer. The average dutch grower is male and about 55 years old. He is very practical and straightforward, but most of all: very proud of his job. He does not have much free time as cultivation takes 7 days a week. Work is priority number one. Although he is 55 years old, he is still eager to learn. However, there are a few younger growers (around the age of 30), who are usually very entrepreneurial: these are the early adopters of growers. The persona is not quickly impressed by words: first seeing then believing is his motto. He learns more about new technologies and improving his cultivation strategies by:

- Consultants and advisors
- Large grower associations
- Small cultivation groups (8 growers)
- Courses (Het Nieuwe Telen)
- Sensor data
- Magazines
- Events

Learning to understand data and graphs takes quite some time and effort. Sensors are mainly used for learning, and once he has learned a new trick with this sensor, the sensor itself can be disregarded. He is constantly busy with crops: even at certain conferences or events he checks his greenhouse climate data on his phone. At

events he is usually not very eager to talk to new people, he is there to gather some information and talk to some friends, but preferably he will not talk to strangers. He has studied at the HAS green academy. He has a very large influence on his fellow growers and the other way around: when someone in their cultivation-group buys a sensor and is happy with it, the rest will follow soon afterwards. Another thing they are very keen on is confirming feeling. Someone we interviewed, an ex-grower, mentioned "growers will do anything to get their feelings and thoughts confirmed". The list above that shows how growers learn new things can also applied in this regard: they use sensors, consultants and the likes not only to learn, but also to get their feelings validated.

Between 2010-2020 dutch vegetable growers had a lot of revenue and therefore money to invest in new technologies and innovation. The war in Ukraine has however increased the price of energy vastly. This results in the fact that growers currently face severe problems with heating their greenhouse. This poses both opportunities and threats:

Threats Because the energy prices increased, growers have no budget left to invest in new technologies.

Opportunities Before 2022, growers had never looked at cost-saving cultivation. If yield can be increased with a higher temperature, they would not think twice and heat up the greenhouse. Their cultivation strategies have been optimized with this in mind. With the current prices, they have to alter their strategies and calculate the trade-off between costs and benefits of energy. *Growing on the edge* has been something they recently adopted, but they are in need of systems that can show where the 'edge' is. By the edge, it is meant that a plant can experience stress, rot, tearing of fruits of diseases if not properly handled.

Now the persona is clear, we can funnel in and learn more about its problems and how it tried to solve these.

4.1.4 New insights | Customer

From the analysis in this section, it was concluded that the first customer (the beachhead market) are dutch growers of high-tech greenhouses. The main reasons to choose this beachhead market were because they are easily accessible to our team, they are relatively well funded as they grow high-value crops and there is more control possible with data (i.e. change temperature) compared to open field crops. By interviewing different markets, we discovered that the customer for sensor technology were not breeders which were initially assumed. By determining the xylem vessel dimensions, we could measure e.g. drought resistance of crops. As breeders use experiments to measure several factors including drought resistance, measuring this beforehand did not really add value in the way we could provide it. Moreover, breeders were mainly concerned with resistance to diseases and know a lot by the DNA of varieties. Our assumption of value creation was wrong and we pivoted to growers (and growers within breeding companies). The Mom Test method allowed us to get objective feedback about our wrong value proposition and the CDM showed why it is important to talk to customers in the very first steps (as advocated in the CDM). If we just started building, we would have made something that nobody would buy. The first dead-end was therefore eliminated.

4.2 What problems can sensors solve for the customer?

In this section, the challenges the customer faces are explained, as well as how sensors can help with these problems. In general, there is a large trend towards data-driven cultivation. This is due to two main drivers. First, technology has already proven it can outperform growers in the autonomous greenhouse challenge of the WUR [48]. Second, there are hardly any growers anymore. In the Netherlands, 80% of all growers over the age of 55 cannot find a successor [49], resulting in exponential scalability of growers [50]. Combining this lack of growers with an increased demand for this sustainable way of food production shows the opportunity for data-driven growing. In Appendix D, the background and current state of the greenhouse sector is described.

4.2.1 Current Problems

As mentioned in Subsection 4.1.3, growers are always learning and optimizing their steering strategies. Questions that growers have where sensors can provide value are the following:

1 What time is the best moment of irrigation at the end of the day? During the night, you need a certain amount of digestion of the substrate. Too much water and the roots will rot, too little water and the plant will experience stress (Figure 10). Currently there is no robust way of measuring the plant stress due to water

shortage. However, a way to do so is the stem diameter sensor (see Subsection 4.3.1). This problem became evident after asking specifically about the irrigation strategy.

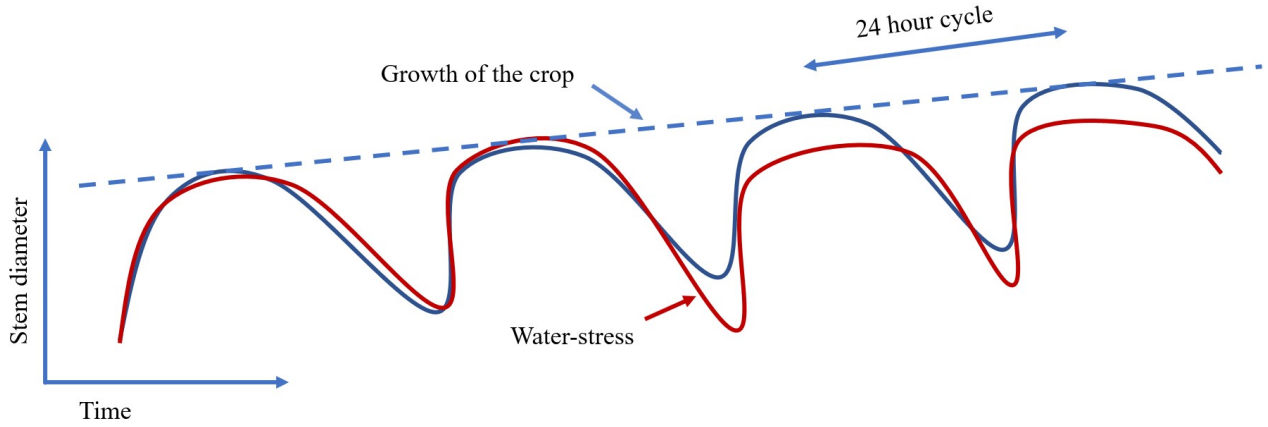

Figure 10: The irrigation of crops results in steady grow (blue line). With a moment of water-stress, this growth is hampered (red line).

2 When should I close the sunscreen? By closing it, I can keep heat in and thereby reduce the cost of heating. However, I will also block sunlight, thereby perhaps missing valuable production time. A stomatal camera or leaf temperature sensor could help here, because this shows the amount of photosynthesis. For the solution, the continuous dependency on sensors should be taken into account (see Subsection 4.3.1).

3 What does my plant want? Growers are always busy with a plant balance trade-off: is my plant growing generative of vegetative. Generative means it is sending energy to the fruits, which will result in revenue (more tomatoes equals more revenue), but hampers growth. Vegetative means sending energy to the leafs that take up sunlight and produce energy. Keeping these in balance is very important for stable and optimized yield. Until today, there is no sensor that can help in this regard and they use manual measurements such as the head thickness to guess the status. Figure 11 shows a hypothesized output that we expect (this is an assumption) our customers will find valuable. The next step is to test and validate this with customers.

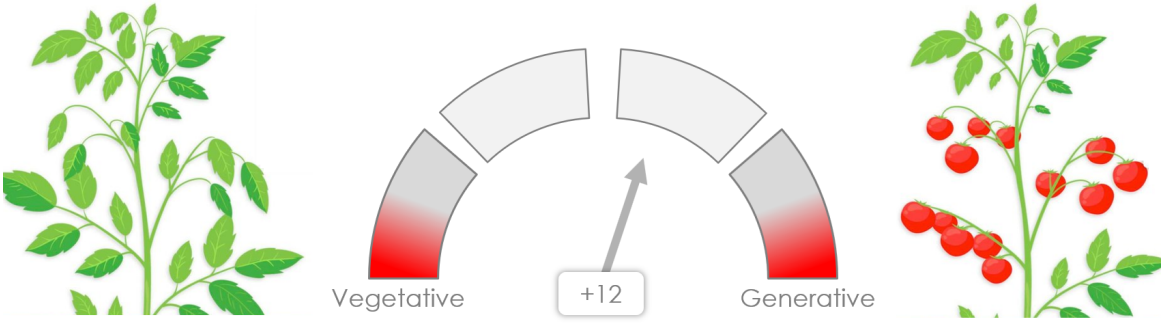

Figure 11: A hypothesized software output for our sensor that we think to be valuable for growers.

Note: we don't have software that outputs our sensor data to a quantified value for the plant balance such as shown in Figure 11, but it is a nice first step to get feedback on a hypothesized product.
Here it should be noted that some growers contacted me directly for a meeting. During this meeting, they came up with the fact that the vegetative/generative state is until today not something people have successfully measured with sensors. Without any lay-up, this was the problem that they wanted to have solved.

4 How much stress is my plant experiencing. To steer the plant generatively, it needs a bit of stress. But when am I using enough and when does it actually hinder growth? The stress sensor of the company Vivent can measure this. They are quite new in the market and therefore not widely adopted yet. However, many growers mentioned their interest in this sensor, but they had not yet pursued this method yet.

5 How much is the plant evaporating? By knowing this, I can see if more light is necessary. If I put on lighting, this costs money, but is it also improving yield? If not, it would be beneficial to turn off the lights. Here the leaf temperature sensor can also apply. However, current methods don't seem robust enough for many growers. Also for growing on the edge, knowing how much my plant is evaporating can reduce costs in winter. During these months, they want to have as little evaporation as possible because this requires a lot of money. They do need the minimum amount of evaporation though, to get enough nutrients to the top part. The related question is: How can I grow the same amount of produce with less energy consumption? With the energy prices rising, growers were very busy with reducing their energy consumption. Some emails in which I contacted growers to ask some questions got a reply such as: "[...] at the moment we have other focus points including energy, so unfortunately we cannot help you at the moment."

6 How is my plant doing? As stated in Subsection 4.1.3, growers are very concerned about their plants. When they are away from their greenhouse, they still check upon their climate settings to make sure they are right. But this is the environment, not the crop itself. Like a parent on a holiday who's child is staying at a babysitter, you would want to know if your babysitter is doing all right, but wouldn't it be nice instead to know if your child was actually all right? The fact that they usually check upon their climate settings right before going to bed shows the benefit of such a monitoring device.
This problem is very different from the previous problems. The previous problems were all about optimizing yield, whereas this problem is more about remote monitoring and becoming more scalable. With this problem, you don't need to measure new processes in the plant, but the sensor could be a replacement for manual measurements.

4.2.2 New insights | Problem

With the lack of growers, sensors and software allow a promising alternative to steer greenhouses. By collaborating with growers, not only do sensors improve yield, but they also make growers scalable to monitor large areas of greenhouses. More specifically, plant data can provide valuable feedback of the crop status, which can be used to both *improve* steering strategies, as well as provide *safety* and stability for growers. When we consider the irrigation system specifically, Figure 10 shows that how these strategies can be optimized. Moreover, an alarm system can detect these 'errors', thereby providing the safety that growers valued. Other value from sensors are remote controlling the greenhouse, better estimating the yield, reduce energy costs and for breeders give more targeted advice on new varieties. Although we did expect sensors would improve the yield, the stability and safety aspect were found to be very valuable for growers as well. Moreover, we did not know how we would improve the yield specifically. By getting to know how this is potentially done, a more targeted strategy to develop such a product can be laid out.
Many of our assumption concerning the problems of our customers were wrong. We thought the main problem of growers would be how much water they would need to give their plants. Although new insights were mentioned as one of the uses for sensors, this does not result in a sustainable business. Once a new insight has been learned, the sensor can be disregarded. A better use to sell data would be what we call the 'babyphone' solution. Most growers know quite well what their plants need, but once they are away from their greenhouse, they want to check upon their crops. Currently they already check their climate settings at night or when away, but not the crops themselves. This shows that for this solution, real-time insights are very relevant. For the 'new insights' solution, data on-demand is less relevant. The Mom Test method was a very valuable tool to get towards these insights. Furthermore, the interviews with organisations such as Priva and Letsgrow showed their understanding of the customer. Here, a more directive approach to interviews can be used. One interview with a business developer from Priva was very insightful after we asked: 'we can measure the water content in the plant. How does this help growers?'
A great way to get a deeper understanding of the customer is via an internship. This revealed not only their workflow, but also their motivation, culture and e.g. what they talk about in their coffee breaks. Knowing their extreme care and concern for their plants showed how the aspect of remote monitoring could solve a large problem. This did not become apparent during interviews. The internship also helped with creating sympathy from customers. Showing you are willing to learn and invest time in getting to know the customer needs paid off later with e.g. setting up pilots and even getting funding.

4.3 How have other parties tried to solve the problems?

As stated in the section above, several problems that growers face already have a solution. However, these solutions are hardly used. In this section I dive deeper into these solutions by implementing the TAM. Furthermore, the landscape is given to show what is already possible.

4.3.1 Current solutions

Next to all interviews with potential customers (Figure 6), I attended an event about sensors in horticulture, specifically targeting growers. The organization held several workshops for growers, and fortunately I could attend these. Using a mentimeter, the adoption was gauged, where roughly 30 growers could privately answer the questions. They asked four relevant questions:

1. Which sensors do you currently use?
2. What is the perceived value of these sensors?
3. What kind of (new) sensor would you want?
4. What hinders you to adopt new sensors?

In Appendix I, the results of this questionnaire which have been published are shown [51]. In Figure 12 I summed up the results from both the interviews and the questionnaire using the Technology Acceptance Model. Note that the Dutch word 'controle' means checking and monitoring, whereas the English word 'control' means steering. The costs should be implemented after attitude as this will always be a trade-off for the actual use. In other words: the perceived value of sensors should exceed the costs to be used.

