From Farm to Future: Designing a Roadmap for Robotics in Agriculture

Master Thesis

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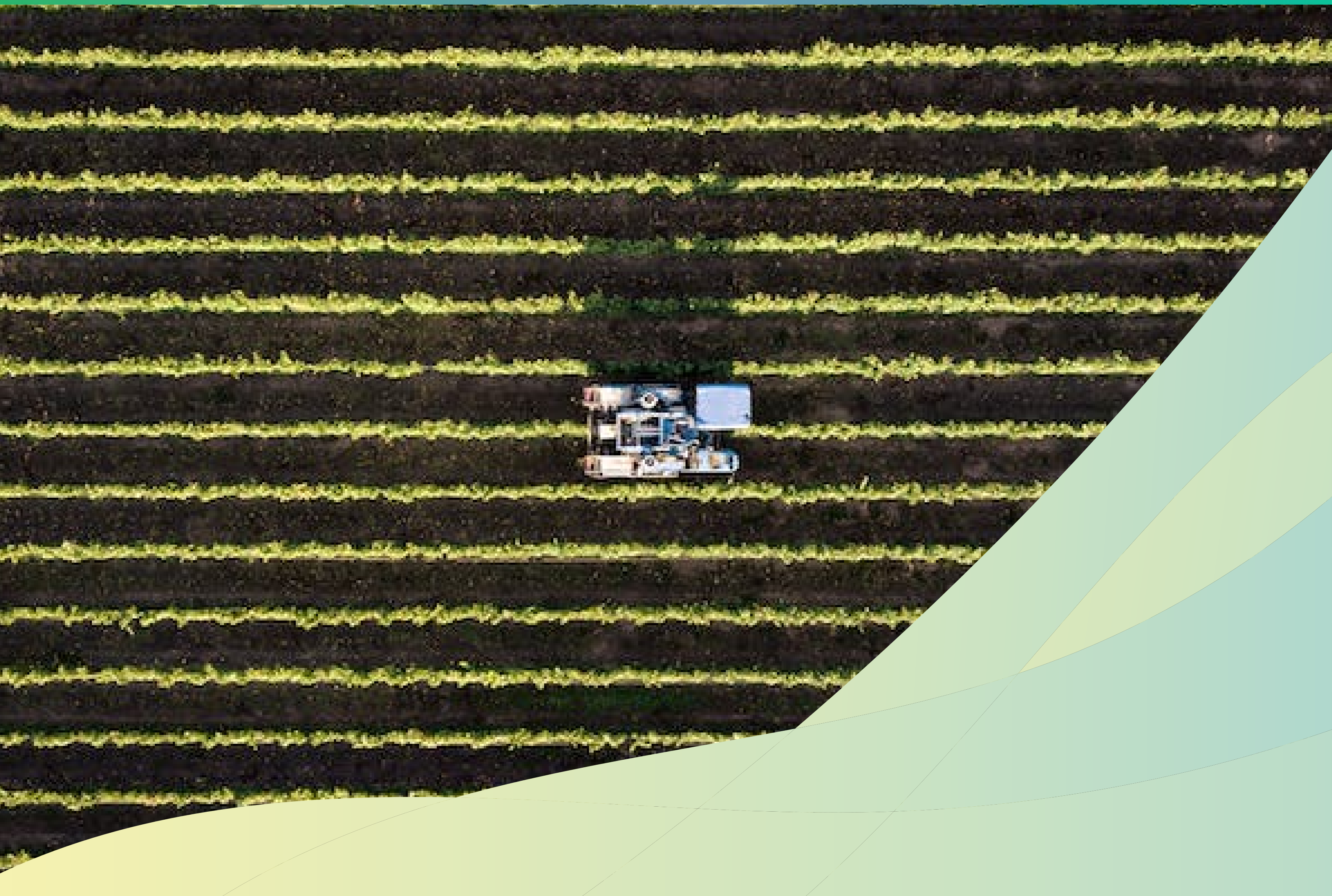


1. Contents

Preface 4
Abstract 5
Project Approach 9
  3.1 Double Diamond Model 10
  3.2. Qualitative research methods 11
  3.3. Design challenge 14
  3.4. Roadmapping methodology 16
Literature and Context Research 18
  4.1. Defining problems and challenges 19
  4.2. Technologies 21
    4.2.1. Benefits of using technology in agriculture 21
    4.2.2. Barriers 25
  4.3. Opportunity areas 27
    4.3.1. Precision agriculture 28
    4.3.2. Regenerative farming 30
Creative trend research 35
  5.1 Depest analysis 36
    5.1.1 DEPEST analysis 37
  5.2 Four clusters of food trends 39
    5.2.1 Cluster 1: The heavy weight of food 39
    5.2.2 Cluster 2: Customisation of food habits 40
    5.2.3 Cluster 3: Consciousness about food 40
    5.2.4 Cluster 4: Organizing the food chain 41
Case Studies 43
  6.1. Farm: Trayplant 44
  6.2. Rapo BV 45
  6.3 Conclusion 45
  6.4. Motives from other cases 47
Design areas 49
  7.1. Ecosystem 50
  7.2. Social acceptance 53
  7.3. Education, communication strategies 54
  7.4. Business models 56
Design goal of future 59
vision 59
  8.1. Direction of future vision 60
  8.2. Speculative design 61
  8.3. Time pacing strategy 62
Roadmap Implementation 65
  9.1. Future vision 70
    9.1.1. Horizon 1: raising awareness 71
    9.1.2. Horizon 2: Community building 72
  9.1.3. Horizon 3: Fostering wellbeing 74
    9.1.4. Stakeholder involvement 75
    9.1.5. TRL and valley of death 76
Validation 79
  10.1. Toolkit 80
  10.2. Stakeholder validation 82
Conclusion 86
Discussion 90
  12.1. Implications of roadmap method 91
  12.2. Implications of robotics 92
  12.3. Limitations of research 92
  12.4. Recommendations 93
Reflection 96
References 99

Preface

I am pleased to present my master's thesis on robotics in agriculture.Throughout this research project, I have gained valuable insights into the complex dynamics within the agricultural sector. I am grateful to all the stakeholders for their knowledge sharing and participation throughout this project.

Special thanks go to my chair Catelijne, mentors Eric and Irma for their guidance. Their feedback was great for shaping this report. I would also like to express my gratitude to my friends for their unwavering support during this journey, thank you for your ongoing support and participation in brainstorming sessions that have enriched this research

To my colleagues at Berenschot, thank you for listening and conversing with me. The attentiveness of the FI team has been very welcoming to me.

This thesis delves into the challenges of implementing robotics in agriculture. Navigating these challenges has been rewarding. I hope that as you read through this report, it may deepen your understanding of this interesting field.

Abstract

This study develops a roadmap to guide the integration of robotic technologies into Dutch agriculture in a responsible manner that benefits farmers and the environment.

The Dutch agricultural sector faces challenges from climate change, labor shortages, and sustainability pressures. Robotics shows promise in addressing these issues through applications like precision farming and reducing physical demands. However, widespread adoption of these technologies has been limited due to barriers like high costs, reliability concerns, lack of awareness among farmers, and uncertainty. A more strategic and coordinated approach is needed to responsibly introduce robotics into Dutch agriculture in a way that benefits all stakeholders over the long run.

An extensive literature review explored technology trends, agricultural challenges, and stakeholder perspectives. Insights informed the creation of a future vision and three-horizon roadmap using a strategic planning process combined with speculative design techniques. Validation gathered feedback from industry experts.

The roadmap envisions autonomous agriculture empowering resilient food systems through three horizons of Raising Awareness, Community Building, and Fostering Wellbeing, towards the future vision:

2. INTRODUCTION

A Roadmap for Robotics in Agriculture

In the complex reality of Dutch and global agriculture, farmers and growers are central to the food supply of our society. The Netherlands is one of the big players in the agriculture industry, and is known for its innovative and efficient farming practices. However, the agricultural sector in the Netherlands is facing a number of challenges, such as the food shortage due to increasing global population, labour shortage, climate change, and environmental concerns.With available agricultural land becoming increasingly scarce and the continued tightening of regulations regarding food production, crop protection products and fertilizers, agriculture faces a unique set of challenges.(Zaken, 2018)

The Netherlands is facing increasing competition from other countries like China that are investing in innovative agricultural technologies.In order to maintain its position as one of the world leaders in agriculture and to address these changes, the Netherlands needs to transition to even more modern and revisited ways of agricultural practices. For example, robotics in agriculture can be used as enablers to improve the efficiency of the agricultural sector in the Netherlands, like robots that can be used to perform tasks such as weeding. This frees up farmers, growers and workers to focus on other tasks, such as managing their businesses and making strategic decisions. (Pizzuto, 2023)

The transition to using robotics in agriculture currently faces a low adoption caused by challenges, such as the high upfront and ongoing costs, uncertainties about benefits, and a lack of stability in the rules and standards governing robotic agriculture systems. Improvements in these areas could help accelerate the adoption of robotics on farms. (Gil et al., 2023)

Amid these challenges, a roadmap can support direction within the community, as it aims to create a pathway through robotic applications for Dutch agriculture. In order to find a route to the goal of this transition, we will develop and employ a roadmap, based on the research in this thesis. This roadmap coverage will delve deeper into the concrete steps and strategies that can help achieve a desirable future.

It is a big journey within the industry, in which a resilient and sustainable future for Dutch agriculture is the focus for the future vision. The direction of the future vision for the roadmap is to Revolutionize Agriculture: Autonomous Agriculture for Resilient Food Systems, with a focus on sustainable systems.
The scope for this direction is both open field agriculture and horticulture in the Netherlands, as these sectors have overlapping interests, not including livestock in the roadmap.
The target group for the roadmap is the Agrobot community, which comprises businesses and end-users in the agriculture and high-tech sectors of the Netherlands. By coordinating efforts, the community is forging innovative and accessible solutions to be deployed across the farming industry. The community is helping that these technologies are developed and implemented in a way that benefits all stakeholders, including farmers, growers, technology companies, and government agencies.

The main research question for creating a roadmap of robotics in agriculture for the Agrobot community is:

How can robots and technology be integrated into agriculture in the Netherlands that is beneficial to the stakeholders?

The following design questions are formulated and used during the roadmap design to address the transition of robotic landscape in the Netherlands:

What are the key challenges and opportunities in the transition of robotic implementation?
How can this transition of robotic agriculture benefit all stakeholders?

Addressing these research questions will help to create a roadmap for the transition to robotic agriculture in the Netherlands that is beneficial to all stakeholders.

Overall, the transition to innovative and modern agriculture in the Netherlands might be essential for the future of the agricultural sector. By transitioning to robotic agriculture and other innovative technologies, the Netherlands has the possibility to address the challenges that the sector is facing.

CHAPTER 3

Project Approach

3.1 Double Diamond Model

3.2 Qualitative research methods

3.3 Design Challenge

3.4 Roadmapping

The purpose of this chapter is to present the outline of the entire project, to clarify the chosen approach, as well as to present the design challenges that come along this project. Section 3.1 presents the double diamond model. Section 3.2 explains the used qualitative research methods. In section 3.3, the design challenges are analyzed. Lastly, section 3.4 covers the methodologies used for creating the roadmap.

3.1 Double Diamond Model

During the complex exploration of integrating robotics into agriculture, a structured approach is used. This project unfolds through four distinct phases from the double diamond model. In essence, this structured approach, integrating insights from the agricultural sector, establishes the robust foundation for this research.The double diamond design process model was well-suited for developing this roadmap due to its structured, divergent and convergent approach that allowed thorough exploration of opportunities and challenges.

Phase 1: Contextual Discovery
The project starts with an extensive research phase designed to delve deep into the agricultural landscape. This phase mirrors the 'Discover' stage, similar to the Jan Buijs Delft innovation method, where the primary objective is to gain profound insights into the context of agriculture. Extensive desk research with broad literature forms the foundation. Moreover, key stakeholders including farmers, technology providers, and policymakers are engaged through in-depth interviews. This approach provides a holistic understanding of the existing challenges, technological gaps, and societal issues that frame the integration of robotics in agriculture.

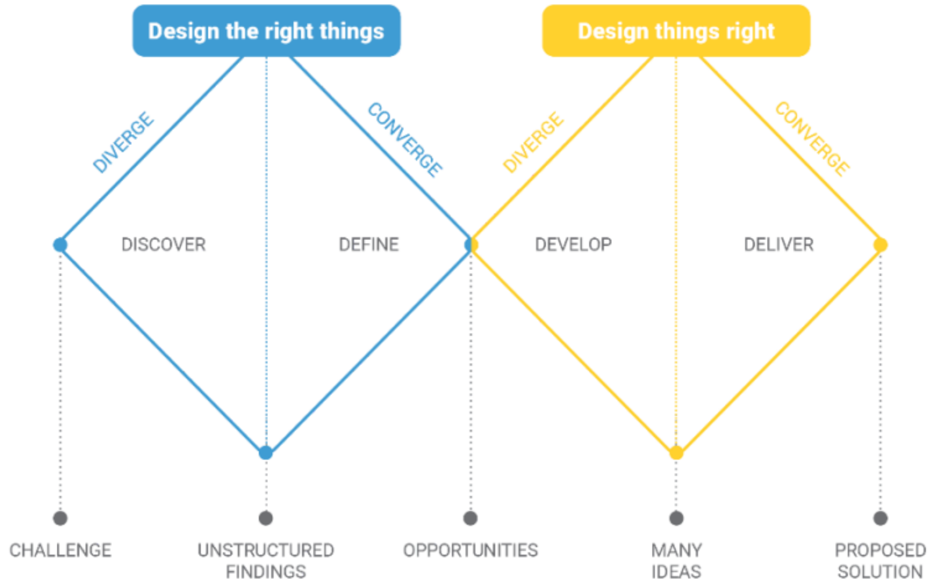


figure 3.1 double diamond (Design for Health, n.d.)

Phase 2: Problem Scoping and Definition
Building upon the gained insights, the research progresses into the 'Define' phase. In this stage, conclusions drawn from the initial research are analyzed. Multiple considerations for design challenges are reviewed, and a converging process is initiated. Perspectives from experts from agricultural organizations, educational institutions, and farmers are gained to refine identified challenges. This phase serves to narrow the problem scope of robotics interventions.

Phase 3: Innovative Design
Transitioning into the 'Develop' phase, the idea is to extract unique and inventive perspectives from the farming community, through engaging with stakeholders. Vision and ideas from farmer organizations, industry experts, and specialists lead to strategies, ensuring the relation with the practical agricultural landscape. This iterative approach ensures that the formed solutions and visions align seamlessly with the needs and aspirations of the target group.

Phase 4: Roadmap Finalization
The outcomes of this research unfold in the 'Deliver' phase. Here, the developed strategies and interventions are subjected to feedback and iteration. The final deliverables, including the innovative roadmap for integrating robotics, undergo evaluation. Conclusions drawn from this phase are concrete and lead to insightful recommendations, finalizing agricultural exploration.

3.2. Qualitative research methods

Qualitative methods offer a deep understanding of the agricultural landscape, to create a roadmap for robotics in agriculture that is not only technologically sound but also socially and practically relevant. By incorporating real-world experiences and perspectives, the roadmap is more likely to be embraced by the farming community and stakeholders, leading to successful implementation and positive outcomes.

Including qualitative methods in the roadmapping process ensures a better understanding of the technological, social, economic, and ethical dimensions of implementing robotic technologies in agriculture. By combining qualitative insights from interviews, events, demonstrations, excursions, documentaries, and academic literature, the roadmap can develop a well-informed and holistic overview that addresses the multifaceted challenges and opportunities in the agricultural sector. The following qualitative research methods were used in this project.

1. In-Depth Insights through Interviews:
Conducting interviews with farmers, agricultural experts, and technologists provides in-depth qualitative data. These conversations offered nuanced insights into current challenges, expectations, and preferences related to robotic technologies. Farmers' practical experiences and expert opinions are essential for understanding the real-world context in which robotic solutions will be implemented. The range of perspectives was gathered through at least 10 interviews and multiple semi-informal conversations asking questions related to the research topic.

figure 3..2 informal conversations

2. Observation and Learning from Smart Farming Events/Conference:
Attending smart farming events/conference allows for direct exposure to new technologies, innovations, and trends in the agricultural sector. Observing live demonstrations, listening to industry experts, and participating in discussions provide a comprehensive understanding of the state of

the art technology. These events were hotspots for networking and knowledge exchange, enabling roadmaps to stay updated on the latest developments.The range of perspectives was gathered through two smart farming events and the AgTech conference in Delft.

fig 3.3 event in Reusel

3.Real-time Understanding through Robot Demonstrations:
Viewing robot demonstrations, such as the Robot One demo from Pixelfarming Robotics, provided first hand experience of how robots functioned in real life settings in Ulvenhout and Reusel. Observing their capabilities, limitations, and interaction with farmers and crops could offer new insights. It allowed us to assess the maturity of existing technologies, helping them make informed decisions about integration and adoption strategies.

fig 3.3 Demo Robot One

4. On-Site Learning from Farm Excursions:
Farm excursions provided a unique opportunity to witness agricultural practices in action through immersion, like exploring the test fields of Wageningen University. Daily challenges could be observed, and where robotic intervention could be beneficial by visiting farms, such as the ones visited in Bavel, Middenmeer or Lelystad. This firsthand knowledge was valuable for decentralized robotic solutions to match the practical needs of farmers.

figuur 3.4 locatie WUR

5. Documentary Films:
Documentaries often provide a visual representation of real-world agricultural practices and challenges. Seeing farmers using traditional methods and witnessing their struggles firsthand can highlight the areas where robotic technologies can make a significant impact. It offers a humanizing perspective, showing the faces and stories behind the agricultural landscape.

Documentaries can raise awareness about the challenges faced by farmers and the agricultural industry. This increased empathy and understanding of the human aspect of farming can drive more compassionate and socially responsible technology solutions.

fig 3.5 proeftuin Lelystad

3.3. Design challenge

The design challenge is to create a roadmap that addresses all of these considerations and that leads to a future where robotic agriculture is widely adopted and benefits all stakeholders. A roadmap typically breaks down complex transitions into doable steps towards a future vision.

The challenge of designing a roadmap for the future of robotics in agriculture is to create a plan that takes into account the key barriers and possibilities that come with the transition to robotic farming. The roadmap must be developed in such a way that it is inclusive and collaborative, while also taking into account the needs and interests of all stakeholders. These stakeholders include farmers, growers, technology companies, government agencies, and consumers.

The roadmap should be developed through a collaborative process that involves all stakeholders. This helps to make sure that the roadmap is comprehensive and addresses the needs of all stakeholders. Additionally, a collaborative process will help to build confidence for the roadmap and make it more likely to be successful.

The design challenge to create a roadmap for the future of robotics in agriculture is to develop a framework that is:

- Comprehensive: The roadmap should address all key aspects of the transition to robotic agriculture, including the technological, economic, social, and environmental challenges and opportunities.
- Realistic: The roadmap should be achievable given the current state of technology and the available resources.
- Beneficial to all stakeholders: The roadmap should be designed in a way that benefits all stakeholders, including farmers, growers, technology companies, government agencies, and consumers.