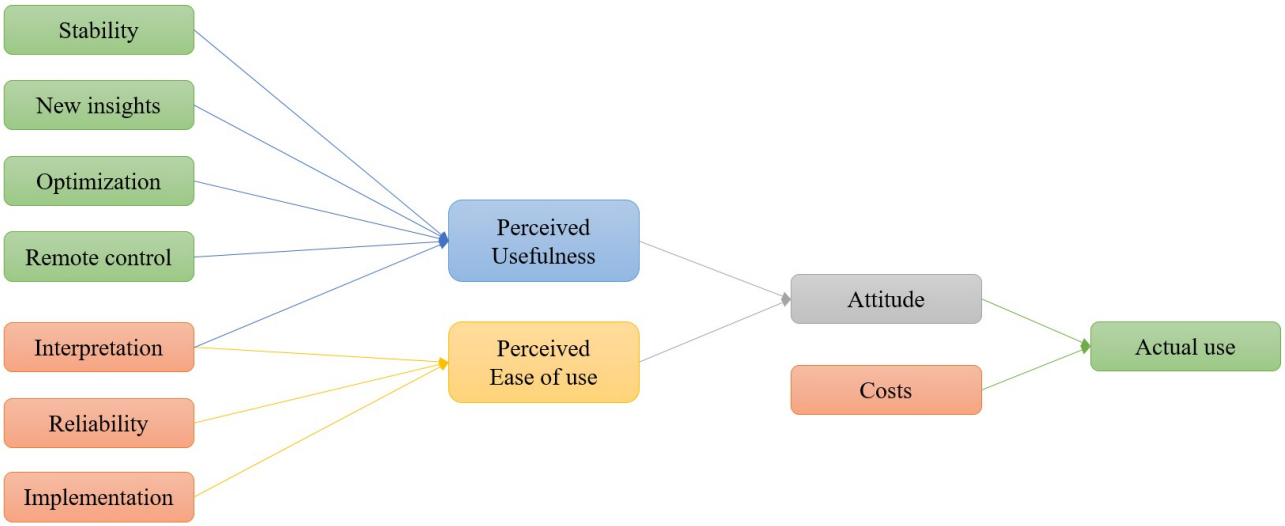

Figure 12: Technology acceptance model of sensors in horticulture. The green blocks summarize the value of sensors as stated by growers. The orange blocks summarize the barriers to use sensors as stated by growers.

In the next paragraphs, both the drives and barriers of the TAM in Figure 12 are elaborated.

Stability In the interviews and the mentimeter, growers will not likely tell you that a sensor can outperform their subjective measurements. The strategy to solve a problem that they will not explicitly mention is to attract them to other parameters and let them find out your solution. In our case, we will optimize growth processes. However, this is not how we will sell to the grower. For the grower, our product supports the grower with clear insights, more control and more certainty. The reality is that it will result in higher yield, but that is for the grower to find out. By telling a grower you can increase his yield can put you on a bad foot ("these guys don't know what they're talking about, I have been optimizing my yield for years").
What they do mention however, is that it is nice to have their knowledge checked. Several growers mentioned "meten is weten" (measuring is knowing) and they do see value in that. It is as if someone has been driving his car (without speed meter) for over 40 years and know roughly how fast they are going. But it is still nice to see how fast you are actually going. By knowing this, you can drive better on the speed-limit and thereby get faster at your destination without speeding fines. This analogy actually makes sense in greenhouses if you consider the vegetative-generative state shown in Figure 11. Too vegetative and you will get not many tomatoes (in the analogy: you are driving slower than the speed limit and you will arrive late). Too generative and you will get many tomatoes in the short term but it will cost you growth in the long term. In the car-analogy you arrive sooner, but you do get a fine for speeding. Growers know roughly how fast they are driving, but wouldn't it be nice to have a speed sensor to see if you are actually driving the speed limit?

New Insights A very important aspect in Figure 12 is the 'new insights' part. During the interviews, it became very clear that growers used sensors to learn. As already stated in Subsection 4.1.3, growers are very eager to learn and they use sensors to do so: learn new tricks. However, after they have learned a new trick, sensors can be disregarded. For a sustainable business, this barrier must be overcome, because for a sustainable business it would be more beneficial to have a sensor that provides value continuously instead of only temporarily. More than once did growers mention the leaf-temperature sensor of 30MHz from which they had learned to close the sunscreen earlier and after this learning they returned the sensor.

Optimization Besides new insights that lead to higher yield (which is an incremental form of optimization), another optimization is also possible. By getting faster and objective feedback of your crops, you can optimize yields. However, this form of optimization was hardly named in the interviews. Also in Appendix I, optimization is hardly named.

Remote Control As stated in Subsection 4.1.3, growers are busy with their crops 24/7. During an event I tapped a grower on his shoulder (he was easy to spot from the persona) to ask a few questions (which he agreed to). I noticed that before I bothered him, he was looking at his phone, where the data about his greenhouse was shown. Even during events, they want to make sure their crops are okay. Several growers referred to their plant as their "babies" during interviews. Plant data that gives growers the opportunity to monitor their crops even when they are not around is therefore seen as a benefit.

Interpretation For this section, I used the literature on Information Design, edited by Jacobson [52]. This paper mentions the *continuum of understanding*, where data culminates towards wisdom. I adopted this method for the use case, which results in Figure 13. This figure is my own vision and interpretation of the menti-meter results from Appendix I, the many interviews with both growers and software companies, the internship, (online) readings and attended events. By improving the interpretation of data, the both usefulness and perceived ease of use can be improved. In Figure 13, I hypothesize the way to do so.

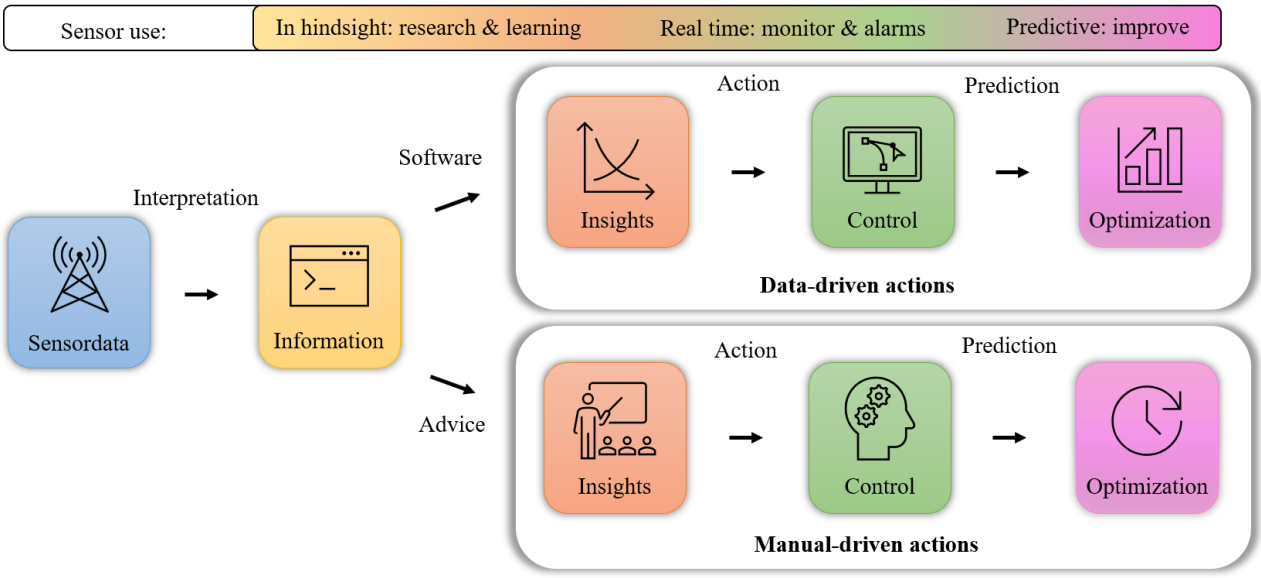

Figure 13: Value for sensor data, which starts at insights. To bring value to the customer, two ways are possible: data-driven or manual-driven. The more you move to the right, the more value you bring.

I hypothesize that the more your product moves to the right in Figure 13, the more value it brings to the customer. Note that the arrows (improving the interpretation of data) not only improve the perceived usefulness, but also the ease of use. The clearer information is brought to the customer, the more value it brings. There are two ways to do this: via software (data-driven actions) or via advice (manual-driven actions). Bringing data to the customer via software can be done yourself or by collaboration with software companies. These software companies will be elaborated in the following section. The second way to do this is to explain manually what the data means. The grower can use this information and combine it with his knowledge and expertise to optimize yields.

Reliability Reliability can be improved by improving hardware and/or software. In any case, this seems like a rather logical issue that should be solved. When interviewing software companies, robustness was also the main issue with current sensors. Although these companies were actively looking for sensors that could input their algorithms, current solutions were not good and robust enough to do so. This is something we will focus on in the next phase when building our hardware: making it as robust and reliable as possible.

Implementation The implementation issues with sensors have to do with the hardware itself: how to make it robust and making it easy to implement.

Costs As stated above, the perceived value of sensors should exceed the costs to be used. In Appendix I it becomes clear that investment costs is still the main barrier for adoption. We can interpret this that the Return Of Investment (ROI) is unclear of lower than the customer is willing to pay. This is actually also something that is hard to calculate: how do you measure the worth of your insights with which the grower can optimize his yield? Many influences, such as weather, crop variety and energy prices make it hard to estimate the ROI solely based on the sensor itself.

4.3.2 Landscape

Here, the landscape of competitors and partners involved in data-driven cultivation will be described. A more detailed background of the market is given in Appendix D.3. Consider the high-tech greenhouse market in Figure 14 (middle part). By implementing plant sensors, you can close the loop in autonomous control (right part). For more information about the different levels of greenhouse autonomy see Figure 24 in Appendix D.3.

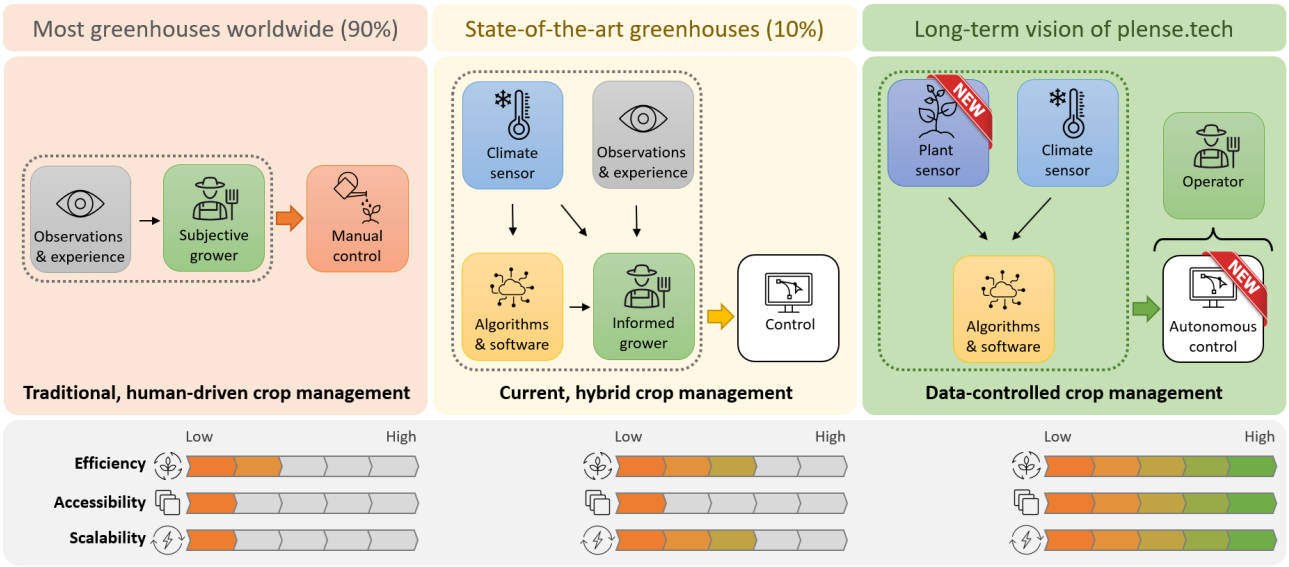

Figure 14: Low-tech greenhouses (left), current high-tech greenhouses (middle) and envisioned future greenhouses (right).

The difference between a primary and secondary customer should be explained. The primary customer is the end user, the one that uses the product. The secondary customer is the one that pays for the product. A good example is a children toy. Even though parents buy these toys, they should be designed for children. In this example, a child is the primary customer and the parent is the secondary customer.
Although the primary customer will always be the grower, climate computer companies or software companies could be a secondary customer. We don't know yet how this would work in a business model (i.e. who pays for the data). One solution would be to provide the hardware for a small price to the grower, but maintain a subscription fee for the data to software companies. As most software companies have only recently started, there is no industry standard for such a collaboration yet.

Figure 15: Use of sensors with software company as channel where the software company translates data and information into advice, control and optimization.

In Figure 16 all parties I interviewed that are involved in data-driven growing are placed. Note that this is a simplified 2D model of the reality. For example, Quantified and Aranet develop very different systems, but both have their core in hardware and are thus placed in the same box. Most hardware companies acknowledged that they only bring value if they can provide at least insights. This can be done by providing software (by themselves or by collaboration with a software company), or by delivering consultancy services. What is interesting is that the companies involved in consultancy have roots in Wageningen, the agricultural university of the Netherlands, whereas the companies coming from a technical background are solely hard- and software focused. What is interesting, is the gap between sensor companies and software companies. Many talks with software companies revealed that sensors are until today not robust enough, but we also noticed that the cooperation between these companies is starting and we expect this gap to be bridged in the near future.

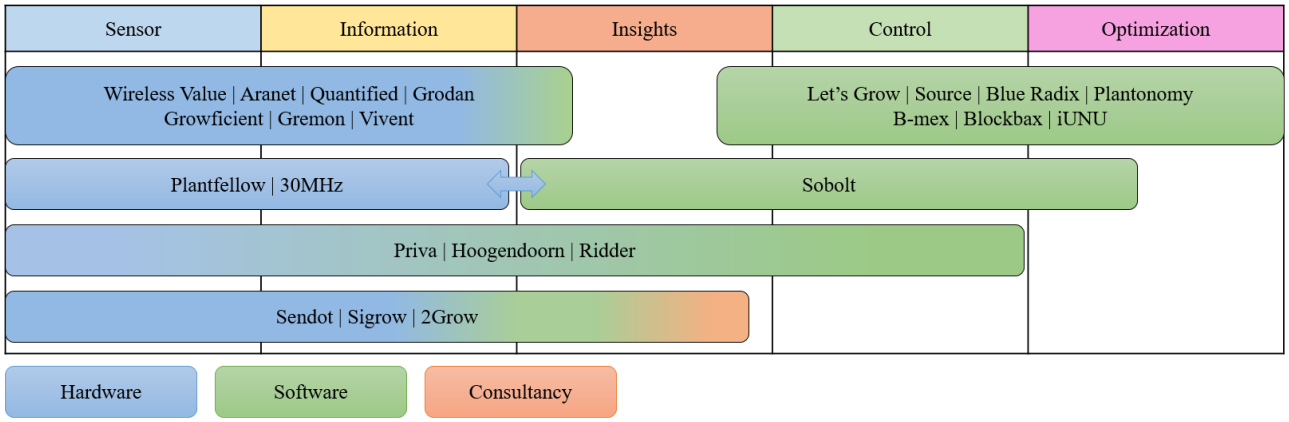

Figure 16: Data-driven growing: a 1-dimensional landscape of companies involved in data-driven cultivation methods. With color, the core of each company is indicated.

Note that Ridder, Priva and Hoogendoorn are very large companies that also have their own software solution. For Ridder this is still unknown, Priva has Plantonomy and Hoogendoorn has Let's Grow which is a spin-off company on itself. These companies are the dominant players in the market, where every grower of high-tech greenhouses has a climate box from one of these three companies. Furthermore, Aranet and Wireless Value don't develop sensors themselves, but they have specialized in taking commercial sensors and making them wireless.

4.3.3 Competition versus cooperation

From Figure 16 it can be seen that there are different ways to go from left to right and improve value: by providing consultancy, by developing software, or by collaborating with software companies. Our vision is to make high-performance cultivation efficient, scalable and accessible to anyone, anywhere. We want to refrain from consultancy, as this is not scalable. Still the question that remains: do we develop software ourselves and compete with companies such as Source and Blue Radix, or do we cooperate with these companies?

A widely adopted framework to chart the competitive landscape is provided by Porter [53] with its so-called five-forces model. However, a framework that is more suitable for the specific case-study is provided by Gans et al. [54]. This framework helps in assessing the positioning inside Figure 16. He builds upon the work of Teece et al. [55] in which it is mentioned that there are two central elements that determine to what extend the market requires collaboration or competition. The two elements are "the nature of the appropriability environment and the distribution of ownership and control over specialized complementary assets". The latter suggests a

vested structure that is semi-definite, such as a manufacturing plant or loyal customer base. The former means competitors that can easily copy your proposed value. Gans refines this analysis where emphasis is put on start-up innovators versus asset owners.

Appropriability In our case this type of appropriability is in the form of Intellectual Property Rights (IPR), which makes the nature of our appropriability quite strong. A cooperation strategy is therefore an attractive choice. This may sound paradoxically if you acknowledge the fact that with strong IPR you can get a competitive advantage over the existing party. However, here it must be mentioned that profits associated with competition are lower than the profits associated with monopolization. Therefore, cooperation is beneficial. In the words of Gans et al.: "the gains from [cooperation] will include the avoidance of costly duplication of investments, and these gains will be shared between the partners in the collaboration" [54].
Next to IPR, the technology in our case is so complicated (3+ years of technology development) that to copy it would take serious financial resources. In general, the effectiveness of cooperation depends on "whether start-up innovators can credibly threaten to compete with potential partners".
Here it is also relevant to mention that most incumbents have mentioned to be hardware agnostic and state so to the public. Appropriation of hardware is therefore not expected.

Assets In our case, assets are not necessarily expensive manufacturing plants, but rather loyal customer base and a head-start. To wit, in our case, one end-users suggested that we should contact the software companies and if the software company would use our technology, he would be open to it as well. As the end-user is leading, this shows that cooperation is preferred over competition.

Can innovation by the start-up preclude effective development by the incumbent?	Do incumbent's complementary assets contribute to the value proposition from the new technology?	
	No	Yes
No	The Attacker's Advantage	Reputation-Based Ideas Trading
Yes	Greenfield Competition	Ideas Factories

Figure 17: Commercialization strategy environments [54]. The Attackers Advantage indicates that competition is fierce. In this environment, start-ups have an opportunity to capture market leadership by effectively developing and diffusing competence-destroying technology. Ideas Factories on the other hand suggest cooperation is the most effective strategy because profits can be shared amongst market players and together these profits can be increased while development costs are reduced. Reputation Based Ideas Trading means that established firms should encourage start-ups to approach them based on a reputation of fairness. The established firms should foster such a reputation, as start-ups are naturally not inclined to develop products in this quarter. Greenfield Competition has the most room for a first-mover advantage and the start-up has the power to choose its commercialization strategy.

For our use-case, incumbent's complementary assets do contribute to the value proposition from the new technology due to the loyal customer base and the innovation by the start-up can preclude effective development by the incumbent due to a strong IPR position. This leads to a preferred Ideas Factories strategy (Figure 17), where cooperation is key.

How to leverage your bargaining position When the *ideas factories* commercialization strategy is chosen, "the key issue is no longer whether to pursue a cooperation strategy but when and how" [54]. Two ways to enhance bargaining power are specifically mentioned. The first is that the value offered must be clearly signaled and demonstrated to the customer. To secure independence and improve our positioning in the cooperative/competitive landscape, it is important to provide value to end-users independently. In our case, this means some form of software to get insights to the customer should be implemented. The second is to let established firms bid against one another. By doing so, the position of the established firm relative to the start-up decreases. By talking transparently with all parties involved in data-driven cultivation, this can be achieved.

4.3.4 New insights | Solutions

Sensor- and software companies are on the rise. However, sensors are not yet widely adopted. The TAM model in Figure 12 shows the main two problems with the adoption: interpretation of data and robustness (robustness comes from both reliability and implementation). We have learned that some growers know exactly what they are doing, so parties saying their sensors will improve or optimize yield is responded to with skepticism. Marketing the sensors as stability and remote control (like a babyphone for parents) may be a better selling point. For the specific irrigation problem, both load scales and soil water content sensors exist. The soil sensors measure the water content in the soil. By doing so, you can monitor the decrease of water during the night, but not the moment of plant-stress due to water shortage.
What stood out was that there are already numerous solutions for the problems that growers mention, but hardly any of these solutions are being used. Simultaneously to developing our product, we will further investigate the limitations of the current solutions. To wit: why develop a whole new technology if an adjustment on an existing technology may already provide the same solution. This will be done by running pilots with customers, where both the customer and we get to see the data. This will provide valuable feedback on the limitations of the current solutions. By finding out how others have tried to solve the problem, the focus on product features became apparent and showed how we can develop a product that not only solves the customer problem, but also outperforms the competition based on what the customer values.

For software companies, the need for sensors was very different. Autonomous growing is very much on the rise, and just like autonomous cars, data that input the algorithms is needed. Although the largest software company Source states it is hardware agnostic, the data has to come from somewhere. Knowing at this stage that software companies are developing autonomous cultivation software is crucial for understanding what to build. That is to say: growers have already invested in a software platform that helps in their cultivation strategies. This shows that this aspect of the data-driven landscape is already saturated and we should focus on the hardware part.
Moreover, talking to other hardware companies showed how they solve customer problems. Although some of these companies could be considered competition, developing a solution that not yet exists would be beneficial for all. With our unique technology, we aim to solve a problem that is not yet solved, instead of copying other companies.

4.4 Towards Customer Validation

The overarching problem in the sector is the increasing lack of experienced growers. This problem is mainly visible at companies that are scaling and buying up greenhouse facilities from retiring growers.
Below this overarching problem, several sub-problems were found as stated above. What stood out was the number of problems growers still had, where we thought current solutions would already suffice. What was most noticeable was the stem diameter sensor (which output looks a lot like our sensor output) that was not adopted at all. When asking why growers didn't try the sensors that could help them with their problems, the barriers mentioned in Figure 12 kept being repeated. The three hypothesized critical barriers for sensor technology adoption are the following:

1. Limited translation from data towards insights
2. Lack of stable data due to non-robust clamping mechanism
3. Lack of stable data due to non-robust sensing method

To really find out the attitude towards sensors, the next step is to test to what extend these barriers form the bottleneck and how these problems can be solved. This follows the customer development insight cycle (Figure 18) from Blank's Startup Owner Manual [1]. As we have heard diverse answers, interviews are not sufficient to get a clear answer. Following the Lean Startup Method, the best way to approach this is to get a prototype in front of your customer. However, in my case we didn't have a working prototype. What we did is we took a commercial sensor and used this to test some hypotheses.

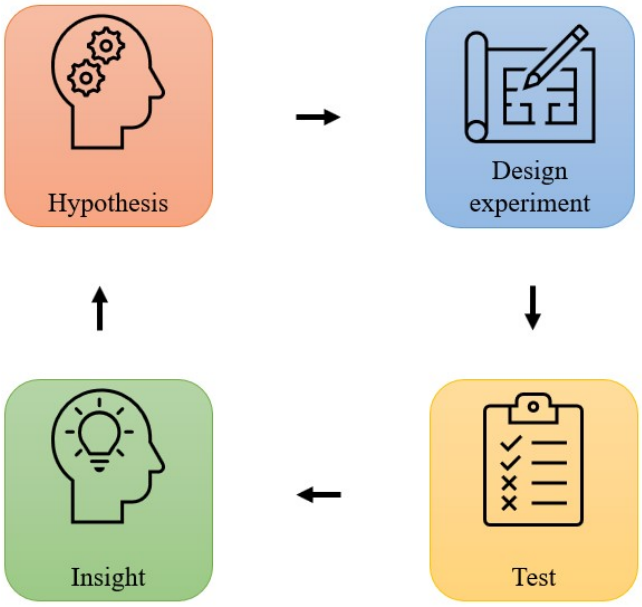

Figure 18: The Customer Development Insight Cycle [1]

Here we are going from customer discovery into customer validation. In customer validation we will run pilots at lead users to get feedback on our prototypes and software. The framework of Silva [36] mentioned in Chapter 2 provides an useful framework for the pilots during customer validation. Here we will focus on the bare necessities and requirements that work towards a Minimum Viable Product (MVP). However, if possible we will also provide several ways to get our information to our client, thereby testing already different approaches. In the pilot with the lead user, we will show hypothesized outputs such as shown in Figure 11. Simultaneously we will use current solutions and investigate why these solutions are not being used throughout the market.
A MVP is different from a prototype. A MVP can already be sold (although to a limited customer base) and therefore generate revenue. A prototype on the other hand is the first part of a solution used as sample to test your solution. Although you can get paid for testing your prototypes, calling it a prototype (instead of a MVP) allows you to test with less expectations.

4.5 A new Framework

By interviewing many potential customers, we found out the problems our potential customers faced, which is extremely important for our product development team. We did so by following the CDM, which emphasizes the importance of understanding the customer and their needs. It encourages entrepreneurs to iterate quickly and make data-driven decisions based on customer feedback, rather than relying on assumptions. The framework provided in Figure 1 provides good guidance, but some alterations are made to improve it as mentioned in Subsections 4.1.4, 4.2.2 and 4.3.4. These are the addition of the coaching program, internship, and the nondirective interviews with suppliers and competitors.

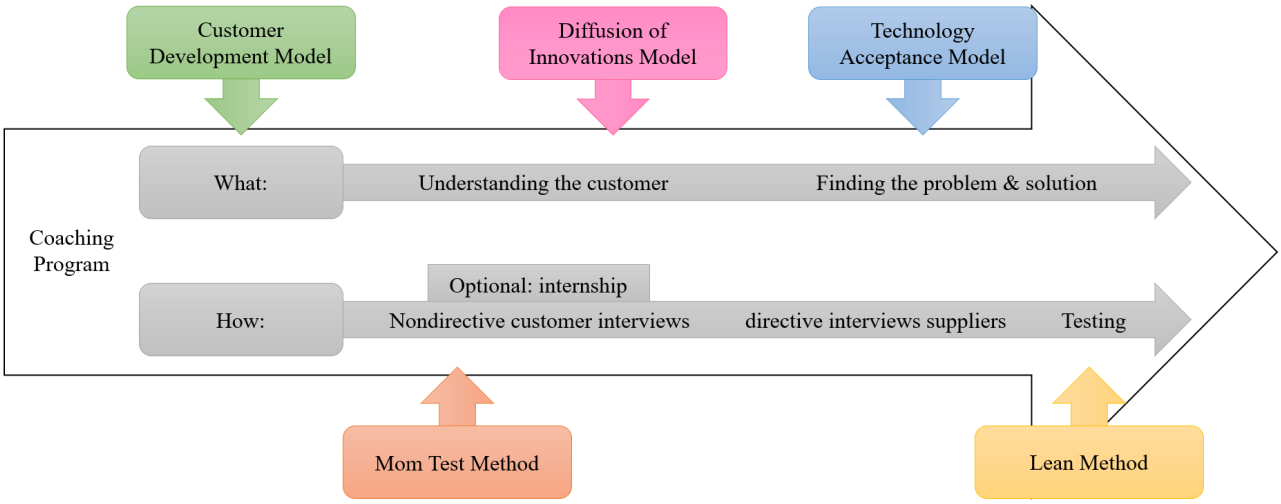

Figure 19: The new framework for customer discovery in an existing market. The CDM helps to structure what steps to take. The Mom Test method and Lean method help you in answering how you should take these steps. The DoIM helps in structuring customers and personas with a different problem and helps in selecting the innovators to sell to first and the TAM helps in structuring current solutions. Each model and method becomes relevant at a different stage during customer discovery, as indicated with arrows. The presented framework should be combined with following an incubator program.

In Figure 19, the core principles are depicted in grey. The coaching program is used throughout the journey and helps in all essential aspects. The colored blocks provide in-depth information about the different aspects. The new aspects compared to the framework in Figure 1 are explained below and discussed in Chapter 5.2.