It is a challenge to create a roadmap that addresses all of these considerations and that leads to a future where robotic agriculture is widely adopted and benefits all stakeholders. By addressing the challenges and opportunities associated with robotic agriculture, the roadmap can help to create a more sustainable and prosperous agricultural sector for the future.

Once the roadmap is developed, it is important to implement it promptly. This will require the cooperation of all stakeholders, including farmers, growers, technology companies, and government agencies. The design of the roadmap should be an iterative process that involves input from all stakeholders. Afterwards, the roadmap should be regularly updated to reflect the latest developments in robotic agriculture and to monitor that it remains on track to achieve its goals.

Here are some specific design questions that can be considered when creating a roadmap for robotics in agriculture:

» *What are the key technological priorities for robotic agriculture research and development?*

» *What are the key policy and regulatory changes that are needed to support the transition to robotic agriculture?*

» *What are the best practices for the adoption of robotic agriculture by farmers and growers?*

» *How can we ensure that the transition to robotic agriculture is fair and inclusive?*

» *How can we measure the progress of the transition to robotic agriculture and ensure that the roadmap is meeting its goals?*

By addressing these questions, the Agrobot community can develop a roadmap for the future of robotics in agriculture that is comprehensive, realistic, and beneficial to all stakeholders.

3.4. Roadmapping methodology

To unite and align the various parties within an ecosystem towards a collective goal, drawing up a joint roadmap can offer a solution. The content of the roadmap varies depending on the purpose, but from the literature there are three central questions that arise when creating a roadmap.(Phaal et al., 2005)

'Where do we want to go? Where are we now? How can we get there?'

Before a roadmap can be drawn up, all parties involved must first be clear about what the end goal is. This can be a concrete, quantitative goal or a vision for the future. Then it is important to analyze the current state of the technology and the market.

A plan must then be drawn up on how the established goal can be achieved. This can be in the form of a phased action plan, determining milestones to be achieved, identifying potential challenges, or a combination of these. (Weller, 2021)

The plan can be supported through the Design Roadmapping method. Variations of roadmapping are explored to create a better understanding of suitable roadmapping approaches. The DR method is a strategic planning process that helps organizations to visualize and plan their future based on the book Design Roadmapping by Lianne Simonse. It is a guide to the Design Roadmapping method, which is a strategic planning process that helps organizations to visualize and plan their future.

The book covers all aspects of the Design Roadmapping process, from defining the scope and purpose of the roadmap to gathering information and insights, and developing a vision for the future.

Creative Trend Research

Business Model Design

Future Visioning

Time Pacing Strategy

Visualise Roadmaps

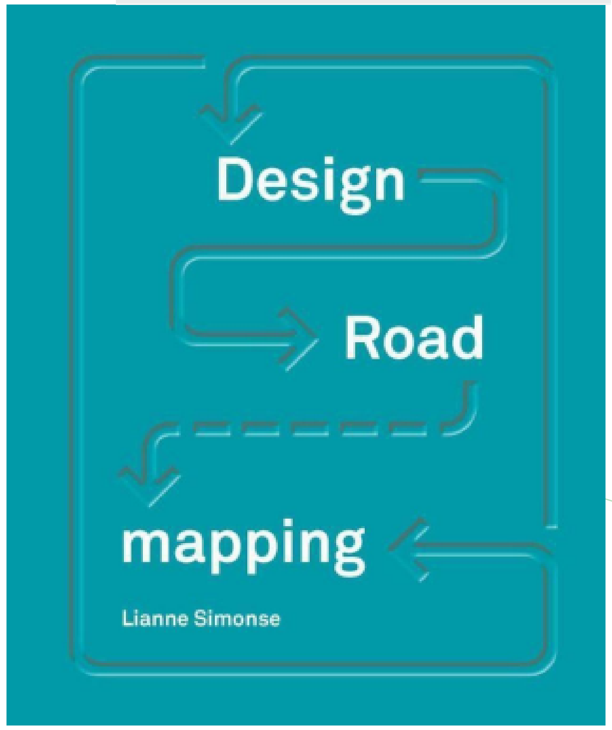


fig 3.6 Book (Simonse, 2018)

CHAPTER 4

Literature and Context Research

4.1 Defining problems and challenges

4.2 Technologies

- **4.2.1 Benefits of using technology in agriculture**
- **4.2.2 Barriers and limitations**

4.3 Opportunity areas

- **4.3.1 Precision agriculture**
- **4.3.2 Regenerative farming**

This chapter outlined several important challenges facing agriculture and opportunities that new technologies provide. Key issues around biodiversity loss and rising demands were presented. Overall, technologies like precision robotics show promise in addressing productivity and sustainability if integrated thoughtfully.

4.1. Defining problems and challenges

Global developments reveal challenges to food security, poverty reduction, and agriculture sustainability. The increasing demand for food, coupled with dwindling natural resources and the impacts of climate change, presents a formidable obstacle. These challenges are strengthened by natural disasters, pests, and conflicts, which negatively impact livelihoods and food systems. Climate change poses threats to food availability and nutrition, making adaptive strategies necessary.Climate change is a major challenge for agriculture. It is leading to more extreme weather events, such as droughts, floods, and heat waves. These events can damage crops and livestock, and reduce yields. Climate change is also making it more difficult to grow crops in some regions. Soil erosion is more prominent due to low ground water levels, causing biodiversity loss. While changing consumer preferences, like the demand for organic and sustainable food, pose a challenge for farmers to stay competitive.(Brevik, 2013)
Additionally, the global population is growing fast, leading to higher food demand. However, climate change, soil erosion, and labor shortages affect farm productivity. Economic factors, such as input costs and product prices, impact profits. Also affecting farm productivity is a labor shortage due to factors like population aging and urban migration, making it hard for farmers to find workers.(Sacks et al., 2010)
Moreover, available agricultural land is limited due to population growth and urbanization, hindering farmers from expanding production. Stricter regulations on the use of pesticides and fertilizer also hinder the yield of production. These challenges highlight the need for innovative solutions.(Food and Agriculture Organization of the United Nations, 2017)

These challenges are interconnected. For example, climate change can lead to soil erosion, which can reduce farm productivity. Additionally, the rising demand for food can lead to farmers using more pesticides and herbicides, which can harm biodiversity.(Syngenta, n.d.)
It is important to address these challenges in order to maintain a sustainable food supply. Some of the key aspects can interact with each other to create the challenges in agriculture :

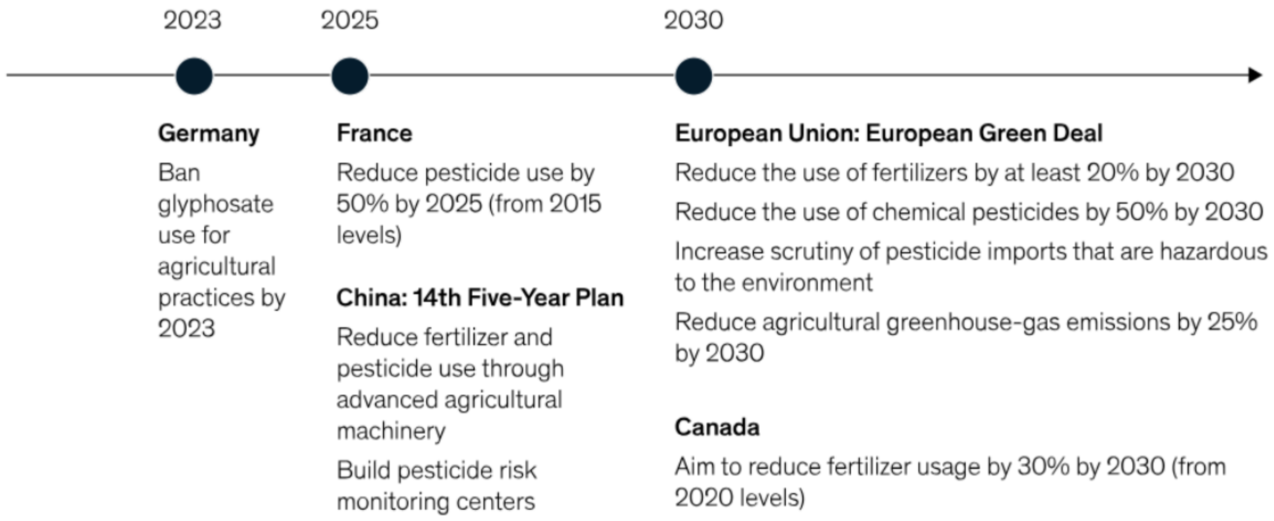
- Consumers are demanding more healthy, sustainable, and ethical food. This can be difficult for farmers to meet, especially if they are facing economic challenges such as volatile commodity prices and high input costs.
- The global population is growing, and so is the demand for food. However, there is a limited amount of land available for agriculture. This means that farmers need to produce more food from less land.
- Farmers need to produce more food from less land, but they are also facing a labor shortage. This can make it difficult for them to meet the rising demand for food.
- Agriculture is a major user of water. However, water resources are becoming increasingly scarce in many parts of the world. This means that farmers need to find ways to use water more efficiently.
- Government policies, such as agricultural subsidies and trade agreements, can have a significant impact on farmers' incomes. This can make it difficult for farmers to invest in new technologies and improve their agricultural practices on their own.

These are just some of the challenges facing agriculture today. It is important to address these challenges in order to prepare for new future challenges.

Key takeaways:

Challenges in agriculture through key aspects

- Climate change
- Loss of biodiversity and soil erosion
- Satisfy consumer preferences and demands
- Higher demands for more food
- farming output
- Financial factors
- Labor crisis
- Usage of space and water
- Political factors
- Social and ethical issues



Germany

Ban glyphosate use for agricultural practices by 2023

France

Reduce pesticide use by 50% by 2025 (from 2015 levels)

China: 14th Five-Year Plan

Reduce fertilizer and pesticide use through advanced agricultural machinery

Build pesticide risk monitoring centers

European Union: European Green Deal

Reduce the use of fertilizers by at least 20% by 2030

Reduce the use of chemical pesticides by 50% by 2030

Increase scrutiny of pesticide imports that are hazardous to the environment

Reduce agricultural greenhouse-gas emissions by 25% by 2030

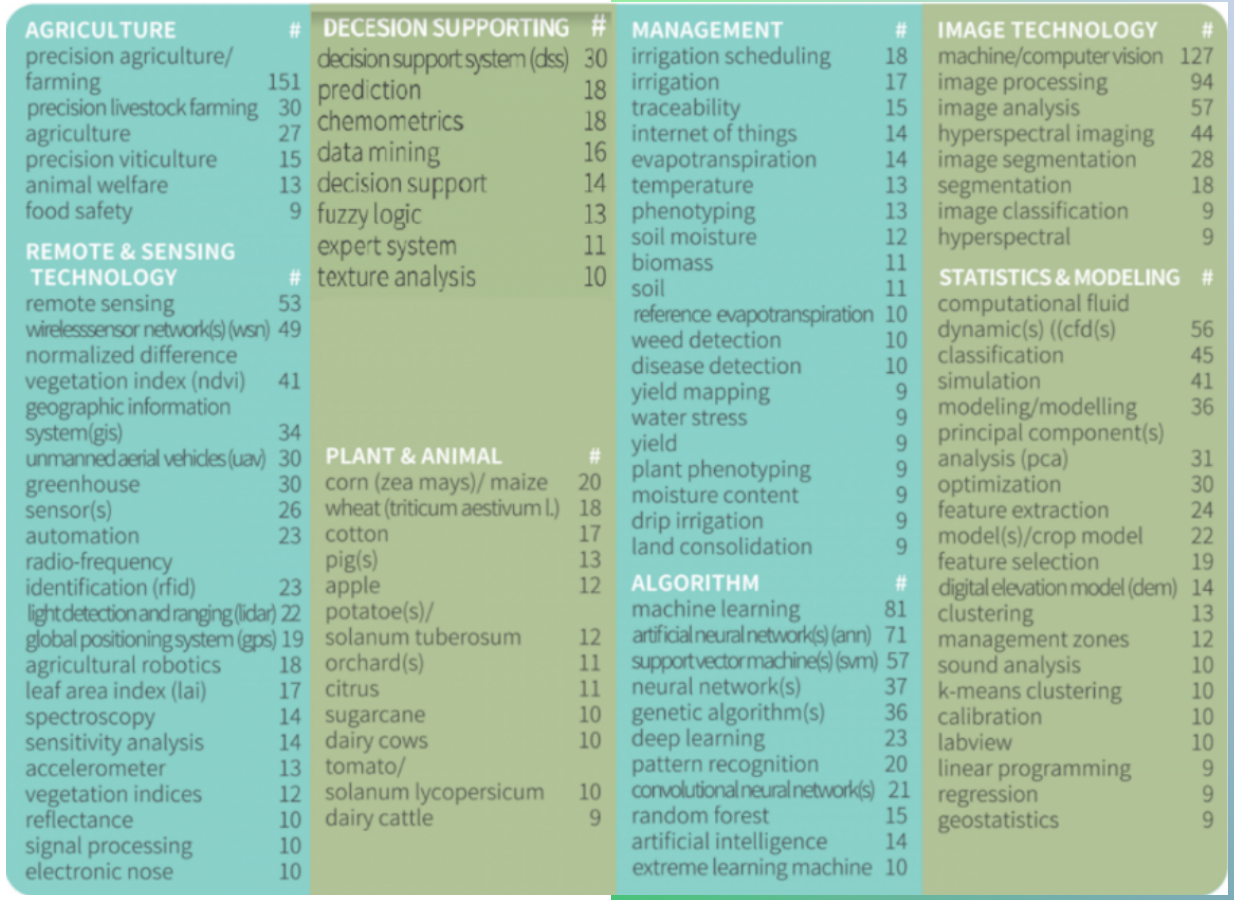
Canada

Aim to reduce fertilizer usage by 30% by 2030 (from 2020 levels)

Fig 4.1 EU emission goals(McKinsey & Company, 2022)

4.2. Technologies

Technologies is a broad term that can lead to multiple forms of innovations. Further overview on agricultural technology can be derived from literature, however not necessarily robotic technology, see figure 4.2.



AGRICULTURE	#
precision agriculture/ farming	151
precision livestock farming	30
agriculture	27
precision viticulture	15
animal welfare	13
food safety	9

REMOTE & SENSING TECHNOLOGY	#
remote sensing	53
wirelesssensor network(s) (wsn)	49
normalized difference vegetation index (ndvi)	41
geographic information system(gis)	34
unmanned aerial vehicles (uav)	30
greenhouse	30
sensor(s)	26
automation	23
radio-frequency identification (rfid)	23
light detection and ranging (lidar)	22
global positioning system (gps)	19
agricultural robotics	18
leaf area index (lai)	17
spectroscopy	14
sensitivity analysis	14
accelerometer	13
vegetation indices	12
reflectance	10
signal processing	10
electronic nose	10

DECESION SUPPORTING	#
decision support system (dss)	30
prediction	18
chemometrics	18
data mining	16
decision support	14
fuzzy logic	13
expert system	11
texture analysis	10

PLANT & ANIMAL	#
corn (zea mays)/ maize	20
wheat (triticum aestivum l.)	18
cotton	17
pig(s)	13
apple	12
potatoe(s)/ solanum tuberosum	12
orchard(s)	11
citrus	11
sugarcane	10
dairy cows	10
tomato/ solanum lycopersicum	10
dairy cattle	9

MANAGEMENT	#
irrigation scheduling	18
irrigation	17
traceability	15
internet of things	14
evapotranspiration	14
temperature	13
phenotyping	13
soil moisture	12
biomass	11
soil	11
reference evapotranspiration	10
weed detection	10
disease detection	10
yield mapping	9
water stress	9
yield	9
plant phenotyping	9
moisture content	9
drip irrigation	9
land consolidation	9

ALGORITHM	#
machine learning	81
artificial neural network(s) (ann)	71
support vector machine(s) (svm)	57
neural network(s)	37
genetic algorithm(s)	36
deep learning	23
pattern recognition	20
convolutional neural network(s)	21
random forest	15
artificial intelligence	14
extreme learning machine	10

IMAGE TECHNOLOGY	#
machine/computer vision	127
image processing	94
image analysis	57
hyperspectral imaging	44
image segmentation	28
segmentation	18
image classification	9
hyperspectral	9

STATISTICS & MODELING	#
computational fluid dynamic(s) ((cfd(s)	56
classification	45
simulation	41
modeling/modelling	36
principal component(s) analysis (pca)	31
optimization	30
feature extraction	24
model(s)/crop model	22
feature selection	19
digital elevation model (dem)	14
clustering	13
management zones	12
sound analysis	10
k-means clustering	10
calibration	10
labview	10
linear programming	9
regression	9
geostatistics	9

fig 4.2 terms in agriculture (Chai, 2021)

4.2.1. Benefits of using technology in agriculture

Literature shows the many applications and possibilities for robots in agriculture. Agricultural robots are designed to perform various tasks in the crop production cycle, with harvesting and weeding being the most focused and labor-intensive ones. These robots need to be capable of different functions and adding value by performing in different scenarios. Fountas et al. addressed applications for agricultural robots. (Fountas et al., 2020)

1. Weeding - Removing labour-intensive and repetitive task
2. Seeding/sowing - Reducing soil impact
3. Disease and Insect Detection - Preventing economic damage in early stage
4. Crop Monitoring - Increasing plant growth, health, quality
5. Spraying - Reducing input with precision farming for pesticides and fertilizers

6. Harvesting - Delicate labor with consistent quality of harvested produce
7. Plant Management -High value crops, irrigation, sorting process
8. Multi-Purpose Robotics- Fast ROI due to their versatility and efficiency in various agricultural tasks.

Left to right Dino, Xaver, RobHortic, Terrasentia, Vinobot, Holland Green Machine, Dogtooth, TrimBot, corresponding order with the applications (Fountas et al., 2020)

1. Weeding:

Indoor agriculture:
- Advantages: controlled environments enable precise robot navigation and targeted weeding without damaging crops.
- Challenges: high initial investment in specialized robots and integration of existing technology.

Outdoor agriculture:
- Advantages: larger-scale autonomous weeding robots are being developed, reducing labor costs and dependency on pesticides.
- Challenges: navigation in uneven outdoor terrain can be challenging, and avoiding damage to nearby crops is crucial.

2. Seeding/sowing:

Indoor agriculture:
- Advantages: precise seeding in controlled conditions with minimal soil impact, leading to efficient use of seeds.
- Challenges: high initial costs, especially for precision seeding equipment in large indoor facilities.

Outdoor agriculture:
- Advantages: automated seeding reduces labor, ensures uniformity, and minimizes soil disturbance.
- Challenges: adaptation to different soil types and weather conditions is necessary for effective outdoor seeding.

3. Disease and insect detection:

Indoor agriculture:
- Advantages: sensors and ai algorithms enable early detection and targeted treatment, preventing economic damage.
- Challenges: integration of detection systems into the complex indoor environment can be intricate.

Outdoor agriculture:
- Advantages: drones and sensors detect diseases/insects across large fields swiftly, enabling timely interventions.
- Challenges: weather conditions can affect the accuracy of detection systems; ongoing advancements in sensor technology are essential.