4.5.1 Coaching Program

The literature should be combined with a coaching program. During customer discovery, a program that highlight the different steps and coaches that push you in the right direction was found to be of great value. The internship that was carried out was the idea of our start-up coaches. This was not described in any of the books, but it gave great insights in the motivations and characteristics of the personas.

4.5.2 Interviews

As stated in Subsection 4.1.4, the Mom Test should be applied to customer interviews, but a more direct approach can be applied during interviews with suppliers. As they understand the customer, they can think along with applications for your technology. You can simply ask them: this is the solution, how would this help the customer? One of the benefits of the nondirective interview technique for customers is that this limits them from just saying what you want to hear. Although this applies for suppliers as well, you can use their experience of the customer to your advantage. By explaining your idea, they can give insights in how this may solve a problem for your customer. This should be tested with non-directive interviews with your customer (the Mom Test method).

4.5.3 Internship

The internship suggested by the start-up coaches proved very insightful in two ways: we got to know the customer very thoroughly and we gained credibility in the sector.

5 Discussion

In the next sections, the research is discussed. The sections discus the method (Section 5.1), results (Section 5.2, which includes the answers to the research questions) and recommendations for future research (Section 5.3).

5.1 Methodology

In this thesis I used the use-case of my own start-up to apply the framework, which has some benefits and some disadvantages. These are described below.

5.1.1 Benefits

The use-case allowed me to go very deep into the material, making the research conducted very thorough. Instead of generic methods, a practical and usable perspective is given, which can help future entrepreneurs in understanding certain aspects in detail. Moreover, the thesis was written during customer discovery instead of long after. This results in the fact that the research is closely related to starting entrepreneurs that still have to discover a lot, instead of by experienced entrepreneurs who can already see the big picture. This might expose insights that are obvious for more experienced entrepreneurs and therefore neglected. Next to that, Shepherd et al. state that "Startups are difficult to study because it is challenging to identify individuals engaged in entrepreneurial behavior before they form an organization" [7]. This study tackles this difficulty by increased contextual understanding of the methods and models. Furthermore, one of the goals of this thesis is to bridge the academic-practice gap. Because the thesis is written from an initial practical perspective, it has increased practical relevance compared to studies written from solely academic perspectives. As literature gap is also missing practical relevant studies, this study partially fills this gap.

5.1.2 Limitations

This research method also has its limitations. The main limitation is that the use-case is very specific as N=1. This makes certain aspects perhaps true in this case, but not relevant for other technologies. For example, A/B testing is advised by Ries in the Lean Startup, but you have to be very careful to do this in the agricultural market. As all growers are much in contact with one another, you can easily destroy your reputation by shipping wrong products. The framework has been designed in a way that it should apply for start-ups in general. However, there could be missing parts that are less relevant for this use-case. For example, in the medical market, an internship could be less beneficial. The skill or certification required to be present with certain operations might limit the practical usability of this method to understand the customer. Another limitation is that an alternative to the customer discovery method is the product development method, where focus would be on developing the technology instead of understanding the customer need. As we chose to pursue the customer development method, we don't know how the product development method would have played out. In his book Zero to One, author Peter Thiel states "[...] companies are not experiments. To get a scientific answer about Facebook, for example, we'd have to rewind to 2004, create 1,000 copies of the world and start Facebook in each copy to see how many times it would succeed. But that experiment is impossible. Every company starts in unique circumstances, and every company starts only once. Statistics doesn't work when the sample size is one." [56]. However, with some certainty I can say that just developing technology and trying to sell it would be catastrophic. During an interview with an Israeli company, we spoke with a lady who was very frustrated with the fact that she tried to help her customers, but they just wouldn't buy. She mentioned that the customers didn't understand that she could help them. In hindsight it was very clear to see why this happened: she just did not understand the customer well enough.

5.2 Research questions

In this section the two theoretical research questions will be discussed.

5.2.1 Which scientific models and methods result in an integral but comprehensive framework for starting entrepreneurs and how can they best be applied?

First, the general framework of Figure 19 is discussed, after which all aspects are discussed separately. The models and methods presented in the literature (Figure 1) provide a general framework for the use-case, because a lot of new insights were found using this framework. By using the approaches stated in the different models and methods, I could objectively and early on discover what to build, and, more importantly, what not to build.

The new framework of Figure 19 has some alterations compared to the framework of Figure 1 described in the literature study. The main differences are the introduction of directive interviews with suppliers, the internship and the addition of the coaching program.
From the literature study, the lessons from other failures and successes are used to shed a light on the path towards success. The general message is 'learn fast'. This can be done by failing fast yourself, but a better way is to learn from the failures of others. This is not only faster than failing yourself, but it also prevents limitations in traction and credibility of your own start-up. Within the models and methods described, I argue that the interaction between the start-up and competitors (or other suppliers for that matter) is insufficiently described. Although the emphasis to 'get out of the building' is clear, it often only refers to talking to customers, instead of suppliers and competitors. I suggest that this is a key part of the customer discovery phase. Although this may be awkward because they operate in the same field, knowing exactly what already is possible also refrains you from developing something that already exist. Refraining from competing with current players is also beneficial for these current players. Using this argument, setting up interviews with suppliers may be easier and less awkward than initially assumed.
It is important to note that a single framework cannot fully encompass the complexities of starting an enterprise. The research objective is not only to develop an integral but also comprehensive framework. Integrating additional methods or models into a framework can undoubtedly enhance its efficacy and scope, but it is crucial to recognize that such additions may also introduce a level of complexity. While complexity can offer depth and comprehensiveness, it may simultaneously present challenges for practical implementation and understanding. When considering the improvement of a framework, it is essential to strike a balance between the benefits gained from incorporating additional methods or models and the potential drawbacks associated with increased complexity. Moreover, time is one of the most valuable resources a start-up entrepreneur has. Extending the framework results in more time required to grasp all methods and models. This time could be at the cost of going out of the building and talking to customers, lesson one of the CDM. At one point, more literature, coaching and lectures does not provide extra value, you just have to go do it. To illustrate this point, Horowitz states: "the only thing that prepares you to run a company is running a company" [57]. This is not to say that additional models and methods would not be beneficial, but more to illustrate the trade-off between integral and simple. To address this potential issue, it is crucial to ensure that the framework's complexity is managed effectively. This can be achieved by providing clear explanations, guidelines, and practical examples that illustrate the application of the framework in real-world contexts. Striving for simplicity without sacrificing depth is essential to ensure the framework remains accessible and usable for its intended audience.
Although the methods and models mentioned in the literature have been widely praised by many entrepreneurs, they are not a guarantee for success. Each startup journey is unique and several aspects mentioned in the books should be carefully considered. One of these elements is the fact that in agri- and horticulture, failing fast (as advised with The Lean method) does not work. With the influencing role that growers have on each other, failing fast could be very disadvantageous, as was the case for the company 2Grow. Moreover, since I have not read all literature where other methods and models are given, it could very well be the case that certain models are missing in the framework. Although I asked some entrepreneurs if I was missing books in this framework, most agreed that the ones mentioned in Figure 19 were the most important ones. The impact of the implementation of the framework on the success of a new venture is not examined, because the venture is still in its infancy. However, the metric of new insights implies that the right steps have been taken so far.

In the following paragraphs, the different aspects of the framework will be individually evaluated.

Understanding the customer The relevance of the customer-oriented approach became clear directly during this research. Knowing both the way our sensor could provide value, as well as the current challenges with sensors that already are out there, helped us already. Not necessarily in designing a product that fits demand, but rather in refraining from designing a product that doesn't fit demand. The thorough understanding of the customer is so important, because often customers don't know what they want, or can't articulate this. Sensors, initially assumed to improve yield, could mainly help with a feeling of safety. Although customers wouldn't say so in interviews, this became apparent during the internship. This highlights the importance of really *understanding* your customer. The challenges with current sensors implicates we should focus on robustness and reliability during development. Moreover, just hardware will not provide any value for growers. A software solution that does not show data, but shows e.g. an alarm, should be incorporated in the development of our products. I am certain that without the extensive customer interviews, our product would not solve a customer problem. Several dead-ends have been found during the customer discovery by following the CDM and applying the other models and methods.

The DoIM was relevant to map each interviewed party into the different adopter groups, because when launching

a first prototype/MVP, you want to do so with the innovators. However, without this model it is quite clear that some parties react more open-minded to your value proposition in contrast to the more conservative ones. Remembering which parties are more striking as early adopter proved valuable, as we started a (paid) pilot with one assumed early adopter right after the interviews.

Finding the problem & solution In the CDM, I found that competition or existing solutions are insufficiently described. When entering an existing market, you can use competitors to your advantage. In our case, many sensor companies already existed in the market (we entered an existing market) but were hardly adopted. Questions about why certain technologies were not used provided very valuable insights in the requirements and perceived value from the customer perspective. The question 'how did you try to solve this' as mentioned in *the start-up owners manual* revealed this, but it should be explicitly mentioned. The Technology Acceptance Model (TAM) can be seen as a complementary framework to the CDM. The TAM proposes that perceived usefulness and perceived ease of use are the two main factors that influence an individual's intention to use a technology. Perceived usefulness refers to the extent to which a technology is seen as useful for achieving a specific goal or task, while perceived ease of use refers to the degree to which a technology is seen as easy to use. By incorporating the TAM into the CDM, entrepreneurs can better understand how their target customers currently perceive products in terms of usefulness and ease of use. This information can then be used to build a product and make it appealing to potential users. Moreover, the TAM can be used with existing technologies to learn what mistakes not to make. The TAM is often found to be useful in understanding individual adoption decisions for technology in detail, in contrast to the more generic models such as the diffusion of innovation (Figure 4).

Interviews The non-directive interviewing technique worked very insightful, especially when interviewing breeders. It showed there was no real demand for sensors to monitor crop factors such as resilience. It also showed how certain competitors seem to 'get' the method. During the interview with e.g. Quantified Sensor Technology, the people we wanted to interview were asking a lot of questions, which forced us to talk more and listen less. According to The Mom Test, the main objective during interviews is to listen. It was as if there was a battle of who could let the other party talk more. We had a hard time to let them do the talking. This was in vast contrast to e.g. 30MHz, who were asking no questions and only answering our questions.
It is very advisable to always go to interviews with two people, so one can ask questions and the other can write down the answers. This helps to streamline interviews and make sure you get the most out of it. But even more important: afterwards you can discuss what you heard during your interviews. During customer discovery you are absorbing huge amounts of information and sometimes certain assumptions turn out to be so wrong that you question your whole business. By discussing these interviews with one-another, you can use the interviews to get a better sense of your problem-solution.

There is a large difference between end-user and possible customer. During one of the first interviews with a research company called Delphy, the non-directive interviewing technique from the Mom Test was applied. This interview was exactly one hour, and for the first 50 minutes we forced ourselves to only listened to the people on the other side of the table. Only for the last ten minutes, we mentioned our technology. From the interview, the last 10 minutes were most insightful, because the researchers from Delphy came up with all kinds of ideas how we could best implement our solution and how that would help growers. This shows the Mom Test is very suitable for customers, but when talking with influencers or suppliers for your customer, you can explain your technology and ask directive questions instead of non-directive questions. This also was the case in one of our interviews with someone from Priva, a company that sells climate computers to growers. By telling our solution and asking why this would be relevant to our shared customer (the grower), he could explain quite clearly how this would be of benefit to the customer. Here it is important to use the five-why method.
The difference between directive and non-directive interviews also have a timely aspect. Initially, you can ask directive questions to get ideas from customers. By asking specifically how your product could provide value may give you some ideas. You can literally ask them "how can this help you make more money". These should be validated using non-directive interviews to see if these ideas are indeed valid. Once this is validated, you can shift again towards directive interviews where you state your (validated) product, and see if customers are willing to pay for them. If they are not, it shows your validation process was incorrect. In other words: after using the Mom-Test method to learn about customer problems and drawing a solution, you can ask more directly if and how your solution would solve this problem. This is thus linked to the Customer Discovery Insight Cycle (Figure 18), where directive interviews can be used as experiment itself, and non-directive interviews could be used to test the experiment. Still, the important part of such an interview is listening to their feedback, not stating your solution.

Internship For future entrepreneurs, doing an internship is very much recommended. There are the two main benefits for this method. First, getting to know the customer is the very first thing that the CDM advises to do. Interviews to learn more from their perspective are already very insightful, but it gives a somewhat superficial view of what your customer does in a day. By really being in their shoes, you not only get a better understanding of the problems they face, but you can also picture your solution in their view. One example of learning was that a grower mentioned that growing is a seven-days-a-week job, because you have to make sure your plants are doing okay. When we suggested a webcam, he showed how that would not solve his trust issues: you really need to make sure that everything works and you can really see that your plants are doing okay. Currently when talking with growers, we argue that our sensor may or may not improve yield. Our main goal is to sell it as a safety measure: 'wouldn't it be nice that you have total security over your plants and that when something seems to go wrong, you already get a notification'. Interviews usually were somewhat superficial and were about learning new things and improving yield, instead of their extreme need for security. The company Growficient does this quite well, they sell their sensors with the slogan 'More control. More security', even though they improve yield with 7%. Also long after the internship, it helped with envisioning your technology at the customer. We often recap what we had done in the internship during discussions about why the customer would want something or not. A very thorough understanding is extremely important when building something for your customer. Literally putting yourself in their shoes helps with this understanding. With learning as a metric for development in this phase, the internship led to great insights. Referring back to Figure 7, the internship was especially beneficial for learnings rather than testing assumptions. For many customer insights, we did not have any assumptions yet. How a grower interacts with his colleagues and materials is something that you may not have assumptions about. A second value from the internship was that it also opened many other doors and improved our sympathy factor because we showed we cared. We even got awarded a large fund and help from the market and after thanking them personally, they wrote: "You're just good [plugged] into [the market]. Which also makes people want to help you. Keep up the good work."

However, there are some factors that should be assessed to determine how to approach this method. These factors are background, timing of funneling in, customer range, duration and what's-in-it-for-them.
First, doing an internship depends on your knowledge and background of the customers. Many companies start out from a customer perspective that faces a problem. In this situation, the company is already very familiar with the problem the customer faces. An internship would then be less beneficial. An internship is mainly useful for people that have developed a technology they want to implement in a market they know next to nothing about. Second, I would advise to wait after a few interviews before diving deep into one customer segment, because doing an internship requires quite some time investment. In the use-case, I was already making a customer-pivot: from breeders to growers. In the linkedin post (Figure 28) we mentioned we wanted to volunteer at a breeders. By the time the internship started, we already knew the customer was not a breeder but a grower. If we were to do the internship at a specific breeding company, the internship would somewhat be in vain. As the internship allows you to get to know one customer very thoroughly, it is advised to first have some interviews with this customer segment to get some sense to what extend you should funnel into this customer segment. Fortunately, our internship was at a company that was involved in the whole supply chain: breeding, propagating and growing of crops. Therefore, we could take a look at these different stages in the supply chain, including growing. That is what is meant with *customer range*. In our case, the customer range was very wide. The ability to join several departments for one day, helped us get a wholesome view in the whole supply chain. It would be beneficial to do an internship with a customer that has a large range of activities where your technology may be implemented. This would allow you to learn as much as possible. Moreover, the duration should be assessed. Our internship was 2 weeks. This was a good trade-off to learn everything in dept, but still be time-efficient. One week more would not lead to new insights, whereas one week less would not allow us to take a look in each department long enough. This of-course depends on the company and the range of its activities. Finally, to get an internship, you have to know what's in it for the company that you work for. An internship usually costs a company time and effort they need to spend on supervising you, so not every company will let you volunteer there. By knowing what the supervising company could get out of there, you can get easier access. Our assumption was that we would offer two weeks of free labour and this would be something the company was willing to sacrifice time and effort for. This assumption turned out to be wrong: they were willing to help us out and let us volunteer at their company, because they wanted a fresh perspective in their company. They wanted to know what they were doing right, and more importantly what they could do better and how they could improve. Our linked-in post was shared by many people, but still there was only one company that actually helped us out. Learning what's in it for the company could help with crafting a message that speaks to them, thereby making it easier to get an internship/volunteer.

Coaching program I very much advise future entrepreneurs to combine the literature with coaching programs. During this research I was incubated in the Impact Studio, which was extremely beneficial due to the following four reasons.
First, they give very practical and targeted advice instead of generic advice that works for most start-ups. They help in how to assess certain strategies from the books and scientific papers. To elaborate: the papers and books are very general and therefore applicable for any entrepreneur, which make these great. However, this is also a limitation, as some strategies that work in one market may not work in another. The generality of the work is therefore a limitation to the practicality of it. To bridge the theory with practice, these programs can really help. In this research, the coaches were both a teacher at TU Delft and an experienced entrepreneur. In the academic-practitioner divide, these coaches were the best of both worlds, which also helped in bridging this divide.
The second reason can be explained using the example of everyday courses such as mathematics. Although papers and books about algebra have been available for many decades, the need for teachers remains. They have a more wholesome view of the different models, methods and frameworks. Good coaches/teachers are therefore crucial in the development of the entrepreneurs and their right mindset. This is not limited to the teacher itself: according to the literature review of Leu, quality of education depends on schools, teachers, supervision, policies, administration and community involvement [58]. If we relate this to to start-ups, it is implied that the quality of an incubator program depends on several factors and e.g. peers can have a great influence as well. The team is found to be the most important part of a start-up for Venture Capitalists, more important than the product or market [59]. This suggests that a coachable team is quite important.
A third reason is time efficiency. Once you start with entrepreneurial activities, it could be that you do not have the time to read all the books and papers mentioned in the framework. Start-up coaches can help you with the right information at the right time. Although the framework presented in Figure 19 helps in assessing at what time, which method/models is most relevant, start-up coaches can give more targeted advice at the exact moment when you need it. This makes it very efficient, something that is paramount in the fast-pacing world of start-ups.
Furthermore, as found by Burnell et al., start-up mentoring is one of the three factors that may enable entrepreneurs to pivot if the situation suggests so [60]. When founders gather information from interviews and assumptions in the business model turn out to be false, the founders should pivot their business model. This has shown to improve the chance of success for start-ups [21, 61, 62]. According to Burnell et al., start-up coaches can help with pivoting, because a mentor would be less biased, whereas the founding team often possess a subjective belief in their own correctness. The other two factors suggested in the article to help in pivoting are entrepreneurial experience and team size.

Competition versus cooperation In Subsection 4.3.3 I discussed the trade-off between competition and cooperation. I used the model from Gans et al. [54]. This was a very specific model that proved value in this practical case. However, this not necessarily means it will be beneficial for many start-ups. The model was therefore not implemented in the framework of Figure 19 to limit the complexity.

5.2.2 What factors influence the use of the framework?

As each start-up is unique and faces different questions, different models or methods may provide valuable guidance or even answers on those questions. A targeted approach is thereafter necessary. That is also why coaching programs are helpful, they can give targeted advice instead of generic advice that suits any start-up. In the following paragraphs, several factors are suggested that influence the use of the new framework. Again note that these factors do not necessarily influence the success of the start-up, but rather the use of the specific models and methods mentioned in the framework.

Financial climate The financial environment is expected to impact the framework, especially for the lean method. This method makes entrepreneurs very stingy and limits the time, money, and effort spend on learning, thereby making the learning process as efficient as possible. With limited financial resources, this efficiency is paramount and entrepreneurs must sell a product as soon as possible to get revenue and sustain the start-up company. If financial constraints are less stringent and efficiency is less important, entrepreneurs can make more mistakes, learn from them and prolong the moment towards revenue. Therefore, the need for the lean method reduces.

Regulatory environment Another aspect that may have an influence on how to apply the models is the regulatory environment. Failing to comply with rules and regulations may affect to what extend the lean method

can be applied. E.g. if certain safety measures must be applied, this may hinder early prototypes to be used by the customer. Especially in the medical sector, founders of start-ups found regulations and safety measures to be a very limiting.

Culture Cultural differences may play a very important role in applying the Mom Test method. To elaborate, here in The Netherlands, people are quite direct. If people don't like something, they will tell you to your face. Moreover, saying no to a superior or client is quite common. The Mom Test is written in the USA, where people may be more polite and not hurting someones feeling is more important compared to people the Netherlands. This cultural factor may also influence the applicability of the CDM. In the Netherlands, people are quite open to new ideas and interviewing many customers (also the more managerial people within companies) was not much of a problem. In a more hierarchical culture, it may be more difficult to arrange interviews with top-level executives, especially if you do not have a product or service that is already established in the market. This is because in a hierarchical culture, there is a strong emphasis on respect for authority and hierarchy. Executives may be less willing to take meetings with individuals or companies that they perceive as being lower in the hierarchy or having less established products. Furthermore, in such cultures, it may be important to have a well-developed product or service before approaching top-level executives for an interview. This is because executives may be more interested in hearing about concrete results and the potential benefits to their organization, rather than speculative ideas or untested prototypes.

Market segment During our interviews, we noticed that in general, researchers were quite fond of new technology. They are more curious in knowing how things work. This in contrast to e.g. growers, who just want to know what value (preferably in euro's) it will bring them. As the goal of the non-directive interviews is to discover what potential problems your customers have, how they currently deal with them and if you could provide value for this customer, the market segment also influences the response of your customer. The Mom Test method is a good way to get objective feedback that is not based on just response, but on specifics. In the case of growers however, a more directive approach is possible, as they will sooner let you know if they don't like your idea.

Market type According to Blank, there are four types of markets that a start-up can enter:

- Existing Market
- Re-segmented Market (niche or low cost)
- New Market
- Clone Market

In the use case, the start-up was entering an existing market. When entering a new market, it means that there is not an established and well-defined market and no existing customers or competitors. The TAM cannot be applied on technologies that do not exist. One of the aspects of the framework is the inclusion of the TAM. This model was useful for mapping the drivers and barriers for the adoption of technology. In the use-case, this could be applied using existing technologies. This arguable also works with new markets, but it would be much more difficult to track the perceived usefulness and ease of use for a product that does not exist yet. In the CDM, Blank also notes that the steps for each market type is different. He states that "different market types require dramatically different discovery, MVPs, and sales and marketing strategies" [1]. Indeed, it is stated that for entering an existing market, customer discovery involves comparing the product and its features with others.

Product type In the CDM, Blank shows the difference between web/mobile products versus physical products. It is mentioned that for web/mobile products, customer discovery can be conducted by reaching hundreds or even thousands more customers by combining online and face-to-face interactions, whereas this is limited for physical products. Moreover, feedback can be generated faster and therefore the product itself can be iterated faster as well. Although the Mom Test method should be applied for both web/mobile and physical products, the effectiveness of this method for physical products may be higher.

Role of the customer With Syngenta, a larger company, we interviewed several people with different roles. Only after these interviews, it became apparent that we interviewed the different roles wrong. In our first interview with 'the boss', we hardly told anything about the solution. This gave some good insights, but not as much as we had hoped. Then we talked with the more practical people (at the time we thought this meeting was

about the implementation for a pilot), so we were in pitching mode. This resulted in some haziness about what value our product would bring. In hindsight, the non-directive and directive interviews with the different roles of the two interviews should have been reversed. Instead of the non-directive interview and just listening to 'the boss', we should have said at one point: *We can measure this. How would that help your company?* This could open our eyes to several applications for our product. Whereas for the practical people, we should have taken a more non-directive approach and asked more questions, steering towards our hypothesized solution, thereby validating the problem-solution. Moreover, it was clear that the boss was an early adopter, in contrast with the practical people. In hindsight, this company was less suitable for a first problem-solution check because the feedback was from the practical people, who where not the early adopters. In other words: the different roles actually shifted the company in its positioning in the DoIM.

Deep tech In deep tech there are three main hurdles: scientific hurdles, engineering hurdles and market hurdles. The customer discovery method is all about market hurdles (from the problem perspective): are you building something that people actually want. The other two hurdles are about the solution. Scientific hurdles are about the science and the possibilities within science. For example, time-travel might face market hurdles, but the main hurdle is a scientific hurdle as it scientifically not possible (yet) to do this. Engineering hurdles are about the solution as well, but it is known that it is possible. Making a sensor wireless for example is an engineering hurdle: it is already proven that you can make certain devices wireless. Customer discovery focuses on finding a problem, not on building your solution. In the project I heard several times: you can always build it, the main hurdle is the market hurdle. However, I object to this absolute statement and I think this trivializes the scientific hurdles that are yet to overcome. I believe when people say this, they mean engineering hurdles. In deep tech, scientific hurdles may be that complicated to overcome, that this may send you in the wrong direction. In our case, we have quite a good example for the two scenarios shown in Figure 20. Let's consider the two scenarios for our use case with solution A: we can measure the water content in the plant stem.
Scenario I: In high-tech greenhouses, solution A is not necessarily a solution to a problem, since the irrigation is already quite well managed. A problem in high-tech greenhouses is the plant balance (problem B). Many parties have tried to solve this problem, as will we. This may take several years of development, and still it is uncertain if it can be physically measured in what way possible.
Scenario II: Another approach is to stick with solution A (the water content) and look at other markets to find a problem that this solves. In our case, this may be low- and mid-tech greenhouses in countries such as Spain.

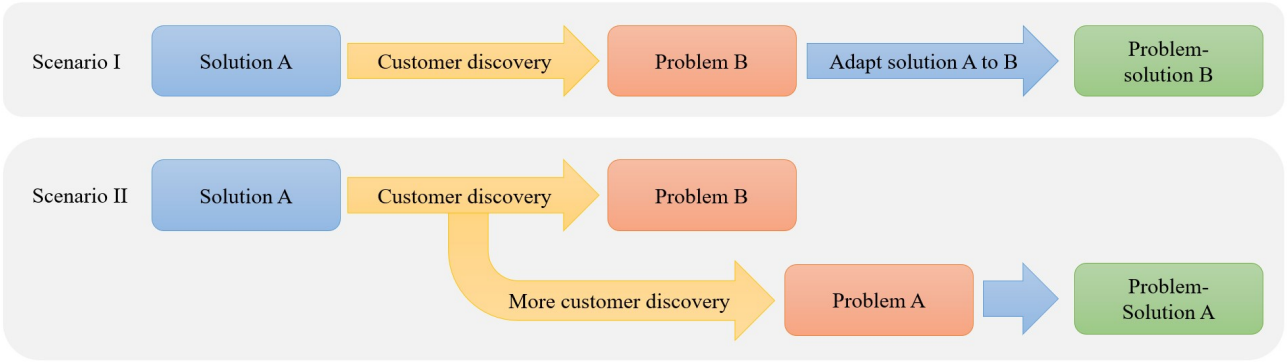

Figure 20: Two scenarios to find a problem-solution when starting with a technology or invention.

To conclude, there is a trade-off between finding a problem and adjusting your solution to this problem or sticking with a solution and further investigating problems where you can apply your solution. In deep-tech, the former might be quite disadvantageous as it will require large investments and development time. This has significant impact on to what extend you should apply the CDM. The choice between scenario I and scenario II depends on two main factors: the 'effort' of adaption needed and the effort of looking for a certain problem. This effort indicates both time and money (which often go hand-in-hand). Scenario II might be more beneficial, as when a problem A can be found that you can solve with solution A, you can already generate revenue while adapting towards problem-solution B. In this scenario it is crucial to focus on problem-solution A before shifting towards problem-solution B, as focus is found to be one of the most important aspects in a successful start-up according to the work of Aulet [19].

5.3 Recommendations for further research

In this section, several recommendations for future research are given. These recommendations are based on the conducted research to either validate the research or to improve the scope.

5.3.1 The framework

The proposed framework (Figure 19) should be analyzed for multiple startups. The proposed framework seems to work for this one use-case, but is therefore not necessarily extrapolatable to other markets or technologies. While this research has resulted in a framework that addresses the specific use case effectively, it is important to recognize that its applicability to other cases may require further examination and validation. By analyzing the framework for multiple start-ups, a quantitative research can be conducted. This is contrast with the current qualitative thesis. This can be done by performing the same steps with different start-ups. However, a more suitable approach would be to interview existing start-up founders and analyze their views on the framework to see how they would change it. Their insights could improve the framework and make it more integral. By continuously evaluating and streamlining the framework based on empirical evidence, practical insights, and user feedback, unnecessary complexities or missing methods and models can be identified and eliminated or added. This iterative process of improvement ensures that the framework remains adaptable, relevant, and user-friendly while accommodating the evolving needs and challenges faced by future entrepreneurs.
Another suggestion is to delve deeper into the different factors mentioned in Subsection 5.2.2. Each factor could be individually assessed for different start-up cases. Another approach is to select a few start-up cases and assess all factors mentioned in Subsection 5.2.2 to get a more wholesome view. The influence of each factor can be mapped for each method/model shown in the framework to see how they influence the applicability of the framework.