4. Crop monitoring:

Indoor agriculture:
- Advantages: precise monitoring of plant health, growth, and quality in controlled environments, leading to optimized yields.
- Challenges: integration of various sensors and data analytics systems requires careful planning.

Outdoor agriculture:
- Advantages: satellite imagery, drones, and ground-based sensors provide extensive coverage for monitoring large fields.
- Challenges: data interpretation and integration can be complex; real-time monitoring is essential for timely decisions.

5. Spraying:

Indoor agriculture:
- Advantages: precision spraying reduces chemical usage and minimizes environmental impact within closed environments.
- Challenges: integration with other robotic systems for coordinated operations is vital.

Outdoor agriculture:
- Advantages: autonomous sprayers optimize pesticide and fertilizer application, reducing wastage and environmental contamination.
- Challenges: wind and weather conditions affect spray accuracy; precise targeting remains a challenge.

6. Harvesting:

Indoor agriculture:
- Advantages: robotics handle delicate harvesting tasks, ensuring minimal damage to crops and high-quality yields.
- Challenges: adaptation of robots to different crop varieties and handling fragile produce without bruising.

Outdoor agriculture:
- Advantages: automated harvesting reduces labor dependency and ensures timely harvesting of large fields.
- Challenges: gentle handling of crops, especially fruits, and adjusting to various shapes and sizes.

7. Plant management:

Indoor agriculture:
- Advantages: automated systems manage irrigation, nutrient delivery, and sorting processes, ensuring optimal conditions for high-value crops.
- Challenges: complex automation systems require regular maintenance and skilled personnel.

Outdoor agriculture:
- Advantages: automated irrigation systems optimize water usage; sorting and packing robots enhance post-harvest processes.
- Challenges: adaptation to diverse crops and field conditions; integration with existing infrastructure can be challenging.

8. Multi-purpose robotics:

Indoor agriculture:
- Advantages: versatile robots designed for multiple tasks provide a faster return on investment within controlled environments.
- Challenges: ensuring compatibility and seamless integration with existing indoor systems.

Outdoor agriculture:
- Advantages: multi-purpose robots reduce the need for multiple machines, offering cost-effective solutions for various tasks.
- Challenges: developing robots versatile enough to handle diverse outdoor tasks

while maintaining efficiency and accuracy. All in all, these applications have several benefits that impact current agriculture problems in a positive manner.

One of the major improvements would be the reduction of pesticides and fertilizers, by applying weeding robots. However, these robots currently lack the high-precision to detect every weed.

Another improvement of agricultural robots is the reduction of manual labor. The robots can aid and even replace many labor-intensive tasks, such as harvesting apples, tomatoes and many more crops in greenhouses. Yet, the current robots cannot handle non-uniformly shaped crops, such as pears. Due to their non uniform shape, harvesting robots are currently unable to harvest these crops without damaging it. Future development might reduce the weight of the limitations. e crops without damaging it. (Bawden et al., 2017)

4.2.2. Barriers

The adoption of robotic technologies in agriculture faces a number of challenges according to Gil et al. Especially, if the rules and regulations governing autonomous systems and their use in agriculture keep changing frequently, this lack of stability and predictability in the policy environment could hinder the transition to robotic agriculture for farmers.

Firstly, robots cannot yet compete with human labor in terms of specificity, especially when dealing with delicate crops. This is due to the limitations of current robot hardware and software that are not yet capable of adequately re-creating the dexterity and precision of human hands. Farmers also tend to set higher bars for robots than for humans. Even though humans make mistakes, robots on the other hand need to be flawless. That is how strawberry picking robots a challenge due to the soft fruit, however for quite delicate flowers there are robots already used in this industry. (Sadak, 2022)

Furthermore, the upfront costs of adopting robotic technologies can be prohibitive for many farmers, especially small-scale farmers. (MarketsandMarkets, n.d.).
This is due to the high cost of developing and manufacturing robots, as well as the cost of purchasing and maintaining them.In addition to the initial hardware costs, the maintenance and operational costs of robotic systems in terms of hardware, software, energy needs to be considered. These ongoing costs are different from traditional farming activities and may discourage purchase.(Gil et al., 2023)
Robotic technologies are also complex and require a certain level of technical expertise to operate and maintain. This can be a challenge for farmers who do not have the necessary training or experience. Additionally, robots can be sensitive to environmental and weather conditions, such as temperature, humidity, and wind. This can limit their ability to operate in certain environments or during certain times of year.

Some farmers may also be hesitant to adopt robotic technologies due to a lack of awareness or concerns about the impact on their workforce. It is important to educate farmers about the benefits of robotic technologies and to help them develop a transition plan that addresses the potential impact on their workforce. Farmers may be reluctant to adopt new technologies until their benefits and impacts are clearly proven, as they have uncertainty about economic and environmental benefits. It takes time to fully assess the economic and environmental benefits of using robots and their performance. (Chun et al., 2021)

In addition to the above challenges, it is also worth noting that the performance of robots in agriculture can vary depending on a number of variables, such as crop type, time of day, weather, and ground surface. This is because agricultural robots are still under development, and their capabilities are not yet fully optimized for all possible conditions. (He, 2018)

Despite these challenges, the adoption of robotic technologies in agriculture is expected to grow in the coming years. (Wang, 2022)
This is due to a number of factors, including the increasing availability of affordable and reliable robots, the growing demand for food, and the need to increase agricultural productivity and sustainability.

Overall, there are several challenges that need to be addressed before robotic technologies can be widely adopted in agriculture. However, the potential benefits of robotic technologies are significant, and it is likely that we will see continued growth in this area in the coming years.

Key takeaways:

- Robots cannot yet compete with human labor specificity i.e. delicate crops
- Better software and hardware are required
- High costs to adopt robotic technologies
- Time lost on technical issues and equipment breakdown
- Some farmers prioritize short-term profit over sustainability, posing obstacles to sustainable agriculture.
- Education and awareness is needed to adapt farmer to new technologies
- Depending on variables, a robot's performance varies depending on crop, time of day, weather, and ground surface.

4.3. Opportunity areas

The adoption of agricultural robots has several key advantages for farmers. Yet, these robots are not used widely in agriculture. In the next section,several opportunities are presented, for which farmers can significantly benefit from these agricultural robots, contributing to the agricultural sector's efficiency, sustainability, and profitability.

One of the primary benefits lies in increased efficiency and productivity. Agricultural robots, operating tirelessly and with high precision, automate tasks such as sowing, harvesting and pest control. This continuous and accurate performance results in increased overall productivity for farmers. Moreover, agricultural robots facilitate cost savings in the long run by reducing the reliance on manual labor, optimizing resource utilization, and diminishing operational costs. Their ability to work tirelessly can negate external factors, such as mitigating issues related to labor shortages, which is especially important during peak seasons. The result is the prevention of financial loss from unharvested crops and the continuation of production schedules.(He, 2018)

Furthermore, agricultural robots foster sustainability and environmentally-friendly farming practices. Through data these robots enable the optimized use of resources like water, fertilizers, and pesticides. By precisely applying these resources based on actual crop needs, waste is reduced, and farmers contribute to environmental conservation. Additionally, the data-driven approach empowers farmers to make informed decisions, increase the quality of produce. For instance, predictive analytics can anticipate disease outbreaks, enabling timely interventions and reducing crop loss. Moreover, the ability to consistently deliver high-quality produce positions farms favorably in the market, meeting the demands of suppliers, supermarkets, and restaurants.

The combination of advantages improves the farm's competitiveness, underlining the transformative impact of agricultural robotics. (Brevik, 2013)

Key takeaways

- Labor can be more than half the cost of growing crop, majority of farmers are impacted by labor shortages
- Consumers' preferences are shifting towards organic and sustainable products
- New technologies, such as autonomous robots and lighter machines, can contribute to reduced soil compaction and increased biodiversity
- Precision farming techniques can reduce environmental footprint
- Combining human labor and robot labor can boost overall efficiency.
- Agricultural robots can cover all crop production operations from seeding to harvesting.

4.3.1. Precision agriculture

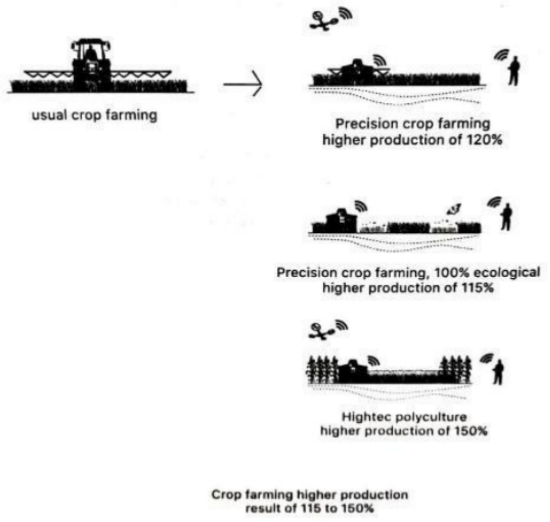


fig 4.1 precision farming (Verhoeven, 2018)

Designing a roadmap for robotics in agriculture within the scope of open field agriculture and horticulture could make use of integrating precision farming techniques with advanced robotics technologies. This integration could involve utilizing sensors, data analytics, and automation to enable accurate and targeted application of resources such as water, fertilizers, and pesticides. By implementing precision farming techniques, farmers can optimize inputs and reduce waste, ultimately increasing their incomes and improving sustainability in agriculture. To consider precision farming when designing a roadmap for the integration of robotics in agriculture, it could combine precision farming techniques with advanced robotics technologies that have the ability to accurately apply resources such as water, fertilizers, and pesticides. (Hassoun et al., 2022)

Precision farming, also known as precision agriculture, involves the use of advanced technology and data analysis tools to optimize various aspects of farming practices. This approach is very relevant for creating a future vision of robotics in agriculture, both for indoor and outdoor applications, due to several advantages. Through the use of sensors, data analytics, and automation, farmers can gather real-time data about their crops and make informed decisions about resource allocation. This targeted approach could use resources in an efficient manner, reducing waste and minimizing environmental impact.

Farmers learning about precision farming is relevant as it provides the foundational knowledge and understanding necessary to integrate robotics effectively with a positive impact. The different aspects of precision farming can be utilized to get closer to the outcomes of the roadmap.(Vernekarl, 2019)
Precision farming allows farmers to precisely manage resources such as water, fertilizers, and pesticides. For indoor applications, like vertical farming, resources are used efficiently within a controlled environment. For outdoor farming, precision techniques help reduce waste by delivering inputs only where and when they are needed, conserving input resources and reducing environmental impact.(Bhuvan et al., 2023)

Furthermore, it relies on vast amounts of data collected through sensors, satellites, and other technologies. An example of this is Tective's SkyHive for automated drone inspection deployment of open fields. Analyzing the data helps in making informed decisions. With the integration of robotics, these decisions can be automated in real-time. Robots equipped with sensors can gather data and respond immediately, optimizing the farming process without human intervention.(Mesías-Ruiz et al., 2023)

By precisely monitoring and controlling factors such as irrigation, fertilizer, pesticides, and precision farming techniques contribute to improved quality and increased crop yields up to 150%, see above figure. Robotics, when integrated, can ensure that these precise conditions are consistently maintained. Indoor vertical farms can achieve year-round crop production with minimal space. (Verhoeven, 2018)

Precision farming techniques help in reducing the environmental impact of agriculture. By optimizing resource use, farmers can minimize leaking chemicals into water and reduce the overall use of harmful pesticides and fertilizers. Additionally, by minimizing soil degradation and optimizing crop yields, it contributes to soil restoration and helps preserve natural habitats.(Pesticides in agriculture, 2019)
Many regions are facing a shortage of skilled agricultural labor. The majority of workers are of immigrant origin. Robotics in agriculture can fill this gap by performing tasks that traditionally require human intervention. Autonomous machines can replace human actions. This not only addresses the labor shortage but also improves the overall precision of agricultural processes. (Zhang et al., 2020)

The development of robotics and automation technologies continues to advance rapidly. Integrating these technologies with precision farming techniques opens up new possibilities for innovation. This includes AI-powered decision-making systems, swarm robotics for collaborative farming, and the use of drones for aerial monitoring and crop spraying.(Hasan & Habib, 2023)

Precision agriculture, with its integration of robotics, is revolutionizing the way conventional farming is done. It allows for more efficient resource management, reduces waste, and helps increase crop yields. By collecting and analyzing large amounts of data, farmers can make informed decisions on when and where to apply inputs such as irrigation, fertilizers, and pesticides. This targeted approach not only improves the quality of the crops but also minimizes the environmental impact by reducing the use of harmful chemicals.

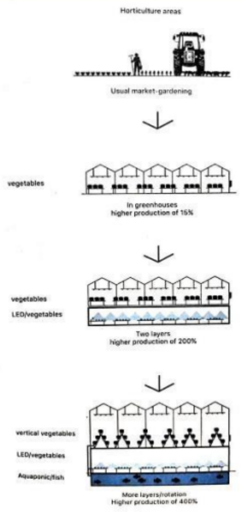


fig 4.2 precision farming (Verhoeven, 2018)

Key takeaways

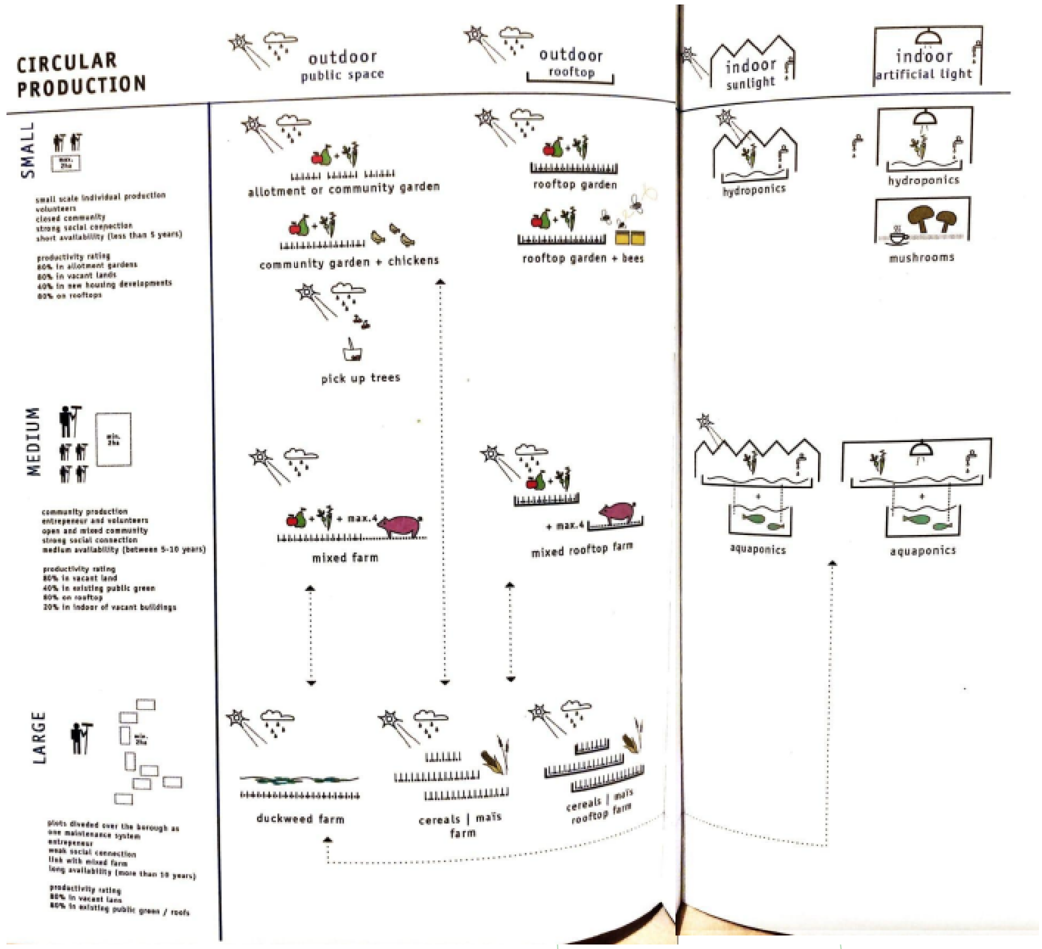
Precision agriculture can support farmer through various aspects:

1. Optimizing Resource Utilization
2. Data-Driven Decision Making
3. Increased Crop Yield and Quality
4. Sustainability and Environmental Conservation
5. Labor Shortage Efficiency

4.3.2. Regenerative farming

Regenerative farming focuses on increasing biodiversity and promoting sustainable agricultural practices. The book Flourishing Foodscapes promotes sustainable practices on multiple scales for both indoor and outdoor (Verhoeven, 2018). This indicates beneficial opportunities for future application in regenerative farming.

fig 4.3 regenerative farming (Verhoeven, 2018)



In an interview with Wijnand Sukkel from Boerderij van de Toekomst and researcher at Wageningen University(WUR), there was discussion about the future of farms and sustainability, focusing on circular agriculture also known as regenerative farming.

Regenerative agriculture strives for significant goals, aiming to eliminate fossil energy use, minimize nutrient and pesticide emissions, optimize nitrogen efficiency, high yields, offer fair incomes to farmers, and increase biodiversity. Achieving this vision involves embracing innovative technologies and transitioning to more sustainable farming practices. However, there are challenges in this transition, including insufficient investments, limited farmer interest in biodiversity, and emission reduction efforts. New technologies like autonomous robots and lighter machines show promise by reducing soil compaction and strengthening biodiversity. Additionally, transitioning to renewable energy sources, such as solar and hydrogen, can encourage sustainable farming methods, although some companies' focus on short-term profits poses obstacles to these efforts. Education and awareness play a crucial role in changing farmers' mindsets and promoting sustainable practices, paving the way for a future where agriculture is highly productive, resilient, and regenerative, with minimal environmental impact and preserved biodiversity.

Regenerative farming focuses on strengthening biodiversity and promoting sustainable agricultural practices through various key strategies. Crop diversification, incorporating new crops, cover crops, and legumes, boosts biodiversity and suppresses diseases for main crops. Techniques like strip cropping and agroforestry, combining arable cultivation with woody crops, create diverse habitats and improved soil quality. Intercropping methods increase yields and decrease competition, benefiting both biodiversity and disease control. Practices like reduced tillage and year-round ground cover minimize soil disturbance, leading to improved soil health and organic matter. Integrated pest management, along with smart fertilization methods using high organic matter content manure, significantly reduces pesticide use and negative impacts on biodiversity. The integration of precision techniques with robotics holds the promise of making agriculture more sustainable, efficient, and productive, paving the way for a future where technology plays a central role in feeding the growing global population.

The downside of regenerative farming lies in the potential challenges related to initial investments and economic efficiency for farmers transitioning from conventional practices.

In a section of the US Energy documentary (US Energy, 2021), Brown discusses the fundamental principles and personal experiences influencing his regenerative farming efforts. The core of his approach centers on soil health, recognizing it as the foundation for nutrient-dense crops. Gabe's pioneering methods, such as no-till farming and cover cropping, revitalized his soil, improving its structure and water retention capabilities. This focus on soil health embodies the dedication of regenerative agriculture to cultivating fertile soil, which is necessary for producing nourishing food.

Additionally, according to Gabe's explanation, regenerative farming takes a view that expands beyond conventional agricultural practices. Gabe's methods involve seamlessly integrating different components within the ecosystem. Working in harmony with nature, Gabe has developed a farming system that is not only balanced, but also highly resilient. The diversification of his crops and integration of livestock played a crucial role in this process, reducing reliance on external resources while boosting productivity and sustainability. Moreover, Gabe's innovative practices go beyond the farm by promoting carbon sequestration, mitigating climate change, and stimulating local economies. Through education and community involvement, regenerative agriculture is not only a method of farming but also a transformational power that enriches both land and communities it serves.

In the end, addressing biodiversity loss in food systems requires a holistic approach. This includes promoting sustainable practices,such as precision agriculture or regenerative farming. The increase of biodiversity loss in food systems is caused by intensive land use, habitat destruction, and the heavy use of chemicals. These factors contribute to the loss of natural habitats and disruption of ecosystem functions.
Additionally, supporting initiatives that promote the conservation of ecosystems, and integrating biodiversity considerations into agricultural practices are essential for addressing biodiversity loss in food systems.

Thus, the key opportunity areas for regenerative farming are improving soil health, boosting biodiversity, adopting more natural techniques, and leveraging technologies like precision robotics to enable its sustainable and productive practices to be implemented more widely. This supports the overall transition to an agriculture system that works in harmony with nature and resilient food systems.
Additionally, according to Gabe's explanation, regenerative farming takes a comprehensive view that expands beyond conventional agricultural practices. Gabe's methods involve seamlessly integrating different components within the ecosystem. Working in harmony with nature, Gabe has developed a farming system that is not only balanced, but also highly resilient. The diversification of his crops and integration of livestock played a crucial role in this process, reducing reliance on external resources while boosting productivity and sustainability. Moreover, Gabe's innovative practices go beyond the farm by promoting carbon sequestration, mitigating climate change, and stimulating local economies.

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CHAPTER 5

Creative trend research

5.1 Depest analysis related to agriculture, robotic and food trends

5.2 Food Trends Clusters

- 5.2.1 Cluster 1: The heavy weight of food
- 5.2.2 Cluster 2: Customisation of food habits
- 5.2.3 Cluster 3: Consciousness about food
- 5.2.4 Cluster 4: Organizing the food chain

5.1 Depest analysis related to agriculture, robotic and food trends

This chapter provides a broad insight of relevant trends, using the DEPEST method related to agriculture, food and robotic trends.

fig 5.1 trend research (Simonse, 2018)

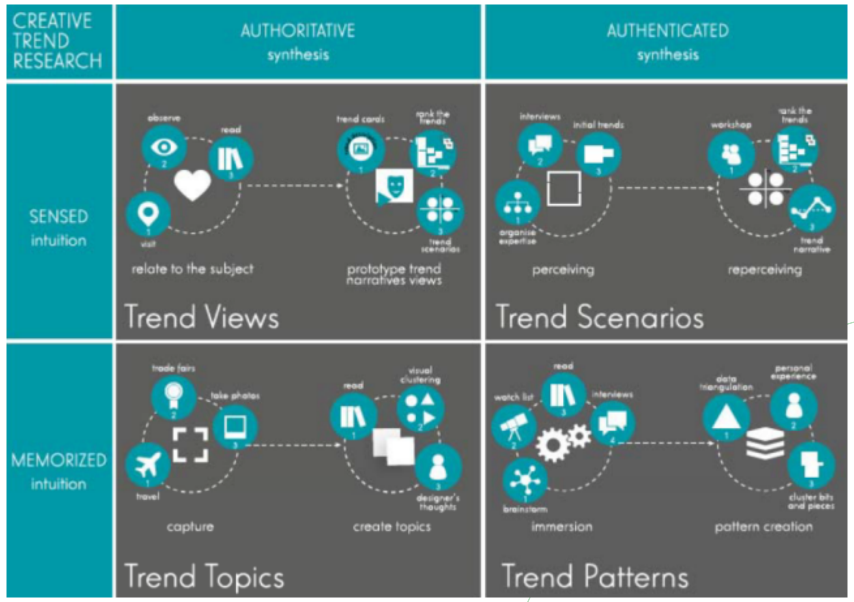
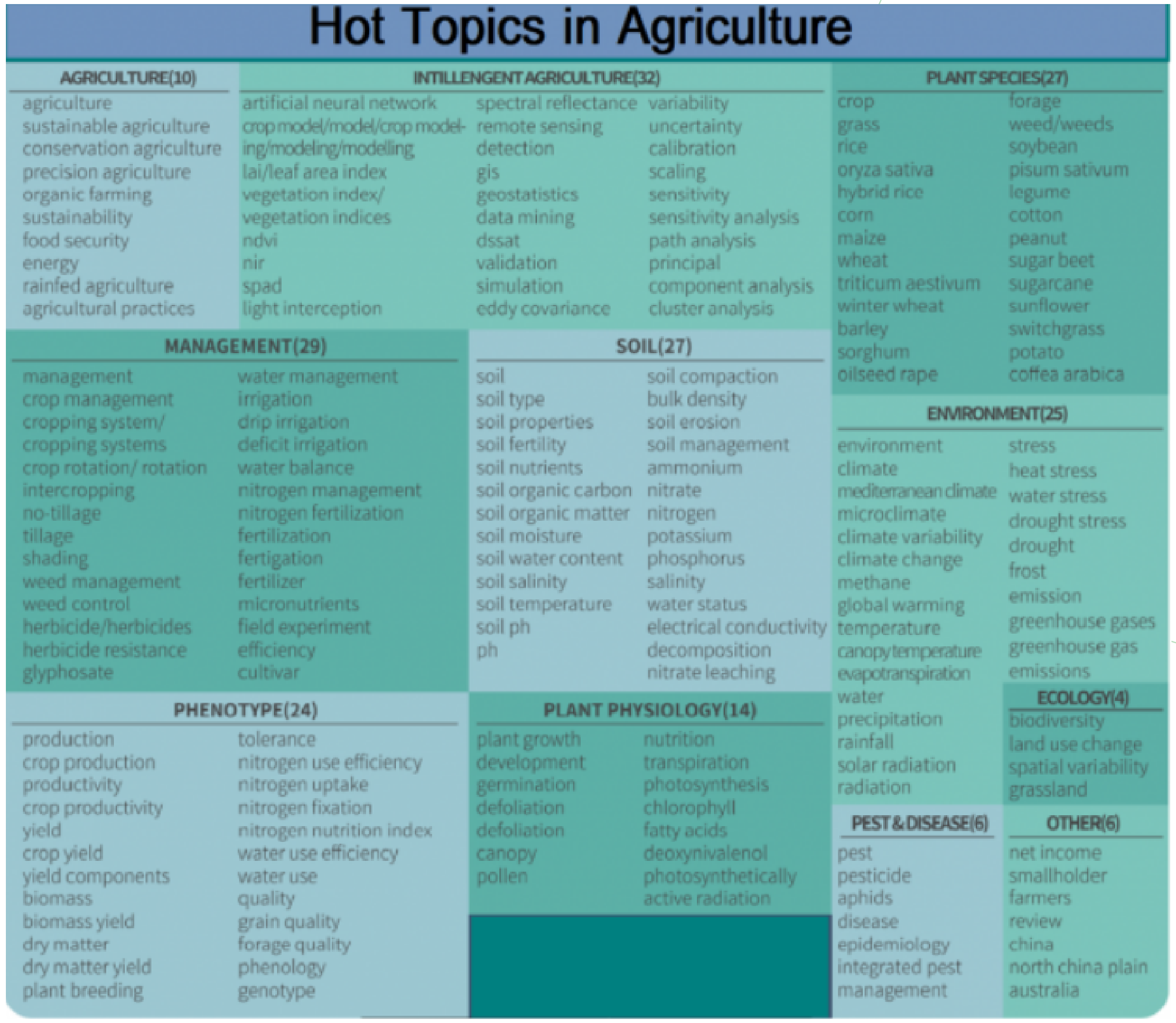


fig 5.2 hot topics (Chai, 2021)



Hot Topics in Agriculture

AGRICULTURE(10)

agriculture
sustainable agriculture
conservation agriculture
precision agriculture
organic farming
sustainability
food security
energy
rainfed agriculture
agricultural practices

INTILLENGENT AGRICULTURE(32)

artificial neural network
crop model/model/crop modeling/modeling/modelling
lai/leaf area index
vegetation index/
vegetation indices
ndvi
nir
spad
light interception
spectral reflectance
remote sensing
detection
gis
geostatistics
data mining
dssat
validation
simulation
eddy covariance
variability
uncertainty
calibration
scaling
sensitivity
sensitivity analysis
path analysis
principal
component analysis
cluster analysis

PLANT SPECIES(27)

crop
grass
rice
oryza sativa
hybrid rice
corn
maize
wheat
triticum aestivum
winter wheat
barley
sorghum
oilseed rape
forage
weed/weeds
soybean
pisum sativum
legume
cotton
peanut
sugar beet
sugarcane
sunflower
switchgrass
potato
coffea arabica

MANAGEMENT(29)

management
crop management
cropping system/
cropping systems
crop rotation/ rotation
intercropping
no-tillage
tillage
shading
weed management
weed control
herbicide/herbicides
herbicide resistance
glyphosate
water management
irrigation
drip irrigation
deficit irrigation
water balance
nitrogen management
nitrogen fertilization
fertilization
fertigation
fertilizer
micronutrients
field experiment
efficiency
cultivar

SOIL(27)

soil
soil type
soil properties
soil fertility
soil nutrients
soil organic carbon
soil organic matter
soil moisture
soil water content
soil salinity
soil temperature
soil ph
ph
soil compaction
bulk density
soil erosion
soil management
ammonium
nitrate
nitrogen
potassium
phosphorus
salinity
water status
electrical conductivity
decomposition
nitrate leaching

ENVIRONMENT(25)

environment
climate
mediteranean climate
microclimate
climate variability
climate change
methane
global warming
temperature
canopytemperature
evapotranspiration
water
precipitation
rainfall
solar radiation
radiation
stress
heat stress
water stress
drought stress
drought
frost
emission
greenhouse gases
greenhouse gas
emissions

ECOLOGY(4)

biodiversity
land use change
spatial variability
grassland

PHENOTYPE(24)

production
crop production
productivity
crop productivity
yield
crop yield
yield components
biomass
biomass yield
dry matter
dry matter yield
plant breeding
tolerance
nitrogen use efficiency
nitrogen uptake
nitrogen fixation
nitrogen nutrition index
water use efficiency
water use
quality
grain quality
forage quality
phenology
genotype

PLANT PHYSIOLOGY(14)

plant growth
development
germination
defoliation
defoliation
canopy
pollen
nutrition
transpiration
photosynthesis
chlorophyll
fatty acids
deoxynivalenol
photosynthetically
active radiation

PEST & DISEASE(6)

pest
pesticide
aphids
disease
epidemiology
integrated pest
management

OTHER(6)

net income
smallholder
farmers
review
china
north china plain
australia

5.1.1 DEPEST analysis related to agriculture, robotic and food trends

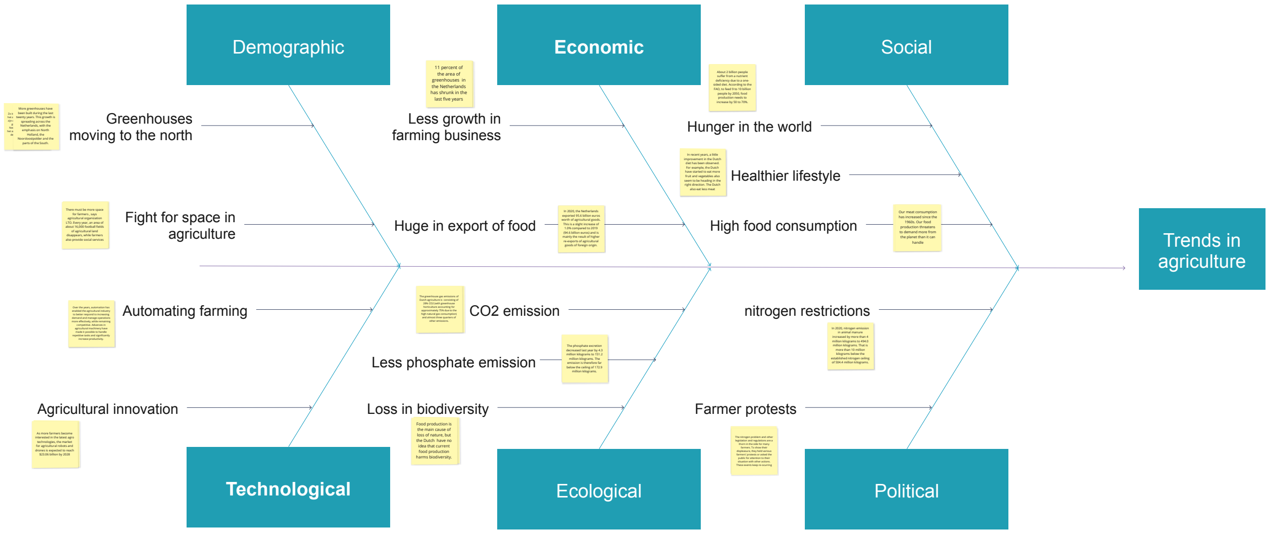


fig 5.3 Trends in agriculture

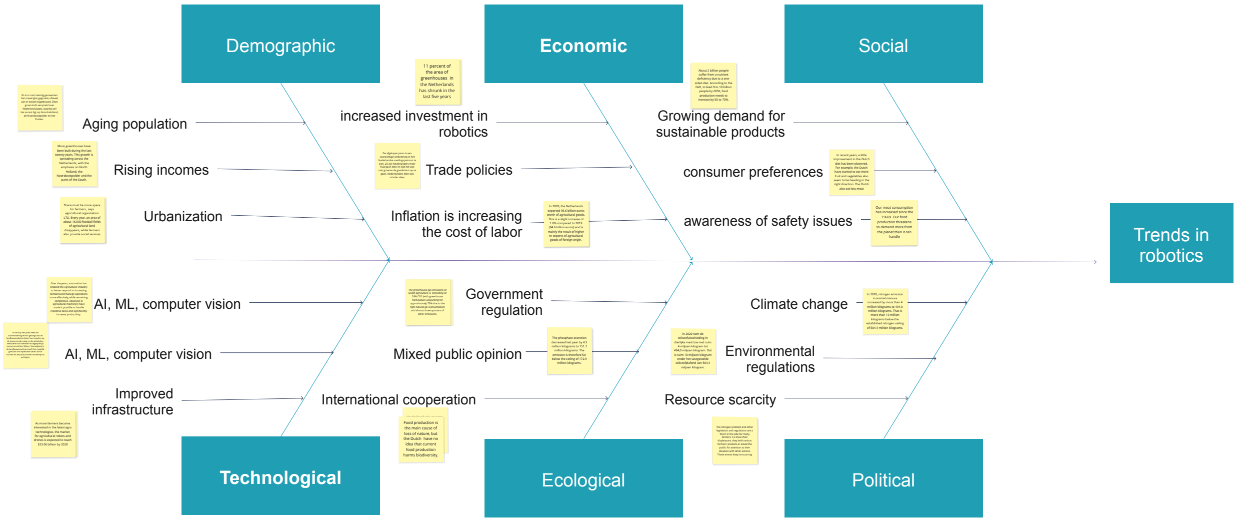


fig 5.4 Trends in robotics

Demographic:

- Aging population is leading to a shortage of workers in many industries, including robotics.
- Urbanization is increasing the demand for robots in urban areas, for tasks such as delivery and construction.
- Rising incomes in developing countries are driving the demand for robots in these countries.

Economic:

- Economic growth is leading to increased investment in robotics.
- Inflation is increasing the cost of labor, which is driving demand for robots.
- Regulations are impacting the viability of robotics companies.

(MarketsandMarkets, n.d.)

Social:

- Growing demand for sustainable products and services is driving the development of robots that can help to achieve these goals.
- Increasing awareness of safety issues is leading to a demand for robots that can perform dangerous tasks.
- Changing consumer preferences are impacting the demand for robots in different industries.

(University of Reading, UK et al., 2023)

Technological:

- Advances in artificial intelligence, machine learning, and computer vision are enabling the development of more sophisticated and capable robots.
- Advances in robotics hardware and software are making robots more affordable and accessible.
- Improved infrastructure is making it easier to deploy and maintain robots.

(Selby et al., 2021)

Environmental:

- Climate change is leading to a demand for robots that can help to mitigate and adapt to its effects.
- Resource scarcity is driving the development of robots that can help to conserve resources.
- Environmental regulations are impacting the design and operation of robots.

Political:

- Governments around the world are developing new regulations to govern the development and use of robots. These regulations are designed to address concerns about safety, security, and privacy.
- Public opinion on robots is mixed. Some people are excited about the potential benefits of robots, while others are concerned about the potential risks. This public opinion will likely shape the political landscape for robotics in the years to come.
- Governments and companies from around the world are cooperating on the development and use of robots. This cooperation is essential for ensuring that robots are used in a safe and responsible manner.

(McKinsey, 2023)

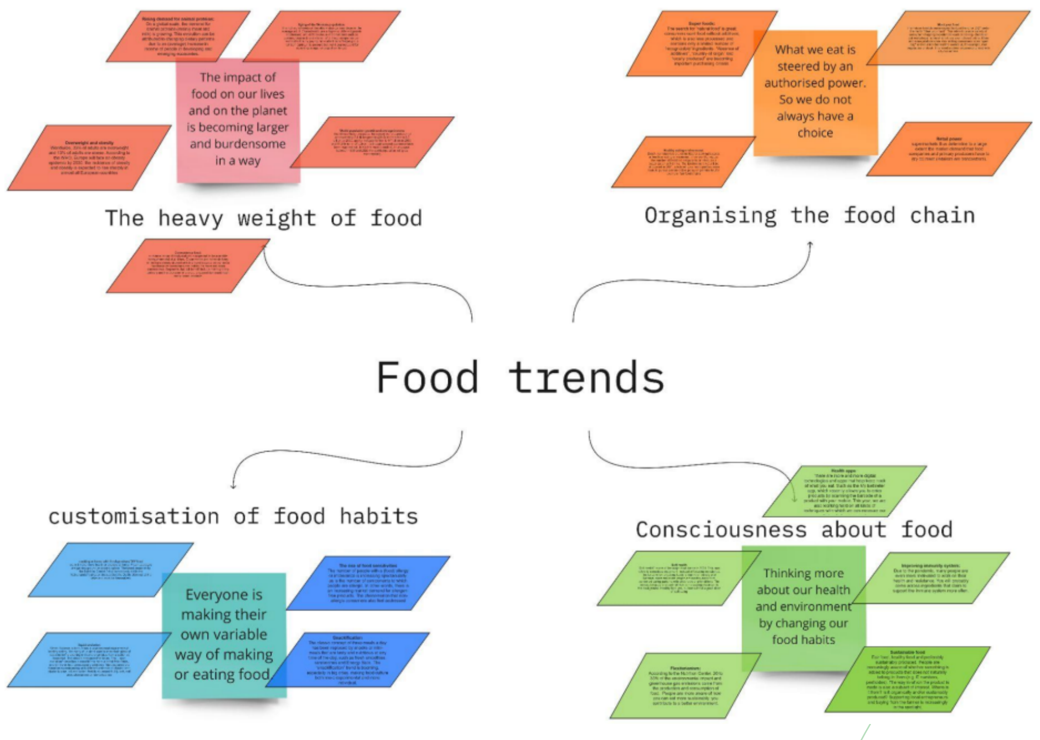


fig 5.5 food clusters

5.2 Four clusters of food trends

5.2.1 Cluster 1: The heavy weight of food

The impact of food on our lives and on the planet is becoming larger and burdensome in a way.