5.3.2 Customer validation

After this research, a framework for the customer validation phase could be proposed. As this is the following phase for a start-up, new methods, models and frameworks can be applied to guide entrepreneurs further in their journey. Although the framework from Figure 19 do provide many insights that are applicable for the customer validation phase as well, perhaps new insights will result in a more wholesome framework with a larger scope. The CDM shows the steps during the customer validation phase, but as indicated in this research, several other models and methods should be included for a more integral framework.

5.3.3 The Mom Test

Another recommendation is to investigate the Mom Test method described by Fitzpatrick further. Works from other research fields such as psychology and marketing, should be incorporated for future studies, because human responses (on your questions and product) are rather psychological. A future research question would read: *To what extend should interview questions during customer discovery be directive?* and *What factors influence a customer response on interview questions during customer discovery?* This study should also include differences such as the innovative and open-minded character of certain persons. To wit, interviews with growers yielded very different responses. Some growers were enthusiastic about trying new things, where others felt no need to change anything of their current business. This shows that personality has a great influence on how to use the Mom Test method. Finally, a link to the the Diffusion of Innovation model should be made, which can indicate how lead users react differently compared to late adopters. This also has influences on which interview questions one should use. I hypothesize that you can more openly discuss your proposed solution with lead-users where they can help you find your problem-solution, whereas this may not be the case with late adopters where mainly listening is advised.

6 Conclusion

It is commonly said that learning from mistakes is very beneficial. This is particularly true for the start-up industry. Where learning from your own mistakes is good, learning from (mistakes of) others is even better as this is a quicker and more cost-effective option. This approach can twice be applied in this research: learning from other entrepreneurs, but also from customers and companies operating in a competitive landscape. I will elaborate both, starting with the lessons from fellow entrepreneurs.

This thesis aimed at finding out which scientific models and methods result in an integral but comprehensive framework for starting entrepreneurs and how they can best be applied. In this research, several scientific methods and models were combined to provide a framework for starting entrepreneurs. These methods and models were the CDM, DoIM, TAM, the Mom Test method and the Lean method. Several academic papers have been published about these methods, especially about the lean method. Moreover, books have been written by former start-up founders about these methods in a practical start-up context. Not only have these authors used the models, they also showed how they failed without these models. This indicates how we can refrain from the same mistakes by following their advice. By using the framework (which combines the different methods and models), we can learn from the mistakes of former founders and other start-ups. Besides the literature, two coaches helped me during customer discovery, which proved very insightful. With the combination of literature and coaching found in the framework, starting entrepreneurs have sufficient tools to take the first right steps when starting a venture in an effective way. Moreover, this combination of literature and coaching helped in bridging the academic-practitioner gap.

For the use-case specific perspective, the focus was on customer discovery, which is about learning what your customer needs. An internship provides great insights, as this goes beyond superficial interviews and helps in creating a thorough understanding of your customer. This is much in line with the goal of the customer discovery: learning how you can solve a problem for your customer. The internship was a novel addition to the CDM.
Learning means not only learning from customers, but also from competitors, thereby speeding up the learning process. By learning how other products, solutions or start-ups do or do not provide value for your customer, you can learn before you even make your own mistakes. Due to the many interviews and internship, not only do we know how we can provide value, we also know why current solutions are unsatisfactory. The limits in current solutions for the use-case (mainly limits in robustness, reliability and interpretation) imply the opportunities for our technology and indicate where we should focus our efforts. This part is insufficiently described in models such as the CDM. The addition of the TAM was therefore a crucial element of the framework. Furthermore, learning from other suppliers besides customers or competitors also proved beneficial, as they (should) know your customer and its problems thoroughly. Although it is advised to apply the non-directive interview technique advocated in the Mom Test method with customers, a more directive interviewing technique can be applied by suppliers.

Fail fast and cheap is the lean philosophy that advocates extensive testing and incremental development to determine whether an idea brings value to your customer. Instead, *learning* fast and cheap is a better approach. Why make the mistakes yourself if you can already learn from the mistakes of others. The framework proposed in this research shows an integral yet comprehensive framework for starting entrepreneurs that speeds up the learning process. The internship, start-up coaching, and interviewing suppliers, proved to be a great addition to the initial framework extracted from several scientific sources, because they all accelerated the learning process. By applying the methods and models stated in the framework, future entrepreneurs have the right tools to make informed decisions in the earliest phase of their start-up. Specifically the trade-off between directive- and non-directive interviews depends on several factors, one of which the phase of the Customer Development Insight Cycle is critical. Other factors that influence how the framework can best be applied are the financial climate, regulatory environment, culture, market segment, market type, product type, role of the customer and the relevance of deep tech. These should be further evaluated to map their influence and importance in their effect on the framework.

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A Acronyms

Acronym	Meaning
CDM	Customer Development Model
DoIM	Diffusion of Innovation
TAM	Technology Acceptance Model
MVP	Minimum Viable Product
WUR	Wageningen University & Research
BMC	Business Model Canvas
MON	Market Opportunity Navigator
ROI	Return On Investment
IPR	Intellectual Property Rights

Table 2: List of acronyms

B Recommended books

Several founders at the start-up incubator YES!Delft were asked which books they recommended for insights during customer development. Boris ter Haak (co-founder of the start-up Unifix Care) conducted this research [63]. Table 3 below shows the books that were recommended.

Book	Author	Nr. of references
The Lean Start-up	Eric Ries	6
The Mom Test	Rob Fitzpatrick	4
Zero to one	Peter Thiel	2
Start-up Owners Manual	Bob Dorf & Steve Blank	2
Running Lean	Ash Maurya	2
Value Proposition Design	Alexander Ostwalder	2
Crossing the Chasm	Geoffrey Moore	1
How to win friends and influence people	Dale Garnegie	1
Disciplined Entrepreneurship	Bill Aulet	1
Hacking Growth	Morgan Brown & Sean Ellis	1
Building your story brand	Donald Miller	1
Strategic Selling	Miller Heijman	1
Smart Cuts	Shane Snow	1
From idea to product market fit	Omar Mohout	1
Never split the difference	Chriss Voss	1
Lean pricing	Omar Mohout	1
The hard thing about hard things	Ben Horowitz	1
Escaping the build trap	Melissa Perri	1
Strategize	Roman Pichler	1
How to become investor ready	Stefan van der Ploeg	1

Table 3: Recommendations for books from start-up founders at YES!Delft

C Business Model Canvas

<table>
<tr><th>Key partners</th><th>Key activities</th><th>Value Proposition</th><th>Customer relationships</th><th>Customer segments</th></tr>
<tr><td rowspan="3">Research partners
TUD, WUR, NPEC, Delphy

Test locations
Tomatoworld</td><td>Build hardware
Build software
Build plant models
Customer feedback and retention</td><td rowspan="3">Using our unique technology we translate plant status into objective data, resulting in:
• Clear insights
• More control
• More certainty</td><td>Pilots (including advice)
Direct sales</td><td rowspan="3">Dutch growers
Dutch breeders</td></tr>
<tr><td>Key resources</td><td>Channels</td></tr>
<tr><td>Testing locations
Plant knowledge
Patent
Specific technical knowledge</td><td>Cultivation groups
Cultivation consultants</td></tr>
<tr><th colspan="3">Cost streams</th><th colspan="2">Revenu streams</th></tr>
<tr><td colspan="3">Employees
Materials
Commercial sensors</td><td colspan="2">Base station sales
Sensor hardware sales
Software subscriptions</td></tr>
</table>

Date: 24-02-2023

Figure 21: One Business Model Canvas during customer discovery. This BMC was iterated after each new insight or learning.

D Background: Technology in Agri- and Horticulture

In this section I will give some background information about the history of technology in horticulture. In Section D.1 I explain some of the challenges for food security. In Section D.2 I present the history of technology and horticulture and continue in Section D.3 with the current state of technology in horticulture. Finally, Section D.4 shows the specific sensor use-case.

D.1 Why the need for innovation in Horticulture?

We are facing one of the greatest challenges there is: food security. This challenge arises due to six causes. Firstly, as the worldwide population grows, the demand for crops grows along. Not only for nutrition, but also for medicines, fertilization and ornaments. Additionally, due to more extreme weather conditions, our farmers have to deal with bad harvests. These circumstances will only deteriorate further. Thirdly, with limited capacity of land, water, energy and human resources, sustainable and effective ways of farming our crops is paramount. Furthermore, the rise of global temperatures move us to adapt our farming lands [64]. Moreover, plagues continue to develop and alter, which forms a perpetual risk for our crops. And to add to this, governments are tightening policies for energy consumption and pesticide usage in the horti- and agriculture. For example, the Dutch government has demanded the greenhouse horticulture to become climate-neutral by 2040. These challenges have moved farmers towards controlled and protected cultivation.
These six mayor challenges need to be tackled and innovation is key. Optimism is present, as the Dutch minister of Agriculture, Nature and Food Quality recently said: “I find the motivation of entrepreneurs to supply high-quality products and to always keep innovating typical of the greenhouse horticulture sector. That is also essential to get through the energy transition." [65]. With the government on board, it would seem that all lights are on green for innovation in the horticultural sector. However, not all innovations reach the market [66, 67, 68, 69].
With an export value of €9.5 billion for the horticultural sector in 2020 [70], the Netherlands are in a leading position of smart farming. The government has mentioned it wants to remain in this leading position. It is therefore important to understand what kind of innovations are required and demanded in order to refrain from unnecessary expenses or dead-end technological research. This works both ways: if a new technology is advanced but not adopted, it is both unfortunate for the producers that have wasted time and resources on technology that is not beneficial, and the consumers will not improve efficiency, something that is needed for society as a whole. One of the historical innovations is protected and controlled agriculture in greenhouses.

D.2 Historical Overview of Greenhouses

Nemali recently described the history of greenhouses [71]. The following is based on his research. The earliest record of greenhouses is 14 to 27 CE in Rome. This 'greenhouse' was nothing more than a house in which the plants were placed during cold nights. Around 1450 heating for crops was used for the first time in Korea. A few centuries later glass windows were used that allowed sunlight. This was used in France for orange trees. With improving technology, mainly on the structural design of glasshouses, greenhouses improved greatly during the 19th century. The commercial greenhouses found everywhere in the Westland region in the Netherlands became operational during the 20th century [72]. During world war 2, many greenhouses were damaged, totaling up to 1.8 million square meters. After this period, reconstruction began with better isolation, improved height, drainage and irrigation and improved load-bearing with aid from the Wageningen University and Research. The design is called the Venlo-style design and is still often seen in this region. Further improvements of greenhouses include temperature regulation, ventilation, artificial lighting and hydroponics. The latter is growing crops in water instead of soil. For future trends, Nemali expects the following five improvements: Improved temperature regulation, mainly cooling systems, automated steering made possible by sensors, increase in renewable energy usage and decrease fossil fuel usage, increased water-use efficiency, insect and disease control without chemicals.

Specifically sensor technology began in the seventies. The first climate computer of Priva was introduced in 1977. Sensors that collect data from plants itself have only recently been introduced. This started around the 1990's, mainly due to a lack of technology available [73]. However, stated by Zude-Sasse et al. in 2016: "[...] no mainstream technologies or strategies for measuring yield in orchards and vegetable production are yet in place, while this review may inspire new research for other horticultural crops using more automated methods for yield mapping that are needed." [74]. They expanded this by mentioning that quality management techniques for measuring fruits in situ were in the experimental phase, but required for the sector. Today however, few sensor companies that monitor actual crop status have risen.

D.3 Current state of the adoption of technological innovation in horticulture

Innovations are more likely to be implemented when they reduce current resource scarcity [75, 76, 77]. With increasing population, our food and other agricultural commodities naturally become more scarce and therefore we expect the adoption of innovation. That is why there is a shift from traditional farming in open fields towards high-tech farming (Figure 22). Currently, the most advanced forms of farming are autonomous greenhouse farming and indoor vertical farming which is also autonomous. There is currently a lot of debate whether indoor farming is actually the future, as it requires a lot of energy. Autonomous high-tech greenhouses use the natural power of the sun. This makes them more effective energy-wise, but also more prone to disturbances and therefore inefficient growing. Note that really autonomous greenhouses are not possible yet and that indoor growing is only available on small-scale for high-value crops with a small iteration time. With iteration time, I mean the time between two harvests.

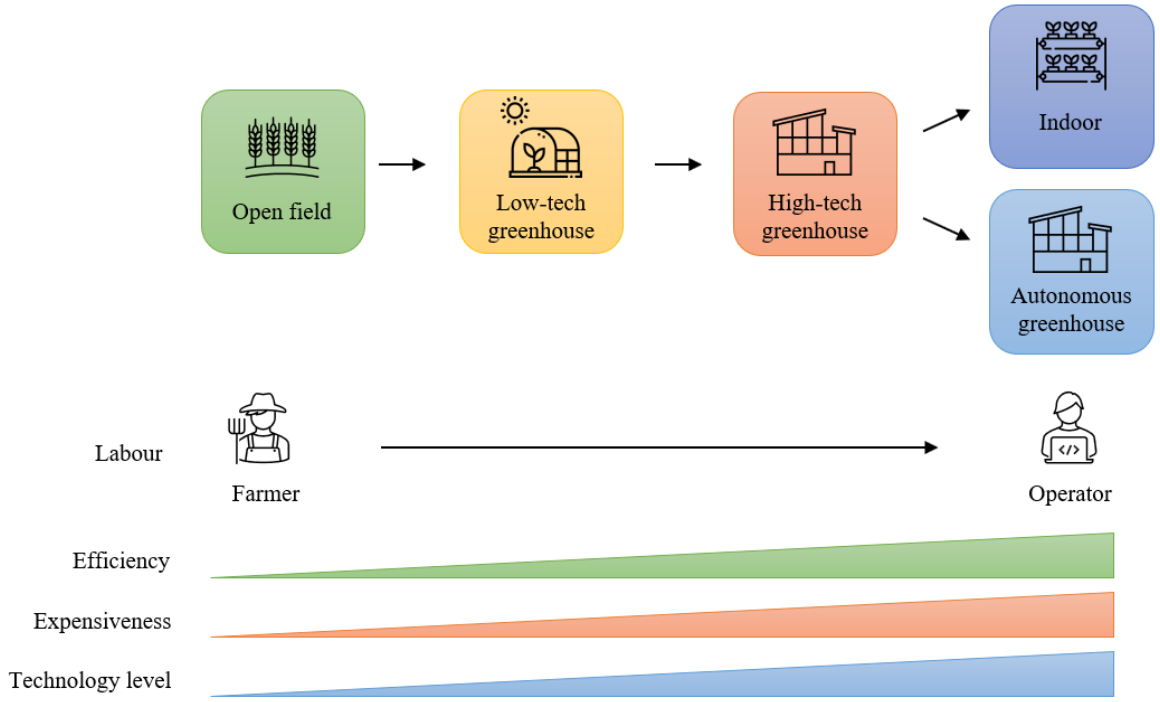


Figure 22: Evolution of agriculture

High-tech farming is one of the names we have given this new method of cultivation. Another name is data-driven growing (Figure 23). Traditionally, growing crops was done by humans that go into the greenhouse, take a look around and with their findings know how to steer the greenhouse. There is however a shift from human driven crop management towards data driven crop management, where the steering is done based on objective data instead of human interpretations. This shift is gradual and it is driven by both improved efficiency and shortage in labour. This shift also means a shift from role as farmer/grower to operator, where the operator has to manage the data. The human is still in charge, but he or she can manage more land and crops with data-driven methods compared to human-driven methods.

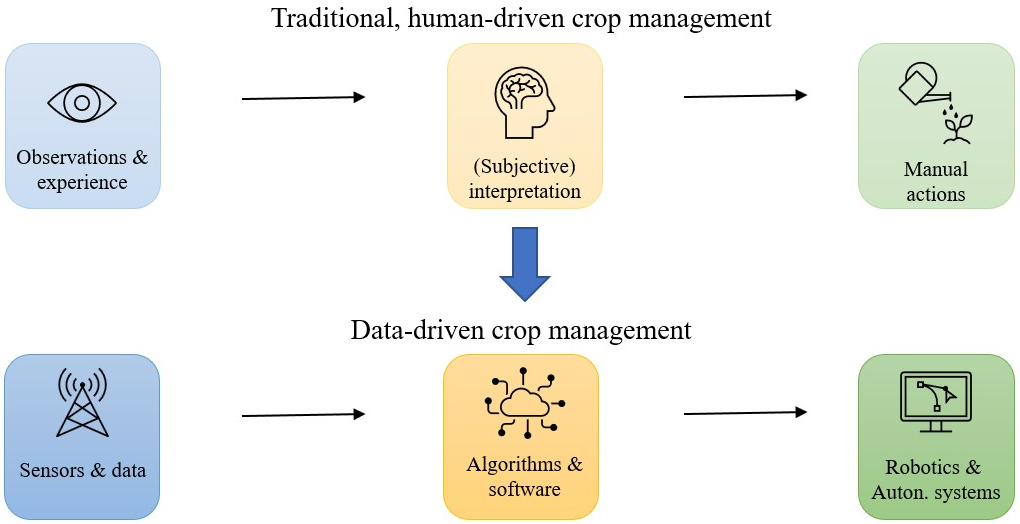


Figure 23: The shift of human driven growing towards data driven growing, where sensors and data, combined with software, algorithms and AI provide the input for autonomous systems. Note that in both cases, the grower is manager of the process.

I have learned that the last part of control (robotics and autonomous systems) are adopted in all high-tech greenhouses (see middle part of Figure 14). There are three main companies here that have developed climate computers for this control part, which are Priva, Hoogendoorn and Ridder. They use the basic environmental

sensors (temperature, humidity, light intensity) and developed software to select and maintain the desirable values for your greenhouse environment. In the last 2 years, new companies have started that focus on the algorithms, AI and software. They use environmental sensor data and manual observations as input for their algorithms that give an efficient greenhouse steering strategy and crop forecasts. The three main players are building this application as well, but other companies have risen as well, such as Blue Radix, HortiTech and Source.ag. In Figure 14 these companies are shown with the white block.
For the autonomous system (right part of Figure 14), Priva (a climate computer company) developed a framework to show the different stages of autonomy, see Figure 24 [78]. During an event called HeroFestival on June 8th 2023, both a product manager from Priva and the Chief Strategic Officer from Ridder (also a climate computer company) mentioned that we are currently at level 2 of autonomy. This level indicates partial automation, which corresponds to the middle part of Figure 14 where the system executes the commands, but monitoring and fallback is still human-driven. With plant sensing technology, we can move up in automation from hands-off towards eyes-off and even brain-off. To get there, e.g. Ridder aims at developing solutions for monitoring crops themselves using vision technology. Although this solution is yet to be developed, it got nominated for the concept award of 'the most promising new idea' during GreenTech Amsterdam 2023 (the global meeting place for all professionals involved in horticulture technology) [79].

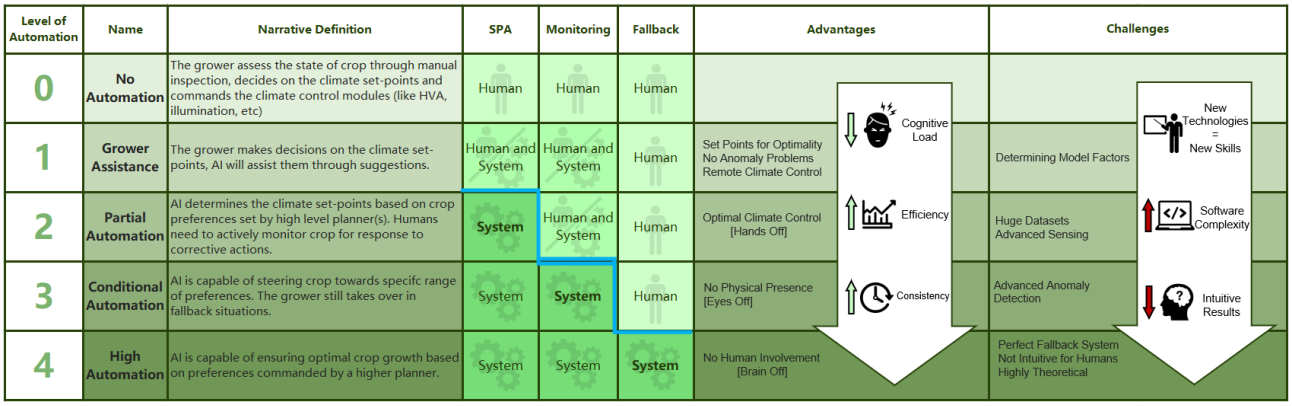


Figure 24: Level of automation for each level of responsibility. This is divided in Execution (Sense, Plan, Act: SPA), Monitoring and Fallback. Currently, we are at level 2 where execution is automated, but monitoring and fallback is still human [78].

The first thing that becomes clear when looking at the adoption rate of *sensors* in the agriculture is the difference between two types of sensors. These are *environmental* sensors that map environmental parameters such as temperature, humidity, nutrition etc. and there are sensors that scan the *plant itself*. When we compare for example the adoption of sensors for plant health to sensors for the environment, it can be seen that the latter is adopted far more (Figure 25) [80, 81].

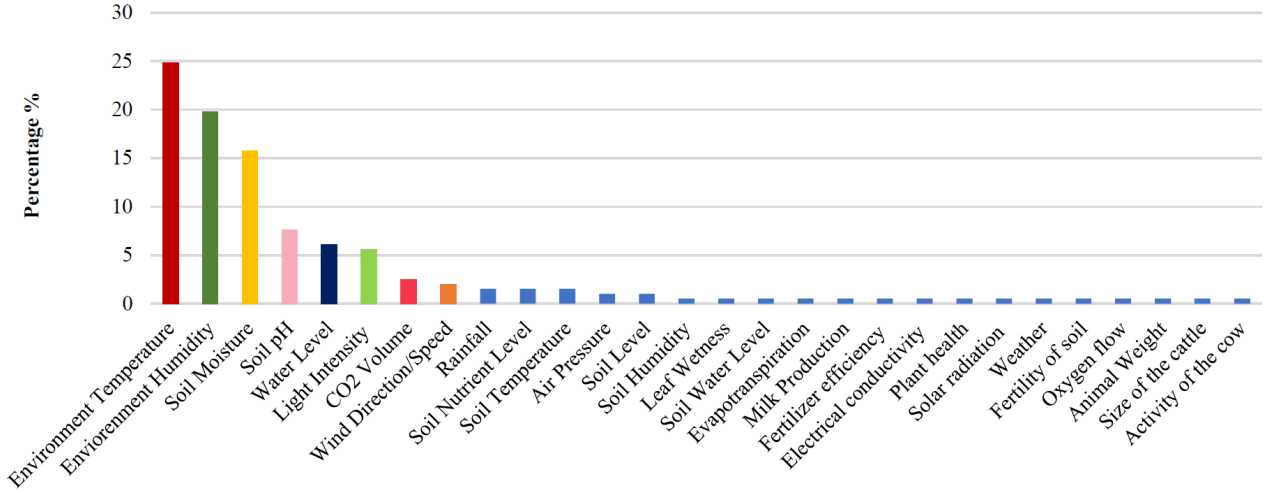


Figure 25: Utilization of sensor data based on farming activities (2019) [81]

D.4 The case study: our ultrasound crop sensor technology

I am currently pursuing building an agri-tech business that will help with the above-mentioned challenge. I am doing this together with my co-founder Thijs Bieling. When we initially started, we had a passive sensor that could measure the internal structure of crops (see Figure 26 for a picture of our first prototype). As the size of the tubes, through which the water is transported in the plant, is linked to drought resistance, we assumed that breeders would be interested. The fact that the sensor was passive means we had to wait for crops to emit a signal which we could observe. Initial talks with breeders (we first thought they would be our initial customers) made us realize that waiting for signals is not a viable option, they wanted a result immediately. This made us add an active component to assure data on-demand. This resulted in a new invention: to monitor water content inside crops. This also means that we now had technology with multiple applications, which opened doors to other customer segments.
So the actual solution we had is that we could measure water content inside crops. With this solution, we aimed at finding a problem we could solve.

Figure 26: The first prototype of our passive ultrasound sensor module

E Customer Development Model

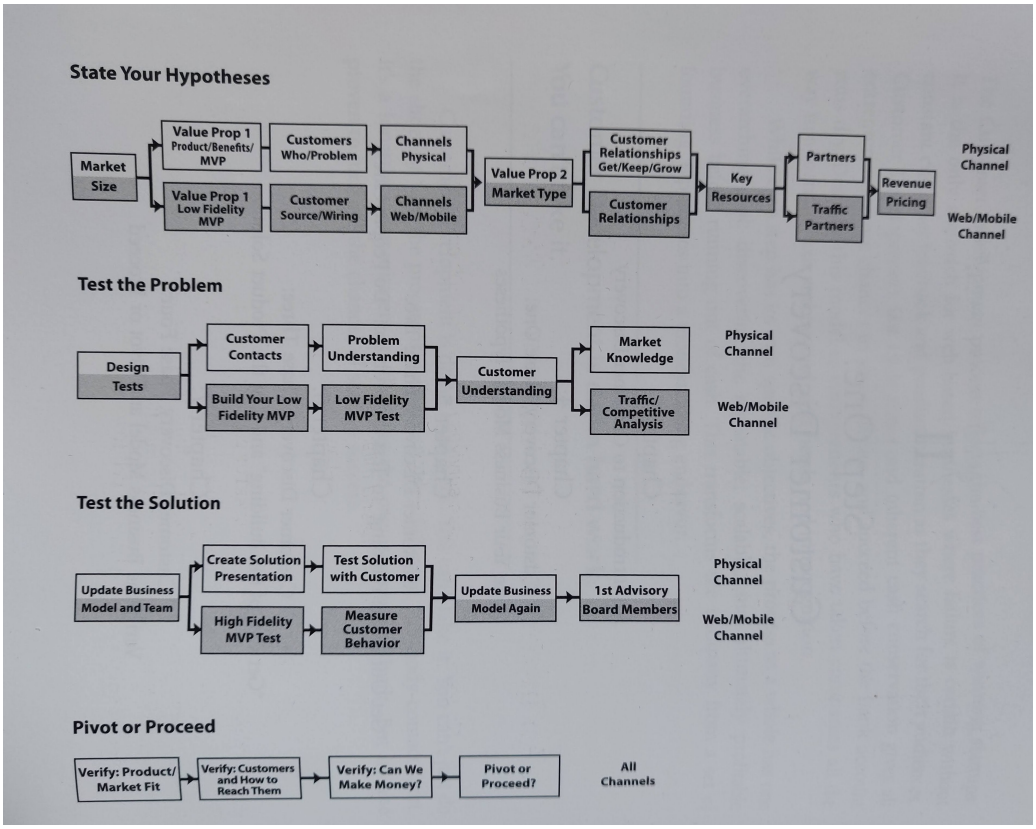


Figure 27: Overview of the Customer Discovery Process [1]

F Example Interview Questions Growers

1. If you could know everything about your plant, what would you want to know first? So, for example, some information to improve the yield.
2. Can you talk me through your week? What are your weekly activities?
3. How much time did you spend on these activities last week?
4. How do you determine the state (generative vegetative) state of your crop?
5. OUTPUT: What can you steer in the greenhouse?
6. INPUT: What other parameters do you measure to control your greenhouse?
7. What technologies do you use to measure these parameters?
8. How do these technologies help your business?
9. Why only these technologies?
10. How did you acquire these technologies?
11. Have you tried sensors from 2Grow, Vivent, Sigrow etc.? Why (not)?
12. If data is too complicated: have you sat down with the manufacturer to solve this?
13. What are some no-goes when monitoring crops?
14. Do you notice a labor shortage among growers? How do you solve this?
15. How do you try to solve this?