Convenience food

a diverse range of food products is expected to be available everywhere and at all times. E-commerce and home delivery of food are closely aligned with this trend towards convenience food because consumers are looking for more and more convenience. Segments that will benefit include home grocery delivery and the provision of pre-cut, prepared items and fresh ready-to-eat products.(Food From Food, n.d.)

Overweight and obesity

Worldwide, a third of adults are overweight and more than a tenth of adults are obese. According to the WHO, Europe might face an obesity epidemic by 2030; the incidence of obesity and obesity is expected to rise sharply in almost all European countries

Rising demand for animal proteins

On a global scale, the demand for animal proteins (mainly meat and milk) is growing. This evolution can be attributed to changing dietary patterns due to an (average) increase in income of people in developing and emerging economies.

World population growth and average income

The United Nations expects the current world population of approximately 7.3 billion people (2015) to increase to 8.5 billion by 2030, and to increase further to 9.7 billion in 2050 and 11.2 billion in 2100, although several scenarios have been mapped out, this is the most plausible. In any case, between 2050 and 2100 the world population will grow exponentially (Nations, n.d.)

Aging of the Western population

The nutritional needs of the elderly change from those of the average adult. Characteristic are a higher or different protein requirement, and deficiencies in micronutrients such as calcium, vitamin D and vitamin B12. Food companies can respond to this by paying more attention to 'target group nutrition' (taking into account that nutritional needs differ according to age, among other things). (Chai, 2021)

5.2.2 Cluster 2: Customisation of food habits

Everyone is making their own variable way of making or eating food.

Cooking at home with fresh product/ DIY food
People will make more healthier choices at home. Fresh packages are gaining ground as a quick option. The latest research by the Nutrition Center ('How consciously eat in the Netherlands?') already showed that the Dutch often eat at the table and cook for themselves.

Liquid evolution
When it comes to food, there is a widespread awareness of healthy eating. Yet many of us don't want to miss their glass of red wine in the evening or their orange juice from a carton at breakfast. This should change in the future. The "Liquid evolution" describes a transition to more alcohol-free drinks, and drinks without unnecessary additives. Manufacturers are therefore experimenting with different methods of offering non-alcoholic wine, infused water, freshly squeezed fruit juices, soft drink alternatives or fermented tea.

Snackification
The classic concept of three meals a day has been replaced by snacks or mini-meals that are tasty and nutritious at any time of the day, such as fresh smoothies, sandwiches and Energy Balls. The "snackification" trend is booming, especially in big cities, making food culture both more experimental and more individual.

The rise of food sensitivities
The number of people with a (food) allergy or intolerance is increasing spectacularly, as is the number of components to which people are allergic. In other words, there is an increasing market demand for allergen-free products. The phenomenon that non-allergic consumers also feel addressed
(FSIN, n.d)

5.2.3 Cluster 3: Consciousness about food

Thinking more about our health and environment by changing our food habits

Soft health
"Soft health" is one of the major food trends in 2021. This term refers to conscious enjoyment. Instead of focusing on calories, the focus when choosing foods is mainly on variety and balance. more and more people are moving away from controlled eating patterns with strict rules or prohibitions. The concept of good and bad nutrition is increasingly fading into the background. Healthy food yes, but not without a good dose of well-being.

Sustainable food
Fair food, healthy food and preferably sustainably produced. People are increasingly aware of whether something is added to products that does not naturally belong in them (e.g. E numbers, pesticides). The way in which the product is made is also a subject of interest. Where is it from? Is it organically and/ or sustainably produced? Supporting local entrepreneurs and buying from the farmer is increasingly in the spotlight.
(Voedingscentrum, 2018)

Flexitarianism:
According to the Nutrition Center, 20 to 35% of the environmental impact and greenhouse gas emissions come from the production and consumption of food. People are more aware of how you can eat more sustainably, you contribute to a better environment.
(Hassoun et al., 2022)

5.2.4 Cluster 4: Organizing the food chain

What we eat is steered by an authorised power. So we do not always have a choice.

Super foods
The search for 'natural food' is great: consumers want food without additives, which is also less processed and contains only a limited number of 'recognizable' ingredients. "Absence of additives", "country of origin" and "locally produced" are becoming important purchasing criteria.

Healthy eating environment
Dutch municipalities are committed to working towards a healthier eating environment. They want to reduce the number of fast food restaurants or introduce a sugar tax on soft drinks. The Environment Act will be introduced in 2021, which will give municipalities more tools to pursue a more active policy on permits for, for example, fast food chains. (Munnik, 2022)

Meet your food
The Future Institute summarizes this food trend for 2021 under the motto "Meet your food". This refers to a wide variety of consumer shopping experiences such as baking, cheese or deli workshops, some of which are even offered online. More and more producers are also inviting consumers to an "open day" to take a look behind the scenes at, for example, root vegetables or steak. This trend is about experiencing food with all your senses.

Retail power
supermarkets thus determine to a large extent the market demand that food companies and primary producers have to (try to) meet (retailers are trendsetters).
(Lambregts, n.d.)

A conclusion drawn from the food trends is that the food industry is undergoing many different changes and challenges driven by evolving consumer preferences and global trends. To survive and thrive in this dynamic landscape, the industry would need to adapt and innovate in each of the clusters.
The overall conclusion from the DESTEP analysis is that robotics is a rapidly growing field with the potential to transform many industries, including agriculture. The adoption of robots is being driven by the trends that need to be taken into account

The political dimension is also important to consider when considering the trends. Governments around the world are developing new regulations to govern the development and use of robots, in which regulations are designed to address concerns about safety, security, and privacy. (Langman et al., 2021) . Robotic companies and other stakeholders in the robotics industry need to be aware of the key trends that are impacting the industry in order to make informed decisions about how to invest in and develop new products and services.

CHAPTER 6

Case Studies

6.1 **Farm: Trayplant**

6.2 **Rapo BV**

6.3 **Conclusion**

6.4 **Other Cases**

This chapter examines case studies of farms and their attitude towards agricultural robotics and automation technologies. Case studies can provide real-world examples of how technologies are implemented in practice. Examining these cases revealed themes that include the motivation for adoption.The learnings from these examples could form new strategies.

6.1. Farm: Trayplant

A tour was held in Bavel by Trayplant, which grows starting material for strawberries from cuttings with automated sorting machines
The farm uses solar panels as its main energy source and works with a 100 percent closed water system. This means that the water from tray fields and greenhouses is caught and reused, without wasting valuable raw materials in energy. There are no emissions of crop protection products into the environment, because the farm is moving to a completely climate-neutral working method. They invest in electric vehicles, solar panels and use very economical LED lighting. In addition, they save waste heat for deployment of the temperature on keeping the greenhouses and offices comfortable in both summer and winter, which equates to 82,000 square meters of greenhouse space.

The farm has a total of 65 hectares of production area spread over 6 locations. Since March 2022, they have had a hypermodern new vertical farm in addition to their tray fields and greenhouses. The company has 52 permanent employees and the number of flex workers varies between 20 and 300 people. They grow 45 different varieties of strawberries and raspberries into high-quality propagation materials. This diversity in varieties implies the farm's expertise and commitment to delivering high-quality products.

The guide of the tour discusses powerful technologies in agriculture, such as unmanned tractors that work on data. Discussions include the challenges of programming these systems and the possibility of selling the technology as applications to other farmers. The conversation is also about communication between technical experts and farmers. Good communication is essential for successful implementation of new technologies. It becomes inconvenient that technicians have to divide farmers in the development process to ensure that the technology meets practical needs on the farm. So highlighting the importance of good communication between technicians and farmers, and illustrates the pursuit of sustainability and innovation in modern agricultural practice. Although the farm is not fully modernized, the R&D department strives to find innovative methods everyday.

Their overall pursuit in sustainability includes the use of solar panels as the main source of energy on the farm, the 100 percent closed water system used to purify and reuse water, and other sustainable practices such as electric vehicles, economical LED lighting and storing waste heat for deployment of the temperature in greenhouses and offices.

6.2. Rapo BV

Rapo BV is located in Roosendaal, which propagates and produces strawberry plants for growers. They grow strawberries, asparagus and fruit trees on sandy soils in the Roosendaal area. The company has a sorting process in which plants are sorted based on thickness and quality by 200 employees. However, the manual sorting process is labor-intensive and expensive, and it becomes difficult to find suitable personnel. It is also difficult to maintain consistent quality due to the natural properties of the plants.

Rapo is considering automation to require fewer workers, reduce costs and achieve better quality. But automation has challenges due to the dissimilar shape and properties of the plants. Other propagators have similar problems and are also considering automation to optimize the sorting process.

The current sorting process at Rapo is labor intensive and takes place in a shed. 200 employees are involved in sorting the plants. The plants are sorted manually. Because it is a natural product, the plants are not uniform in shape and size. This makes the sorting process complex. There are another 20 employees who continuously check the quality of the plants and correct any errors. This process is time-consuming and expensive as it requires a large number of employees and a lot of manual effort.

The sorting process with so many employees in the shed leads to significant costs for the company. Over the years, wages have increased, which has further increased personnel costs. Moreover, finding suitable workers has become a challenge. The company mainly employs workers from Poland and Romania, but it is becoming increasingly difficult to attract and retain these employees. The changing mentality of younger employees also plays a role in this, because they are less inclined to work intensively and hard like the older generation did.

Overall, the labor-related aspects within Rapo's sorting process are complex and are a driver to consider automating the process to reduce costs, improve quality and rely less on labor-intensive methods. The company wants to automate the sorting process to reduce costs and improve quality, despite the challenges associated with the natural properties of the plants.

6.3 Conclusion

All in all, in the comparison of the two farms, the distinctive methods employed by Trayplant and Rapo BV were examined in incorporating innovation and automation into their operations within the agricultural industry.

Trayplant's investment in advanced technologies, such as automated sorting machines and vertical farming, in addition to their dedication to cultivating diverse crop varieties, displays their commitment to safeguarding their business against future challenges. Meanwhile, Rapo BV's proactive stance towards automation showcases their preparedness to adapt to market dynamics, ensuring long-term sustainability and competitive edge.

Both farms exemplify the importance of being independent from external factors in maintaining the longevity of farming operations. Trayplant's use of solar panels, closed water systems, and energy-efficient measures demonstrates their dedication to environmentally-friendly farming. Likewise, Rapo BV's efforts to automate their operations in order to reduce their reliance on labor that can ensure the continuation of their business for generations to come.

Additionally, both farms prioritize cost-effectiveness and rely on independent resources for their operations.
Trayplant's use of independent resources, such as solar power, decreases operational costs and establishes an example for other farms. Rapo BV's implementation of automation, even with initial obstacles, demonstrates their commitment to long-term cost-effectiveness. Both approaches emphasize the significance of self-sufficiency and efficient use of resources in agriculture.

These practices align with goals of climate resilience and environmental neutrality.
The farms' utilization of renewable energy and implementation of closed-loop water systems significantly contribute to climate resilience. Trayplant's adoption of waste heat for temperature control and Rapo BV's pursuit of automation to reduce their environmental footprint exemplify their dedication to climate neutrality. These initiatives serve as examples of environmentally responsible farming practices
with low environmental impact.

In summary, the agricultural industry faces a turning point where sustainable practices and innovative technologies are necessary. The attitude by Trayplant and Rapo BV serve as an admirable model for the industry, as they try to integrate innovative practices, embrace automation and prioritize the sustainability and longevity of their operations. Consequently, these farms ensure their future to be more stable.

fig 6.1 Unknown brands vs trustworthy well known brand John Deere (Ramin Shamshiri et al., 2018)

6.4. Motives from other cases

Further insights are derived from previously mentioned qualitative methods such as stakeholder interviews or visiting smart farming events. These cases provide a deeper understanding of underlying problems or needs relevant for the roadmap.

The low adoption of agricultural robotics stems from a multitude of leading motives. The foremost one is the labor shortage. Farmers encounter mounting difficulties in hiring sufficient workers for their farms. Robotics presents a potential solution to this scarcity by automating various tasks. However, persuading farmers of the reliability of this technology remains a challenge. Many farmers do not have sufficient evidence or real-world examples to confirm the reliability of robotic solutions. For example, companies such as Fotoniq offer promising technologies with an impressive lifespan of 8 years. However, these innovations have not been in the market long enough to establish a strong track record, which creates skepticism among potential users.

Furthermore, there is a significant lack of awareness among farmers regarding the alternatives available in the market. Farmers often rely on their current knowledge and practices, without awareness of alternative agricultural robotics advancements. This informational gap leads farmers to pursue traditional farming, instead of employing more efficient robotic solutions. Farmers put effort into attending gatherings to educate themselves on topics like spraying regulations, but they may not be aware of existing robotic alternatives. Farmers' limited awareness of robotic alternatives is constrained by insufficient information communication.

Moreover, the uncertain capability of robotics presents substantial challenges. Anticipated regulations mandating constant supervision of robots during agricultural operations potentially limit investment in robotic technology. Fear of risks also pervades among farmers. Many individuals are hesitant to pioneer the adoption of new technologies, opting to instead wait and observe the experiences of their peers before embracing innovations. Despite a desire to innovate, this apprehension about being the first to adopt new technologies creates a significant barrier to the widespread acceptance of agricultural robotics.

Overall, the leading motives revolve around

- Most prominent need for robotics is challenge of the labor shortage eg. exploitative farming is not attractive for Polish contractors and stay in their home country.
- Lack of evidence to convince farmers that the technology is reliable eg. Fotoniq provides technology that has a life span of 8 years but has not been that long on the market yet.
- Lack of farmer awareness, in which the farmer does not know about alternatives on the market and sticks to own trustworthy knowledge, resulting in a large communication gap. eg. farmers educate themselves about spraying regulations to extend their certification by attending gatherings while robotic alternatives for spraying are not widely communicated.
- Uncertainty about the flexibility of robotics eg. future regulations do not allow robots in agriculture without supervision
- Fear of taking risks, waiting for others farmers to try out new technology first eg. farmers would want to innovate but do not want to be the first one

CHAPTER 7

Design areas

7.1 Ecosystem
7.2 Social acceptance
7.3 Education and communication strategies
7.4 Business models

This chapter explores various areas that are relevant to consider when developing a roadmap. Examining these areas provided insights on building an inclusive roadmap that addresses systematic, human and economic factors.

7.1. Ecosystem

In the context of agriculture and robotics, different types of stakeholders are involved. These stakeholders collaborate and interact to promote the use of robotics in agriculture. The stakeholders in the inner circle would be able to steer direction for the implementation in the roadmap.

In conclusion, the ecosystem surrounding agricultural robotics involves a diverse range of stakeholders, both public and private. Initiators such as startups and government play a driving role in fostering innovation. Partners like investors and researchers provide support. Producers including robotic engineers develop novel technologies. Consumers like farmers and food companies ultimately use these solutions.Their aligned interests are beneficial to realize a shared future vision.

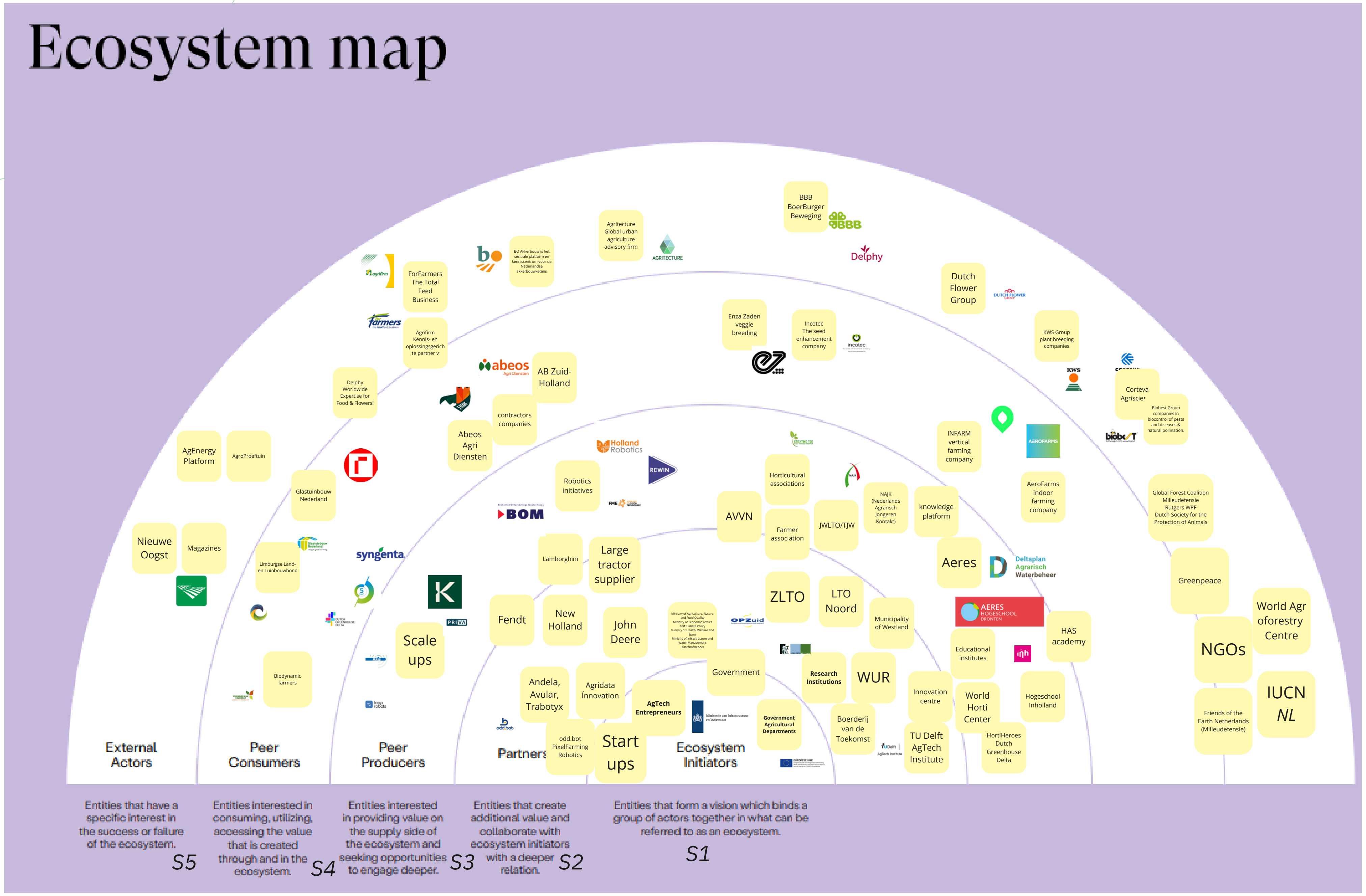


fig 7.1 ecosystem map Mapping tool from (DDC – Danish Design Center, 2021)

S1 Ecosystem Initiators:
Start ups:
Founders initiating the vision of integrating robotics and technology into agriculture for sustainable practices.

Government Agricultural Departments:
Initiating programs and policies that promote sustainable agriculture and technological advancements.

AgTech entrepreneurs:
Providing farming technology solutions for precision farming, automation, and sustainable agricultural practices.

S2 Partners:
Research Institutions:
Conducting research on robotics and sustainable farming techniques, contributing knowledge to the ecosystem.

Investors and Venture Capital Firms:
Investing in AgTech startups focused on robotics and sustainable agriculture technologies.
Government Agricultural Research Funds:
Funding research and development in the field of robotics for sustainable agriculture.

S3 Peer Producers:
Robotics Initiatives:
Project management and development for robotic systems such as planting, harvesting, irrigation, and pest control in agriculture through experts.

Community/Educational Organizations:
Community or educational institutes for robotic systems of education and networking for students or farmers.

Agricultural Engineers:
Professionals designing and creating robotic systems specifically suited for different aspects of sustainable agriculture.
Innovators and Inventors: Individuals creating new robotic technologies, sensors, and AI algorithms for precision farming.

S4 Peer Consumers:
Farmers:
Implementing robotic systems for tasks such as precision planting, automated harvesting, and data-driven decision-making for sustainable farming. A farmer is often a micro entrepreneur with only a few employees and temporary contract workers.

Agricultural Cooperatives:
Groups of farmers pooling resources to invest in advanced robotic technologies for collective sustainable practices.

Food Processing Companies:
Benefiting from higher quality and sustainably sourced raw materials due to robotic-assisted farming practices.

S5 External Actors:
Regulational organizations:
Regulating the use of robotics in agriculture, ensuring safety standards and environmental regulations are met.
Environmental Conservation NGOs:
Monitoring the impact of robotic technologies on the environment and promoting eco-conscious agricultural practices.

Consumers and Advocacy Groups:
Advocating for sustainably sourced agricultural products, encouraging the use of robotics for transparent and eco-friendly farming.
Environmental Conservation Groups:
Promoting eco-friendly practices within agriculture, including the use of robotics for reduced environmental impact.

7.2. Social acceptance

The social acceptance of robotics in The social acceptance of robotics in agriculture is a complex issue that is influenced by a variety of factors, including the TRLs of the robotic technologies involved and the ARLs of the individuals and groups involved. By understanding the relationship between TRLs and ARLs, we can better understand the factors that influence the social acceptance of robotics in agriculture and develop strategies to promote the adoption of robotic technology in a socially responsible manner.(University of Reading, UK et al., 2023)

According to Vik et al, evaluating emerging agricultural technologies depends on the existing Technology Readiness Level (TRL) framework by adding additional dimensions for Market Readiness Level (MRL), Regulatory Readiness Level (RRL), Acceptance Readiness Level (ARL), and Organizational Readiness Level (ORL).

While keeping those dimensions in mind, see figure 7.1, a farmer with a high ARL for robotics in agriculture (e.g., they are familiar with robotic technology and see the potential benefits) is more likely to be accepting of a new robotic agricultural technology, even if the technology has a low TRL (e.g., it is still in the early stages of development).

A farmer with a low ARL for robotics in agriculture (e.g., they are not familiar with robotic technology or do not see the potential benefits) is less likely to be accepting of a new robotic agricultural technology, even if the technology has a high TRL (e.g., it is fully developed and proven).

A farmer who is concerned about the potential impact of robotic agriculture on jobs and livelihoods is less likely to be accepting of a new robotic agricultural technology, even if the technology has a high TRL (e.g., it is fully developed and proven).

A farmer who is concerned about the ethical and social implications of using robots in agriculture is less likely to be accepting of a new robotic agricultural technology, even if the technology has a high TRL (e.g., it is fully developed and proven).
It is important to consider the ARLs of the individuals and groups involved when developing and implementing robotic technologies in agriculture. So, robotic technologies can be adopted in a socially responsible way.(University of Reading, UK et al., 2023)

Level	TRL «Development»	MRL «Commodification»	RRL «Legalization»	ARL «legitimization»	ORL «domestication»
1	Specific technological idea is formulated	Hunch of a market need	The legal and/or regulatory aspects of the technology is unpredictable or unknown or unpredictable	The technology is or will be seen as illegitimate or unacceptable	The technology represents a fundamental break with existing work processes or organizing
2	The technology idea is explicitly described	Market and product are described	Use or production will require changes of laws.	The technology will be seen as controversial in large parts of the population	Unclear how the technology might be adapted to existing work processes/organization
3	Experimental proof of concept	Market need and market supply are explicated.	Use and/or production will require change or reinterpretations of regulatory framework	The technology is seen as unwanted or inappropriate among groups of the population	An idea about integration domestication exist
4	Technological elements are tested and validated in lab or simulated environment	Validation of market/small pilot campaign	Use and/or production will require demanding permissions or approvals	The technology is seen as controversial among groups of the population	Integration with work processes/organization is formulated
5	Integrated technology tested and validated in lab or simulated environment	Business model described	Use and/or production will presuppose accessible permissions or approvals	Use of the technology is seen as unwanted or inappropriate among key actors in the sector	A concrete plan for integration with existing work processes is formulated
6	Technology demonstrated in relevant environment	Products are being launched in limited scope	Necessary approvals are likely	Use of the technology is seen as unwanted or inappropriate among a few actors in the sector	Large/fundamental organizational changes are needed in order to use the technology
7	System prototype demonstrated in natural environment	Customers confirm progress/improvement	Necessary approvals for use or production are "just around the corner"	The technology is seen as controversial in parts of the sector	Small organizational changes are needed in order to use the technology
8	Product tested and validated, and the functionality is being optimized	Stable sale makes income predictions possible	Use or production fulfill general conditions	The technology is seen as controversial among marginal interest groups	Technology is adapted to work processes and/or existing technology
9	Actual system proven functional in natural environment	Market confirms stability/growth	Use and production are regulatory unproblematic	The technology is generally accepted/applauded	The technology works seamlessly with existing technology

fig 7.1 Scales (Vik et al., 2021)

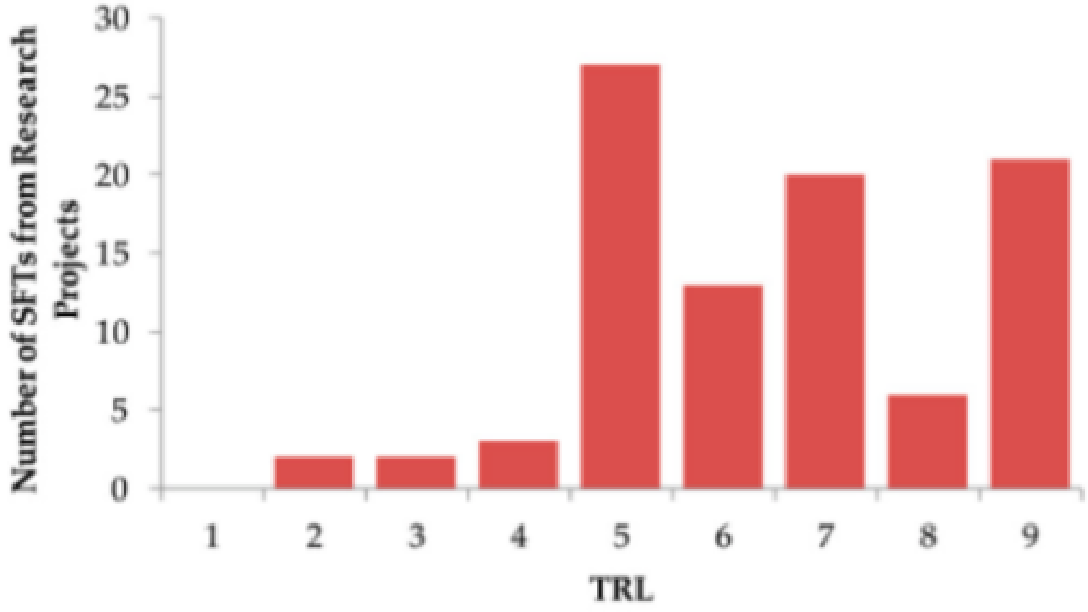


fig 7.2 Smart farming technologies and TRL (Balafoutis et al., 2020)

7.3. Education, communication strategies

The involvement of stakeholders through communication increases the effectiveness that farmers receive accurate information and opportunities for learning to become more aware of robotics in agriculture, ultimately leading to successful adoption of agricultural robots. Different kinds of strategies are possible.

On-Farm demonstrations and Workshops:
Key Stakeholder: Agricultural Technology Companies
Technology companies are crucial for on-farm demonstrations and workshops because they can provide the actual robots and expertise. They can showcase the technology in action, allowing farmers to directly interact with the robots and understand their capabilities.

Collaborative Research and Demonstration Farms:
Key Stakeholder: Research Institutions and Universities
Research institutions and universities are essential for collaborative research farms. They bring scientific expertise, conduct studies, and provide credible data. Their involvement adds credibility to the demonstrations, making them more convincing to both farmers and other stakeholders.

Interactive Online Platforms and Webinars:
Key Stakeholder: Technology Educators and Trainers
Technology educators and trainers are important for online platforms and webinars. They can create educational content, conduct webinars, and provide technical support. Their expertise ensures that the online materials are informative and engaging, helping farmers learn about robotic technologies effectively.

Farmer-to-Farmer Knowledge Study groups:
Key Stakeholder: Farmers' Associations and Cooperatives
Farmers' associations and cooperatives play a central role in farmer-to-farmer knowledge exchange. They can identify experienced farmers willing to share their insights. These associations create a platform for successful adopters to interact with their peers, building trust through real-life success stories and experiences.

Key take aways

Communication Strategies:
1. Education and Awareness
2. Demonstrations and pilot projects
3. Success stories and testimonials
4. Training and support

7.4. Business models

There are several economic factors and business cases that demonstrate how farmers can benefit from the implementation of robotics and automation in agriculture. There is the possibility of cost savings, while the initial investment in agricultural robots and automation technology can be significant, the long-term cost savings are substantial. By reducing the need for manual labor and optimizing the use of resources such as water and fertilizers, farmers can lower operational costs in the long run. Additionally, automation reduces the dependency on seasonal labor, which can be costly and unreliable.

The economic advantages make a good business case for the adoption of agricultural robotics, offering substantial benefits to farmers in various aspects of their operations and profitability.

There are several profitable business models in the field of agricultural robotics. As technology continues to advance and the agriculture industry increasingly embraces automation, entrepreneurs and businesses can explore various avenues to create profitable ventures. Here are some potential business models related to agricultural robotics:

Robot-as-a-Service (RaaS):
This model involves providing agricultural robots to farmers as a service. Farmers can rent robotic equipment for specific tasks such as planting, harvesting, or weeding. This approach eliminates the need for significant upfront investments for farmers and ensures a steady revenue stream for the RaaS providers. The service can include regular maintenance, software updates, and technical support.

Robotic Tools or Equipment Sales:
Companies can design, manufacture, and sell agricultural robots and automation equipment to farmers. This model requires expertise in robotics engineering and manufacturing. Businesses can offer a range of robotic solutions tailored to different farming needs, such as autonomous tractors, harvesting robots, or drones for crop monitoring. Continuous innovation and a focus on user-friendly designs are essential for success in this model.

Data Analytics and Insights:
Agricultural robots generate vast amounts of data. Businesses can offer data analytics services to farmers, providing valuable insights for decision-making. This can include predictive analytics for crop diseases, yield forecasting, or optimal resource management. Data-driven insights can help farmers optimize their operations, leading to increased productivity and profitability.

Farming Software:
Develop software solutions that integrate with agricultural robots and sensors. These software platforms can enable farmers to remotely monitor and control robotic equipment, analyze data, and receive real-time alerts. Subscription-based models or one-time software sales can generate revenue. Features like machine learning algorithms for predictive analysis can add value to the software.

Robot Maintenance and Repair Services:
As agricultural robots become more widespread, there will be a demand for maintenance and repair services. Businesses can establish service centers or offer on-site repair services for robotic equipment. This model ensures a continuous revenue stream through service contracts and one-time repair services.

Training and Consultation:
Provide training programs and consultation services to farmers interested in adopting agricultural robotics. Training can include operating robotic equipment, maintenance best practices, and safety protocols. Consulting services can help farmers assess their needs and choose the right robotic solutions. Training and consultation can be offered as paid services or through workshops and seminars.

Farm Management Platforms:
Developing comprehensive farm management platforms that integrate robotic systems, IoT sensors, and data analytics. These platforms can provide farmers with a holistic view of their operations, allowing them to monitor crop health, automate irrigation, and manage robotic fleets. Subscription-based models can be employed for access to premium features and ongoing support. Also specializing in designing custom robotic solutions tailored to specific agricultural needs. Farms and agricultural businesses often have unique requirements based on their crops, terrain, and climate. Offering customized robotic solutions can be a lucrative business. This model requires close collaboration with clients to understand their specific challenges and develop bespoke robotic systems.

Drone Services:
Offering drone-based services for aerial crop monitoring, surveying, and mapping. Drones equipped with cameras and sensors can provide valuable data to farmers. Businesses can charge farmers on a per-flight basis or offer subscription packages for regular monitoring services. Drones can also be integrated with ground-based robots for comprehensive farm automation.

Vertical Farming and multifunctional farming:
Focusing on developing robotic solutions specifically tailored for vertical farms and controlled environment agriculture facilities. Farms can expand with additional facilities like vertical farms or selling surplus resources or energy supply through solar panels.

In summary, the agricultural robotics industry offers diverse opportunities for profitable business models, ranging from equipment sales and services to software development and data analytics. Entrepreneurs and businesses entering this field should focus on innovation, reliability, and addressing specific pain points faced by farmers to create sustainable and profitable ventures.

CHAPTER 8

Design goal of future vision

8.1 Direction of future vision
8.2 Speculative Design
8.3 Time spacing strategy

Chapter 8 defines the future vision and direction guiding this roadmap and discusses the concept of a future vision as distinct from goals, outlining key elements like clarity, value drivers, artifacts and magnetism. This chapter introduces speculative design as a strategic tool that explores scenarios to anticipate critical thinkng.

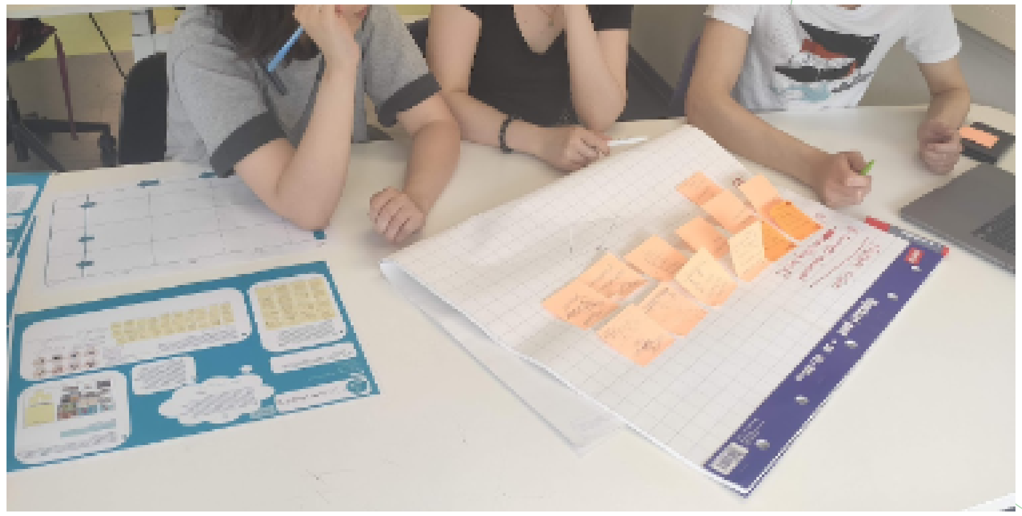
8.1. Direction of future vision

Future vision is a creative depiction of an envisioned future, distinct from a mere goal. It offers a guiding direction for innovations, imagining potential future experiences in a tangible manner. The art of visioning involves capturing people's desires for the future, expressing specific and attainable dimensions that can make a difference. The concept includes four key elements according to Simonse:

1. **Clarity:**
   It ensures a clear understanding of future innovations.
2. **Value drivers:**
   It identifies the essential benefits and needs
3. **Artifacts:**
   It materializes imagined values using 2D or 3D representations.
4. **Magnetism:**
   It embodies the desirability and appeal of the vision.

However, the future vision is not just a designer's vision; rather it is a shared vision co-created by various stakeholders, exploring the future without being limited by present problems. It is also distinct from a corporate vision, which relates to a company's strengths and values, although the two can be connected.

Vision concepts are crafted to explore and discuss innovative strategic ideas. They convey new values, are useful for user interaction tests, and aid in strategic decision-making regarding resource allocation for future designs. Unlike production prototypes, they do not aim to be sold. These concepts demonstrate the feasibility of a future vision, allowing stakeholders to explore it and provide feedback. They foster the creation and sharing of a clear vision, serving as public representations of an organization's innovative direction. While they traditionally involve physical models, virtual techniques are increasingly valuable for engaging user interactions and exploring new values and technologies.(Simonse, 2018)



The direction of the future vision for the roadmap is to Revolutionize Agriculture: Autonomous Agriculture for Resilient Food Systems.

This direction is further developed towards the future vision through research insights, speculative writing, workshopping, discussions and brainstorming with peers.