16. Is there anything else I should have asked?

17. Who else should we talk to?

Combine with the 5-why method: ask 5 times why after the interviewee explains something.

G Customer Segments

G.0.1 Research institutes

End user: Plant physiologist
Application: Gain new insights in crop behaviour to discover new traits or develop new crop models.
Benefits: The user would gain new insights about the crop and its reaction to different stimuli. Moreover, he or she would get an opportunity to get information about the inside of the crop without destroying it, thus continuing experimenting with it.
Lead Customers: Highly regarded research institutes such as Wageningen University and Research or Delphy.
Well-fundedness: Good. **Accessibility:** Good, in the Netherlands we have highly regarded research institutes of plant sciences, specifically the Wageningen University and Research that is known globally. **Market Characteristics:** Very keen on new technology, able to pay for expensive sensors to get specific information.
Partners/Players: Not necessary, but it wouldn't hurt to partner up with other university or researchers.
Size of the market: Very limited number of customers. However, the few customers are often well funded.
Competition: One of the interviewed customers, OnePlanet Research Center, has collaboration with Imec. When OnePlanet Research Center wants certain technology, Imec is their partner to go. This does not hold for Wageningen University and Research.
Complementary Assets Required: No.
Current use of sensors: For many experiments they use different kinds of sensors, even combining them.
Suitable for beachhead market: Yes. Especially considering the fact that they are able to buy expensive sensors just to get plant information makes this an attractive beachhead market. They are willing to become early adopters for new insights. However, the market is not very large. One possibility is to develop our sensor together with research institutes, but move fast to other markets.

G.0.2 High-tech Dutch horticultural growers

End user: Grower.
Application: Support in greenhouse steering.
Benefits: Sensors provide faster or better insights which can improve yield. They are very busy with learning as much as possible about different greenhouse steering strategies and what the effects are on plants. One can see it as top-sport, where they want to get everything out of their greenhouse. With limited land in the Netherlands, optimization is a key aspect in growing.
Lead Customers: Large companies and young growers. They see that sensors and software can help them become more scalable.
Well-fundedness: Compared to low- and mid-tech good, but with the current energy crisis they became much more sensitive to costs. **Accessibility:** Good, very close to Delft. **Market Characteristics:** Very collaborative. They are keen on new technologies, but they have to see that it works. They are very careful and will observe technology for more than a year before trusting it and relying on it.
Partners/Players: The companies that provide the climate computers and their software. Growers want the data implemented in their software and not use a new software package.
Size of the market: Large.
Competition: Sensor companies and vision companies. Sensor companies are used to learn about their steering strategies. Vision companies are used to simplify and scale.
Complementary Assets Required: For the full potential of our product, it needs to be connected to software companies that use the data to steer the greenhouse steering strategy. In the Netherlands the two largest growing co-operations signed a contract with such a company on April 28 and October 27 [82, 83]. Furthermore, the companies that provide the climate computers and their software need to be included. Growers want the data implemented in their software and not use a new software package.
Current use of sensors: Most have used different sensors to learn from. Other sensor companies have also sold to this market. However, many of them used them for a while and then disregarded them, as they learned what they needed. It is therefore necessary to make sure the sensor is sustainable in usage and not just used to 'learn the trick'.

Suitable for beachhead market: Yes. Especially considering the fact that they are easy to reach, it is a large market and they have also used other sensors, this is a very interesting market. Some have become early adopters of new sensing technologies.

G.0.3 High-tech horticultural growers abroad

End user: Grower.
Application: Support in greenhouse steering.
Benefits: Compared to the Dutch growers, they are not necessarily interested in optimizing their yield, they mainly want to make it easier to scale. With cheap land, it is easier to scale land than to get the last few percent extra yield.
Lead Customers: AppHarvest (USA) or e.g. Zone Agtech, Vineland Research and Niagra College (Canada)
Well-fundedness: Good.
Accessibility: Bad.
Market Characteristics: Similar to dutch high-tech market. The main difference is that in the Netherlands, growers buy all components of their greenhouse separately, whereas in e.g. USA and Canada they buy an integrated system (so climate computer, greenhouse, sensors etc. together).
Partners/Players: The companies that provide the climate computers and their software. They want the data implemented in their software and not use a new software package.
Size of the market: Large in Canada, USA, Mexico and the Gulf region.
Competition: Vision companies.
Complementary Assets Required: For the full potential of our product, it needs to be connected to data companies that use the data to steer the greenhouse steering strategy.
Current use of sensors: ?
Suitable for beachhead market: Medium. Considering the fact that they don't need it to work very good, but just good enough, makes this an attractive beachhead market. However, service is a very important aspect where the technology supplier should be available anytime. With a time-delay, this makes it harder to offer this service. The lack of accessibility limits the potential as beachhead market.

G.0.4 Low-tech horticultural growers abroad

End user: Grower.
Application: Support in greenhouse steering.
Benefits: Understanding how to steer the greenhouse with limited experience and knowledge. Especially where greenhouses have recently been introduced they still need to learn how to effectively steer the greenhouse. Sensor data can help them with that.
Lead Customers: ?
Well-fundedness: Bad.
Accessibility: Bad.
Market Characteristics: No rich customers, as they have not adopted technology available. This is mainly due to the price.
Partners/Players: The companies that provide the climate computers and their software. Environmental data is the basis, with which you can extend to crop data.
Size of the market: Large but not with much money.
Competition: Undetermined.
Complementary Assets Required: See partners/players.
Current use of sensors: None.
Suitable for beachhead market: No. As this market requires very cheap sensors and is hard to reach for the salesforce, this is not a market worth pursuing for our beachhead market.

G.0.5 Software companies (new market)

End user: Grower/data scientist
Application: Provide input for autonomous system. In this case the sensor will be at a grower and will send data to the data company.
Benefits: Data companies need objective, robust and fast data as input for their system. Currently they only use environmental data or manual crop data. Especially the latter differs between growers and is not very

reliable.
Lead Customers: Growers.
Well-fundedness: Good.
Accessibility: Good.
Market Characteristics: Data companies are even more careful compared to growers, as one mistake in data input will lead to disaster (where a grower can manually prevent this).
Partners/Players: Growers need to approve. The companies that provide the climate computers and their software need to send their data as well.
Size of the market: Still small as they are just starting. However, they are increasing rapidly.
Competition: Other sensor companies such as vivent. The data companies are currently doing experiments with competition to see which are the most stable and robust.
Complementary Assets Required: The companies that provide the climate computers and their software.
Current use of sensors: When these companies think they found a suitable sensor, they will test it intensively for more than a year to see if it gives them stable data of high quality.
Suitable for beachhead market: No, it must be very high quality and stable before they will rely on the sensor. However, this will be the envisioned market, especially considering the fact that growers might use them temporarily, but for data companies our solution will be permanent.

G.0.6 Breeders

End user: Breeder.
Application: Breeding companies can monitor the status of their new varieties at growers. Also breeders make crop manuals, where they tell growers how the new variety is best grown.
Benefits: When a new variety doesn't do well at a customer, breeders want to know why and if the grower hasn't made any mistakes. Moreover, they want to improve their crop manual to get a more satisfied customer. A different application is monitoring the different responses of new varieties.
Benefits: The goal of breeders is to create new varieties with certain traits as fast as possible. The sooner an aspect is measured, the better. Moreover, sensor provide objective data where the current practice is done manually and therefore subjective.
Lead Customers: NAK tuinbouw, Syngenta.
Well-fundedness: Good.
Accessibility: Good.
Market Characteristics: Very competitive, therefore they are keen on technology. Anything that gives them an edge over competitors is worth pursuing.
Partners/Players: -
Size of the market: Medium.
Competition: No.
Complementary Assets Required: None.
Current use of sensors: They use sensors in the later stage. When breeding a new variety, they start with many different varieties. Then they call it the art of throwing away: any crop that has bad aesthetics or grows bad is thrown away. The less varieties are left, the larger the tests they perform. For the last few varieties, they have extensive tests to for example test the drought-resistance or sugar quality. Currently, not many sensors exist for this.
Suitable for beachhead market: No, as we currently don't have a product for this. We can link the signal to the inner structure, but that is not something breeders are interested in. Once we can link this structure to real applications (drought-resistance, vase-life etc.) then yes.

G.0.7 High-tech agricultural farmers

End user: Farmer.
Application: Monitor the crops.
Benefits: This helps them determine when irrigation is needed.
Lead Customers: Greenhouse growers.
Well-fundedness: undetermined.
Accessibility: undetermined.
Market Characteristics: A bit less adoptive compared to greenhouse market.
Partners/Players: ?

Size of the market: Large.
Competition: Satellites.
Complementary Assets Required: ?
Current use of sensors: Mainly satellites and drones as they are scalable.
Suitable for beachhead market: No, our product is not scalable enough. Moreover, they drive with large vehicles over the crops, which the sensor should withstand. Finally, the steering is limited. So monitoring crops is nice, but it's hard to give a follow-up action.

G.0.8 Indoor farming companies

End user: Data scientist
Application: Monitor the crop.
Benefits: Iterate faster how the crop should be grown.
Lead Customers: Growy (Amsterdam).
Well-fundedness: Bad, the energy crisis made many indoor (vertical) farming companies go bankrupt.
Accessibility: Good.
Market Characteristics: Very adoptive, but still in early phase. Currently only high value small cress crops are grown in door due to large energy prices required.
Partners/Players: ?
Size of the market: Small but rising.
Competition: New sensor companies such as Quantified Sensor Technology.
Complementary Assets Required: ?
Current use of sensors: They mainly use vision technology.
Suitable for beachhead market: No. The crops are currently too small for our sensors. Moreover, those crops grow quite fast. This makes iteration of the growing recipe easy and sensor data less required. This market becomes interesting to pursue when they grow 'slower' crops such as tomatoes that grow for roughly 11 months.

H Companies I interviewed

Growers

- 2Harvest (online)
- 4Evergreen
- Agro Care
- Breugem Horticulture
- Bryte
- Duijvestijn
- FoodVentures (online)
- Gebroeders van der Lelij (phone)
- Gitzels
- Growers United
- Hogenboom Dahlia's
- Looye
- Lucel
- Naktuinbouw
- Koppert Cress
- Overgaag
- Prominent
- Prominent Groeneweg I (phone)
- Slaman Paprika's
- Solyco
- Tomato Trial Center
- Tomato World
- Tomato Vision
- Van Ruijven
- Voort Tomaten
- Vortus
- Vreugdenhil
- Zentoo

Breeders

- Anthura
- Bejo Zaden
- Dekker Chrysanten
- Deliflor
- Dümmen Orange
- Enza Zaden
- Evanthia
- Floricultura
- Hazera
- Keygene
- KWS (online)
- Pop vriend seeds (phone)
- Rijk Zwaan
- Royal van Zanten
- Sango Seeds

- Sion
- Syngenta
- Vreugdenhil

Software companies

- Blockbax
- Blue Radix
- B-Mex
- HortOS (from Ridder)
- iUNU
- Let's Grow (from Hoogendoorn)
- Linkthings
- Plantonomy (from Priva)
- Source.ag
- Sobolt
- WayBeyond

Sensor companies

- 2Grow (online)
- 30MHz
- Aranet (phone)
- Gearbox
- Grodan
- Growficient
- Quantified
- Sendot
- Sigrow
- Vivent (online)
- Wireless Value (online)

Other relevant parties

- AgriData Innovations
- Delphy
- Division Q
- Fruit Tech Campus
- Glastuinbouw Nederland
- Growy
- Dutch Greenhouse Delta
- HortiHeroes
- HortiNL
- Innovation Quarter
- Kekkilä-BVB
- Ledgnd
- NPEC
- OnePlanet Research Center (online)
- PATS
- Radboud University
- Rabobank (online)
- TNO
- Wageningen University and Research

Figure 28: LinkedIn post of HortiHeroes that brought Thijs and me in contact with Vreugdenhil Young Plants where we did our internship. At this point we still thought breeders would be our market.

I Mentimeter results

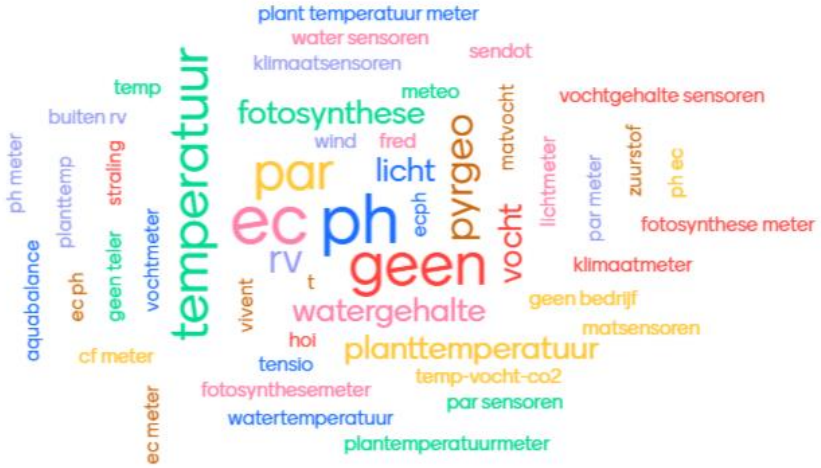
Below the answers of growers to questions about their sensor use are shown. These result come from the event I attended at Delphy, which have been published online [51]. The size of the words indicate the number of times a certain word has been inserted. I.e. the larger the circle with the word in it, the more often this word was inserted by different people.

VERSNELLEN
GROENE DIGITALISERING
GLASTUINBOUW

Go to **www.menti.com** and use the code **8409 8853**

Welke sensoren gebruikt u al op het bedrijf?

Mentimeter



28

Go to **www.menti.com** and use the code **8409 8853**

Wat is de meerwaarde van deze sensoren?

Mentimeter

VERSNELLEN
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26

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Waar zou u een (nieuwe) sensor voor willen hebben?

Mentimeter

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21

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Wat houdt u tegen om (nieuwe) sensoren te gebruiken?

Mentimeter

18

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