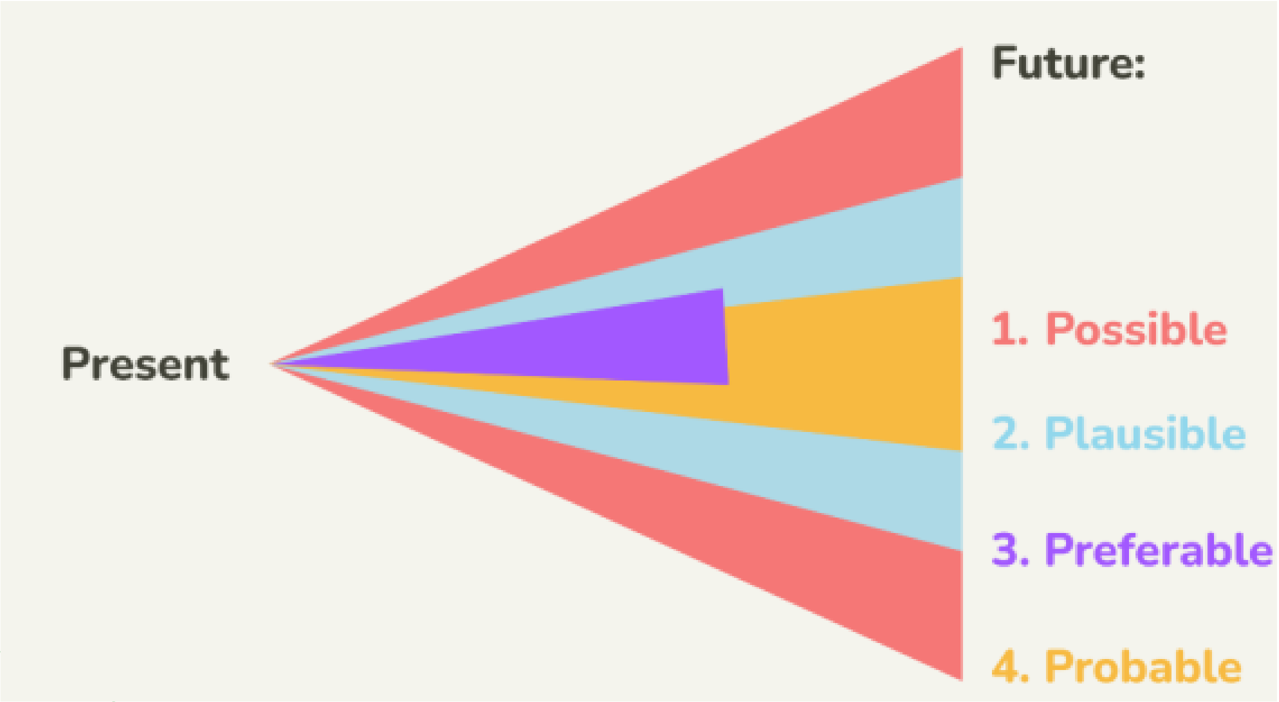


fig 8.1 future cones model for speculative design (UX Tweak, 2022)

8.2. Speculative design

Speculative design can be very beneficial in the context of creating a roadmap for the future implementation of robots in agriculture. (ATTARI et al., 2021)

Speculative design can act as a strategic tool for anticipating and preparing for unforeseen challenges. This way it can serve as a catalyst for innovation, pushing the boundaries of technology and imagination. By contemplating extreme or unexpected situations, it helps identifying actual desires that emerge during the implementation of agricultural robots.

Moreover, speculative design investigates the significant societal consequences that arise due to the widespread integration of robots in agriculture by exploring various scenarios of how robots might be integrated into agriculture in the future.

Similarly, speculative design plays a role in visualizing ethical aspects. The ethical dimension serves as a stepping stone for critical thinking, ensuring that robotic technology is implemented responsibly and with conscientiousness in the agricultural sector.

Furthermore, speculative design serves as a useful strategic tool to prepare for unanticipated challenges. By examining unexpected or extreme situations, both utopian and dystopian, it can identify potential obstacles that may arise while deploying agricultural robots. These challenges can range from technical complexities to regulatory and societal issues. Addressing the challenges in the roadmap ensures a strong, flexible, and resilient implementation strategy. (Dunne & Raby, 2013)

Overall, speculative design is a powerful catalyst for innovation. By envisioning futuristic scenarios where the future inspires groundbreaking advancements in robotics, artificial intelligence, and agricultural practices. Extensive research and critical thinking become the driving force behind the speculative scenarios, leading to the creation of innovative technologies aligned with the roadmap's overarching objectives.

8.3. Time pacing strategy

Creating time pacing for new product development is very important. Roadmaps should establish a rhythm for development, enabling efficient, focused work and increasing flexibility to adapt to market changes according to Shi et al. Implementing a time pacing strategy is relevant in the context of robotics for agriculture as well. For example by maintaining a predictable rhythm, researchers and developers can align their efforts with seasonality and optimize the use of agricultural technologies during specific periods such as planting and harvesting.

Agricultural projects, especially those involving complex technologies like robotics, require significant resources. Time pacing allows for the efficient allocation of resources, both human and financial, ensuring that research, development, and testing phases are well-managed. This efficient resource allocation is significant for the successful development and deployment of robotic solutions in agriculture.

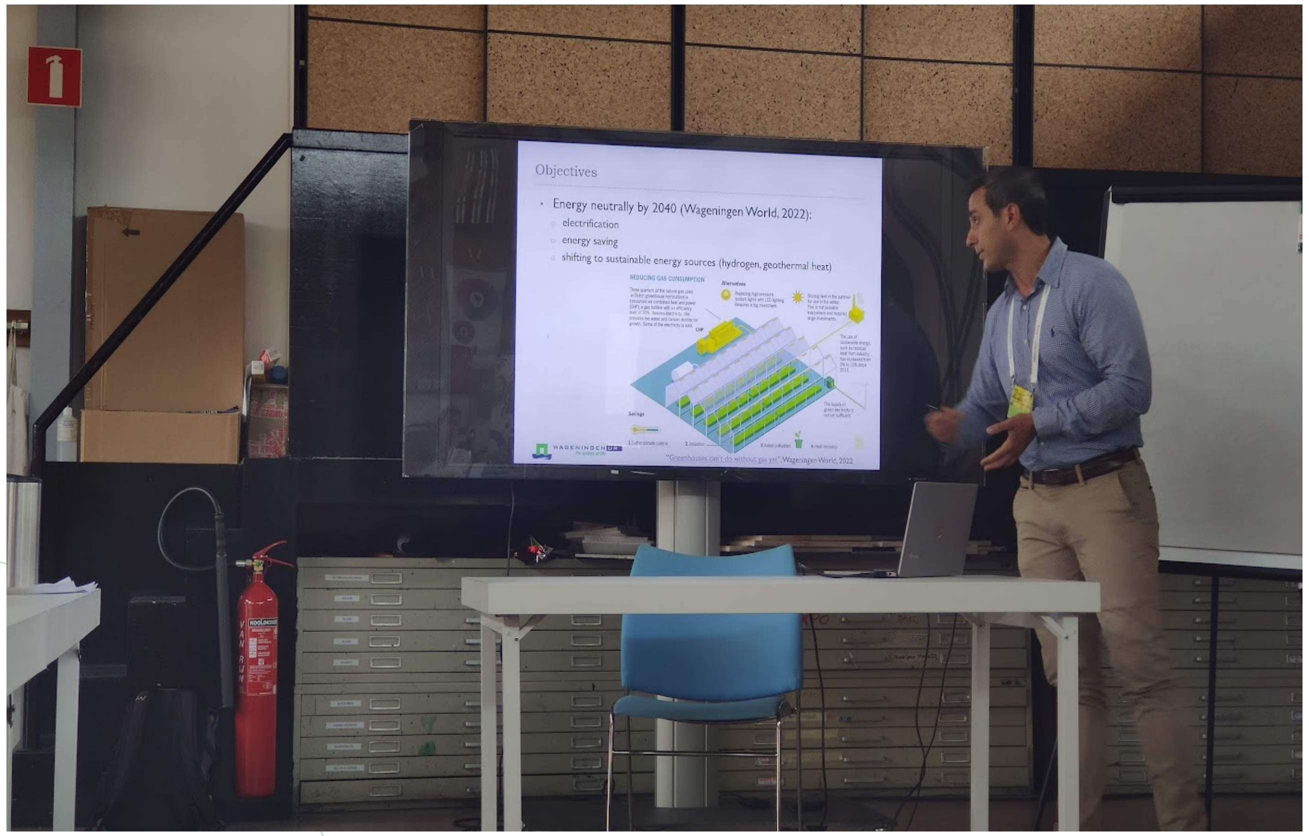
Agriculture is an industry that involves various stakeholders, including farmers, agronomists, engineers, and software developers. Time pacing fosters collaboration among these stakeholders. Clear deadlines and structured development phases facilitate coordinated efforts, allowing for the integration of robotic solutions into the broader agricultural ecosystem. Collaboration between robotics experts and agricultural professionals can lead to the development of specialized solutions tailored to the unique challenges of farming practices.

Agriculture varies significantly across regions and crops. Time pacing allows for adaptability, enabling developers to customize robotic solutions based on the specific needs of diverse agricultural settings, like seasonality. By evaluating progress at the end of each phase, developers can make necessary adjustments.

Transparent development processes and predictable timelines enhance stakeholder confidence in agricultural innovation, including farmers, investors, and policymakers. By demonstrating a structured approach to technology development, stakeholders are more likely to embrace and invest in agricultural robotics, leading to widespread adoption and implementation in the agricultural sector.

Time pacing allows for the identification and mitigation of risks, including those related to environmental impact. Developers can assess the ecological implications of robotic technologies, ensuring that they contribute to sustainable agricultural practices. Monitoring progress and making adjustments at the end of each phase enables the development of environmentally friendly robotic solutions, aligning with the growing focus on sustainable agriculture.
(Shi et al., 2022)

In summary, applying a time pacing strategy to the development of robotics in agriculture leads to strategic alignment, optimal resource utilization, adaptability and continuous improvement.



Objectives

- Energy neutrally by 2040 (Wageningen World, 2022):
  - electrification
  - energy saving
  - shifting to sustainable energy sources (hydrogen, geothermal heat)

"Greenhouses can't do without gas yet", Wageningen World, 2022

CHAPTER 9

Roadmap Implementation

9.1 Future vision and horizons
  9.1.1 Horizon 1: Raising awareness
  9.1.2 Horizon 2: Community Building
  9.1.3 Horizon 3: Fostering Wellbeing
  9.1.4. Stakeholder involvement
  9.1.5. TRL and valley of death

Autonomous Agriculture for Resilient Food Systems

FUTURE VISION

The future of agriculture is an automised and sustainable system which enables farmers to sustain the longevity and resilience of their farming business

Case

Why? Robotics could reduce soil impact, and relieves mental and physical strain of heavy labor for the farmer

How? Conserving resources like water, energy, fertilizer through precision techniques wit low inputs

What? Autonomous lightweight and low input machines that limit negative outputs which can degrade soil over time

RAISING AWARENESS

Focus on raising awareness about the potential of autonomous agriculture on how robotics have matured to help against external factors

COMMUNITY BUILDING

Farmers unite to create a network of shared knowledge and resources, fostering collaboration and knowledge exchange

FOSTERING WELLBEING

Agricultural robots support farmers in ensuring food security and that sustainable production protects biodiversity

2030

H1

Agricultural robots have undergone maturity, in which they work reliable

Resilience against labor shortage and uncertainty

2035

H2

farming communities have united to create a community of shared knowledge and resources

Remove social barriers and support economic factors

2040

H3

farmers are no longer overwhelmed by feeding the planet, empowered by technology

Provide for rising demand for more food keeping sustainable farm productivity

EMPOWER NATURE AND FARMER WELL-BEING

Autonomous Agriculture for Resilient Food Systems

H1: Raising awareness | **H2: Community building** | **H3: Fostering wellbeing**

NOW → 2030 → 2035 → 2040

Challenge

- Counter soil degradation and biodiversity loss
- Nitrogen and crop protection efficiency
- Fair income for farmers
- Reduce fossil energy use
- Satisfy consumers' changing tastes and expectations

Product/ Service

- Plant Management and systems with sensors
- Market overview platform and community apps
- High yield multifunctional farm
- Crop monitoring and robust crops
- Harvesting automatisation
- Weeding automatisation
- Seeding/sowing automatisation
- Precision farming for crop protection and fertilisers
- Disease and Insect Detection
- Multi Purpose Robotics platform
- Integrated Crop Management with Digital Twins

Technology

- Artificial Intelligence systems for individual farms
- Artificial Intelligence for open community
- Customisation of equipment and Multi Purpose Robotics
- Widespread precision farming techniques
- Internet of Things fully implemented in farms
- Fully automated germination, growing, monitoring and harvesting

Resources

Farmers

- Early adaptation of robotics
- Farms semi-automated and running
- Widespread Sustainable practices
- Renewable energy supply
- Circular production / regenerative farming
- Planet proof to more organic
- Small scale testing
- Data collection
- Data-sharing
- Soil conservation
- Farmer wellbeing

Stakeholders

- S1 Study groups of farmers for robotics and wellbeing
- S2 Resilient high value crops against extreme weather
- S2 Demonstrations and technology evidence
- S4 Lease robotics
- S3 New curriculum in argi-education
- S3 Community networks
- S3 Well known training programs
- S3 Market and brand recognition
- S5 Resilient soil and high biodiversity
- S5 Low carbon footprint

Value drivers

Resilience against labor shortage and uncertainty

Remove social barriers and support economic factors

Provide for rising demand for more food keeping sustainable farm productivity

Narrative

Agricultural robots have undergone maturity, in which they work reliable, planting seeds with precision, monitoring soil conditions and autonomously tending to crops. They have significantly reduced the physical demands on farmers and made them resilient against external factors, leading to producing more food with less input, preserving precious resources.

The future of farming with farming communities have united to create a network of shared knowledge and resources to protect the longevity of farming businesses. Farming meetings to discuss the latest advancements in agricultural technology, crop protection strategies, and sustainable farming practices. Many of the younger generation are blending age-old wisdom with new technology to create an economically successful and sustainable future.

The world's population continues to grow, but farmers are no longer overwhelmed by the challenge of feeding them all. In this future, the integration of agricultural robots transformed the uncertain agricultural landscape into one that fosters the wellbeing of both farmers and nature. Farmers, empowered by technology and community collaboration, have not only maintained the longevity of their farm but have also preserved the environment for future generations.

Revolutionize Agriculture:

Empower nature and farmer well-being

FUTURE VISION

The future of agriculture is an automised and sustainable system which enables farmers to sustain the longevity and resilience of their farming business

This roadmap outlines a strategic approach to integrating robotic and autonomous technologies into the agricultural sector in the Netherlands through three distinct horizons. It aims to provide guidance to key stakeholders on achieving a long-term vision where robotics contribute positively to the sustainability and profitability of Dutch farms.

The roadmap was designed based on insights from extensive research, based on literature review and cases exploring robotics applications and the Dutch agricultural context. The strategy outlines three horizons with actionable insights to inspire implementation. This roadmap aims to systematically and incrementally realize a future where robotics strengthens Dutch agriculture. It provides orientation for farmers and organizations involved in robotics integration.

The three horizons included in this roadmap - Raising Awareness, Community Building, and Fostering Wellbeing - a systematic and incremental methodology. Each horizon identifies steps to make progress toward the vision over time frames of the present to 2030, 2030 to 2035, and 2035 to 2040 respectively.

Across the horizons, key themes such as demonstrations of technologies, knowledge sharing platforms, and education are addressed. Alignment with the future vision, clarity of goals, impact of value drivers, representation through artifacts, and motivation of stakeholders are also analyzed.

It is intended that this roadmap serves as a guide for farmers, industry organizations, government agencies and other actors in the Netherlands to work together on a beneficial trajectory of robotics implementation. Their participation and commitment over the upcoming decades will determine how technology can uplift rather than overburden Dutch agriculture.

9.1. Future vision

Future vision:
The future of agriculture is an automated and sustainable system which enables farmers to sustain the longevity and resilience of their farming business.

The future vision of agriculture envisions a landscape where automation plays a major role in ensuring the resilience and sustainability of food systems. Autonomous agriculture, powered by advanced technologies like robotics, artificial intelligence, and data analytics, empowers farmers to reduce their dependence on external factors like manual labor while optimizing agricultural processes. Autonomous machinery and smart systems are capable of efficiently managing tasks such as harvesting and pest control. This technological advancement leads to a more reliable and resilient food supply chain.

The future vision involves empowering agricultural sustainability and improving farmer well-being. Natural resources such as biodiversity, soil, and water can last longer if sustainability practices are applied. This involves adopting agroecological approaches and promoting organic farming. Additionally, prioritizing the well-being of farmers is achieved through the integration of technologies that reduce the physical and mental strains associated with farming. Automated machines decrease physical strain, whereas insights derived from data empower informed decision-making, reducing uncertainty and stress. Moreover, cultivating a sense of togetherness among farmers and sharing knowledge should result in mutual engagement and widespread awareness.

Sustainable and robust farming businesses form the foundation of the future vision.
These measures add to the all-around welfare and longevity of farms. By adopting automation and sustainable practices, farmers can alleviate risks related to climate change, market fluctuations, and resource limitations. Effective resource management, combined with intelligent farming methods can maintain economic stability during challenging times. Sustainable agriculture can grant access to premium markets and increased returns. Additionally, it fortifies individual farming businesses while advancing the agricultural ecosystem, consequently promoting global economic stability and food security.

Ultimately, a harmonious combination of technological innovation, environmental conservation, and social empowerment embodies the future vision for agriculture. By implementing autonomous systems, modernizing traditional practices, and placing emphasis on the well-being of farmers and nature, the agricultural industry can overcome evolving challenges and maintain a durable and adaptable food supply for future generations.

9.1.1. Horizon 1: raising awareness

Narrative H1
Agricultural robots have undergone maturity, in which they work reliable, planting seeds with precision, monitoring soil conditions and autonomously tending to crops. They have significantly reduced the physical demands on farmers and made them resilient against external factors, leading to producing more food with less input, preserving precious resources.

Future Vision Alignment:
In this first horizon, the focus is on raising awareness about the potential of autonomous agriculture as an alternative for conventional methods. The narrative describes how agricultural robots have matured and planting seeds with precision, monitoring soil conditions, and autonomously tending to crops. The vision aligns with the value driver of resilience against labor shortage and uncertainty as it reduces the physical demands on farmers and ensures reliable food production.

Clarity:
Horizon 1 brings clarity by showcasing mature agricultural robots, their precise functions (planting, monitoring, tending), and advanced precision techniques. This highlights a clear understanding of future innovations in agriculture.

Value Drivers:
The value driver here is resilience against labor shortage and uncertainty, achieved through reduced demands on farmers and efficient resource preservation.
Artifacts: The artifacts in Horizon 1 include mature agricultural robots and vertical farming setups, representing tangible 2D illustration of automated and sustainable agriculture.

Magnetism:
The desirability of reduced mental or physical strain on farmers and preserving precious resources makes this horizon magnetizing, emphasizing the appeal of automation and sustainability.

Case H1
The case in Lelystad began with a Fryslan farmer's interest in Farmdroid. At an excursion of the experimental field in Lelystad at Boerderij van de Toekomst, one of the participants, a potato farmer from Fryslan, asked about Farmdroid, which is sowing and tilling robot. The willingness and potential is seen. However, there are still many unknown factors that the farmer had to take into account regarding the actual adoption of robotic technology, in which education and more awareness is required to take next steps.

Similarly, the case of Fotoniq, which is a startup with high tech greenhouse coating technology, For growers it is difficult to understand the benefit of the technology, for them less sun means less plant rule of thumb, while the coating lets 4% less sunlight through but diffuses an improved distribution of light on the whole plant, instead of just the top half of plants receiving most sunlight.

Both cases emphasize the value of educating producers about measurable benefits robotic innovations provide compared to traditional rule-of-thumb approaches. The lack of awareness, in which the farmer does not know about alternatives on the market and sticks to own trustworthy knowledge, results in a large communication gap. Addressing the communication gap, empowers producers to make informed long-term decisions supported by evidence rather than assumptions alone. So it is of high value to raise awareness about alternatives to traditional methods by educating farmers about the benefits related to robots. By raising the awareness, the drivers addressing the resilience in uncertainty and labor shortage are strengthened. By strengthening understanding , it helps lower adoption barriers by building farmer confidence to pursue sustainability and robotics.

Stakeholders H1
S1 Ecosystem Initiators (startups, government departments) and S2 Partners (research institutions, government funds) develop and offer integrated platforms or services, like lease systems, support demos and provide technology evidence.
S3 Peer Producers (educational institutes) initiate new curriculum in argi-education and study groups for farmers or students.

9.1.2. Horizon 2: Community building

Narrative H2
The future of farming with farming communities have united to create a network of shared knowledge and resources to protect the longevity of farming businesses. Farming meetings to discuss the latest advancements in agricultural technology, crop protection strategies, and sustainable farming practices. Many of the younger generation are blending age-old wisdom with new technology to create an economically successful and sustainable future.

Future Vision Alignment:
The second horizon emphasizes the importance of community building among farming communities. Farmers unite to create a network of shared knowledge and resources, fostering collaboration and knowledge exchange. This aligns with the value driver of removing social dilemmas and supporting economic factors, as it promotes a sustainable and economically successful future for farming businesses.

Clarity:
Horizon 2 contributes to clarity by emphasizing the unity of farming communities, shared knowledge networks. It expresses specific and attainable dimensions of collaborative farming practices, aligning with the future vision's goal of empowerment and togetherness among farmers.

Value Drivers:
This horizon addresses social barriers and economic factors by creating a network of support, enforcing collective decision making.

Artifacts:
The artifacts include the community networks and collaborative farming practices, representing tangible 2D illustration of shared knowledge and social collaboration in agriculture.

Magnetism:
The appeal of community collaboration and engaging stakeholders makes this horizon magnetizing, embodying the desirability of collective efforts in agriculture.

Case H2
The case representing horizon 1 would be Trabotyx, which offers services to farmers by operating their weed robot on farms. Trabotyx' weed control services to farmers provides a cost-effective alternative to manual labor or widespread spraying, which can result in positive economic benefits.
For example in carrot cultivation, around 30% of production costs go to weed control. For crops like organic carrots, their robot can reduce weed removal costs by over 50% compared to hand weeding. There are a variety of costs.
~400 euros of spraying crop protection per hectare, spraying 5 times on the same crop
~2000 euros per hectare for hand weeding for organic carrots
~750-1000 euro per hectare for the weed robot
In horticulture, according to a strategic advisor from municipality Westland more collaboration is encouraged and needed through a large stakeholder network. This is exemplified in the case of the AgTech Institute, during a panel discussion where the enthusiasm for digital twins was very big within the panelists and audience. It was noted that vast amounts of data are required from multiple greenhouses to develop optimized models, so collaboration within a strong stakeholder community could stimulate the maturity of digital twins in agriculture.

In regard to each case, it is of high value to build a strong community by letting others know about the (economic) benefits and sharing positive experiences or visions related to robots.
In this horizon the focus is on sharing visions and experiences, so that farmers feel more confident in making decisions, which can lead to positive impact for economic factors, in which farmers need to make an earning in order to survive, by removing the barriers of social acceptance though a strong community of stakeholders supporting each other. In the end stakeholders unite to create a network of shared knowledge and resources, fostering collaboration and knowledge exchange.

Stakeholders H2
S2 Partners (investors, research institutions) invest in projects for resilient high value crops against extreme weather.
S3 Peer Producers (robotics initiatives, community organizations) establish knowledge networks and training programs, increasing market and brand recognition.
S4 Peer Consumers (farmer networks) implement initial technologies and participate in data and expertise sharing.

9.1.3. Horizon 3: Fostering wellbeing

Narrative H3
The world's population continues to grow, but farmers are no longer overwhelmed by the challenge of feeding them all. In this future, the integration of agricultural robots transformed the uncertain agricultural landscape into one that fosters the wellbeing of both farmers and nature. Farmers, empowered by technology and community collaboration, have not only maintained the longevity of their farm but have also preserved the environment for future generations.

Future Vision Alignment:
The third horizon addresses the challenges posed by a growing world population and the need for increased food production. Agricultural robots contribute to food production, that nothing leads to waste through circular production and protecting biodiversity. This aligns with the value driver of providing for rising demand for more food while keeping farm productivity sustainable. It emphasizes the importance of a balanced approach that fosters the well-being of both farmers and nature.

Clarity:
Horizon 3 provides clarity by depicting a future where agricultural robots work in harmony with human farmers, ensuring sustainability and technology balance. It represents a specific and clear dimension of a future-proof agricultural landscape, aligning with the future vision's focus on technological innovation and environmental conservation.

Value Drivers:
The value driver here is providing for the rising demand for food while maintaining sustainable farm productivity. This aligns with the future vision's emphasis on balancing technological advancement and environmental protection to achieve long-term food security.

Artifacts:
The artifacts include the integrated agricultural robots and biodiverse production systems, representing tangible 2D illustration of the harmonious coexistence of technology and nature in agriculture.

Magnetism:
The appeal of a future where farmers are not overwhelmed, agriculture does not strain nature, and both farmers and nature are nurtured makes this horizon magnetizing. It embodies the desirability of a balanced, sustainable future in agriculture.

Case H3
The case of Pixelfarming Robotics illustrates how agricultural robotics can facilitate horizon 3. They have developed a versatile robotic platform that uses interchangeable tools to operate autonomously in the field. Their Robot One can minimize soil impact, weighing around 2000kg, these machines are significantly lighter than traditional heavy tractors which can weigh more than 5000kg. And also prevent the overuse of chemicals that harm biodiversity through automatic weeding. At the same time it can reduce the heavy physical labor usually expected of farmers.This preserves soil viability and farmer wellness through smart automation with minimal environmental impact. Both land sustainability and agricultural workers directly benefit as robotic systems share the workload. Similarly, the case of Trayplant demonstrates another sustainable solution with their automated vertical farming with a circular closed water system. An intelligent irrigation network precisely delivers filtered water and nutrients as needed to optimize crop conditions while preserving freshwater resources.This makes them more resilient against water shortage and extreme or variable weather conditions, which releases uncertainty and stress for farmers.

Ultimately, while taking each case into account, in horizon 3 the threshold of adoption is lowered through raised educated awareness of horizon 1 and well considered decision making through community support in horizon 2, leading to enhanced wellbeing of farmers and nature with the support of robotics.

Stakeholder H3
S1 Ecosystem Initiators (startups) introduce fully automated solutions.
Partners (research institutions, government funds) facilitate widespread adoption.
S5 External Actors (regulatory bodies) regulate safe, sustainable implementation.
S5 External Actors (environmental groups) promote how robotics applications support biodiversity and low emissions.

9.1.4. Stakeholder involvement

In Horizon 1, ecosystem initiators like agricultural startups and government departments lay the foundation for robotics integration. They develop early solutions tailored for planting, harvesting, and precision applications. Research institutions as partners support these efforts through applied studies evaluating robotic prototypes. AgTech entrepreneurs introduce integrated platforms and services connecting the different stakeholders, promoting study groups as well. Ecosystem initiators also design specialized systems, like leasing, meeting the needs of Dutch farms.

Horizon 2 fosters wider collaboration across the ecosystem. Community organizations and farmer networks establish resources as training programs for exchanging information and resilient practices. Through community networks, peers collectively address challenges and visions involving soil health and fair incomes in relation to robotics, increasing market and brand recognition . Peer consumers including farmers and cooperatives begin implementing initial technologies on a small scale to gain experience. This allows gathering data to share within growing knowledge networks.

By Horizon 3, fully automated solutions are envisioned. Startups introduce innovations like digital twin technology integrated across the sectors. Regulators shape guidelines ensuring robotics strengthen sustainability through circular production models beneficial to nature and society. With environmental groups involved, these groups help to advance environmentally friendly practices within agriculture. They would engage in initiatives demonstrating how robotics applications support resilient soil, biodiversity and low emissions.

This evolving partnership between initiators, partners, producers and consumers and with guidance from external actors demonstrates how the ecosystem map can catalyze each milestone towards the responsible and productive implementation of agricultural robotics.

9.1.5. TRL and valley of death

Based on the Technology Readiness Level according to (Vik et al., 2021), an agricultural technology would generally need to be at TRL 7 or higher to be considered ready for market purposes. Then most experts would consider a technology to be market-ready once it reaches TRL 7, where agricultural technology has been demonstrated fully in intended operational environments. TRL 8 and 9 indicate the highest levels for full commercialization purposes.

So in summary, according to the TRL framework presented, agricultural technologies would generally need to be at TRL 7 or higher to be viewed as ready for full market introduction and commercialization purposes. Below TRL 7 would be considered in the Valley of Death, see figure 9.1. The Valley of Death is a term used in technology development to describe the difficult transition from research and development to commercialization. A large number of smart farming techniques are still below TRL 7, not fully ready for the market yet, needing more maturity in development, see figure 9.2. The timeframe for the Valley of Death takes around 3-5 years, partly because of subsidy cycles. (Skillicorn, 2021)

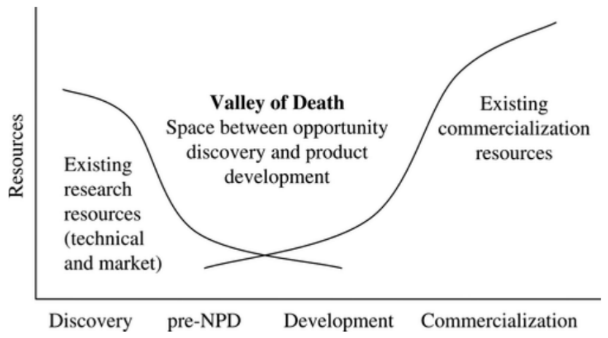


fig 9.1 valley of death (Markham et al., 2010)

According to the representative of Trabotyx in an interview, it would take about 4 years for their technology to reach the early majority group in the open field sector. Similarly, the representative of Gakon Netafim made an estimate of five years for the horticulture sector with an overall transition from conventional agriculture of 5 to 10 years. For the technology systems in the roadmap an estimation was done based on these numbers accordingly. It is difficult to state exact numbers for each technology as the maturity for each sector could be on different levels.

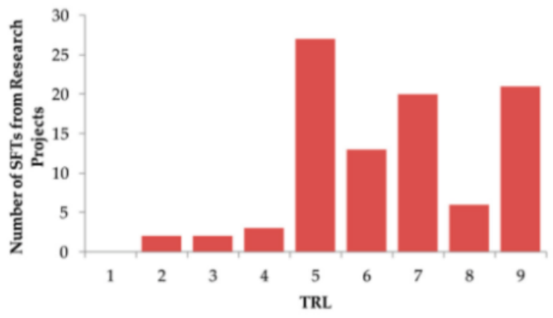
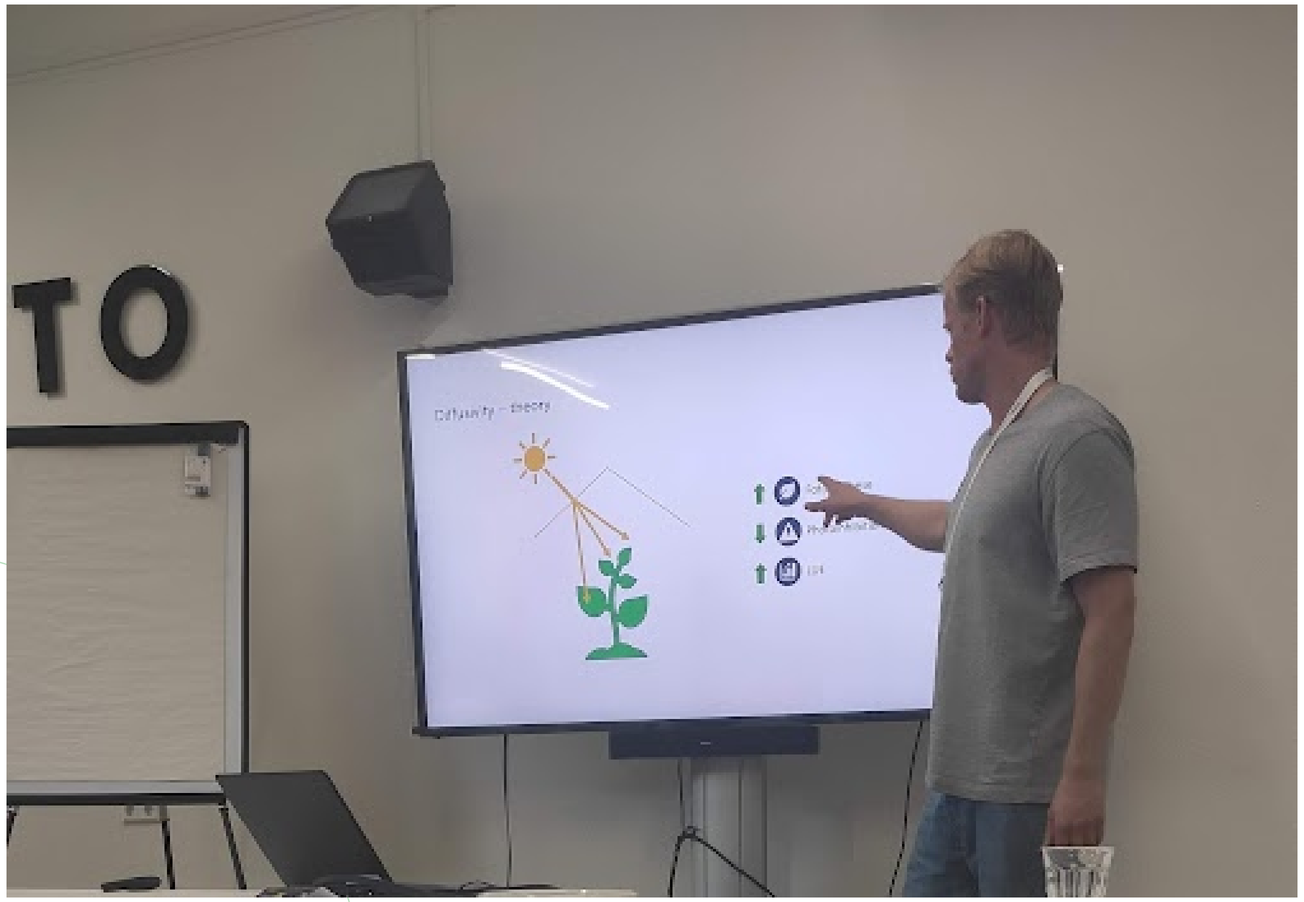


fig 9.2 TRL of smart farm technologies (Balafoutis et al., 2020)



CHAPTER 10

Validation

10.1 Toolkit

10.2 Stakeholder validation

Chapter 10 discusses the validation of the roadmap through a toolkit and feedback from industry experts. Their input provided insight on various aspects to the roadmap.

10.1. Toolkit

A toolkit is making it easier for individuals and organizations to implement the strategies outlined in your future vision and roadmap. It reduces the time and effort required to start working towards the vision. Designing a toolkit can simplify the implementation of the future vision and also creates a supportive ecosystem where people can learn, collaborate, and innovate based on the shared goals outlined in your roadmap.How can toolkits add value to the roadmapping?

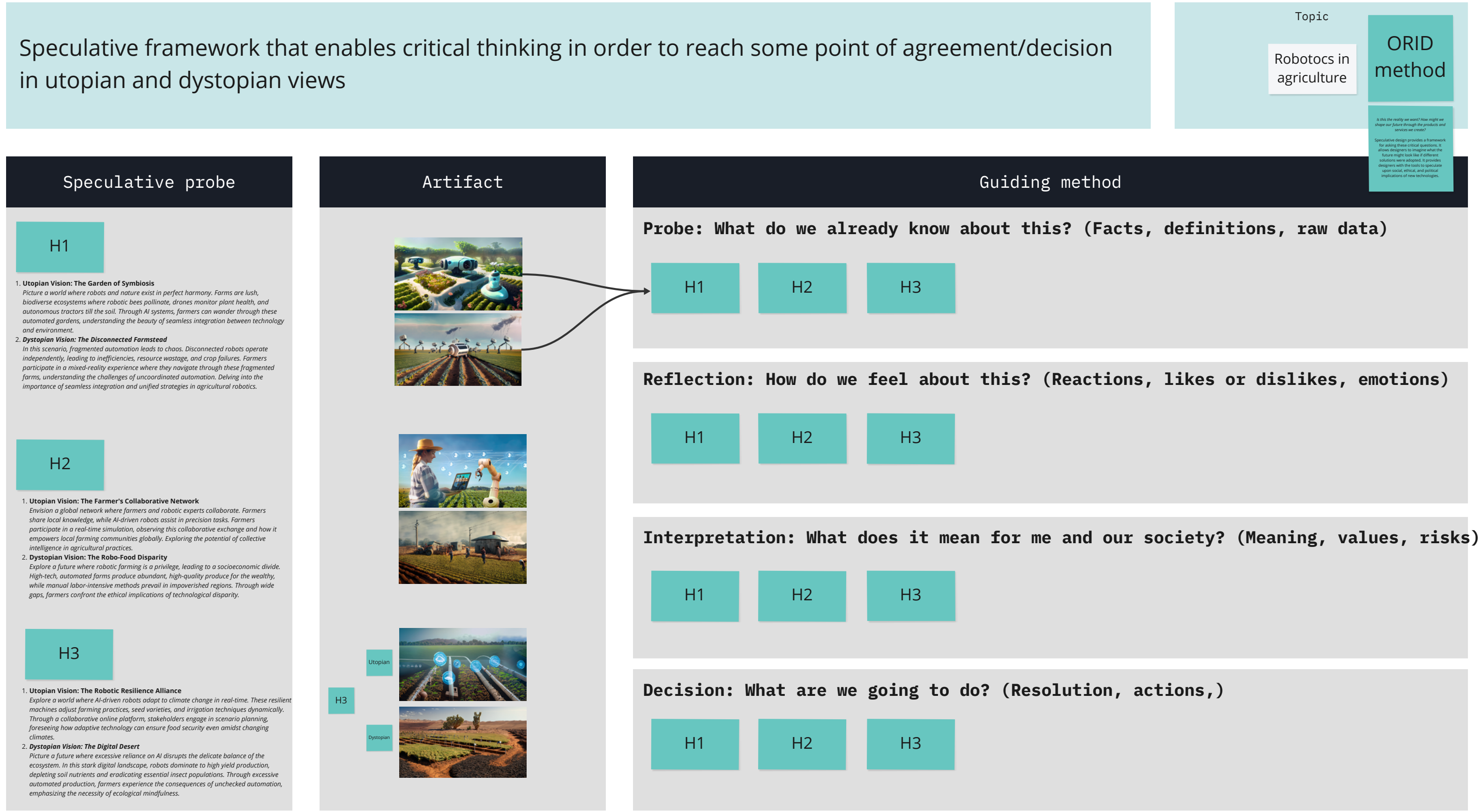
- **Knowledge Transfer:**
  Through documentation, tutorials, and examples, a toolkit facilitates the transfer of knowledge. It helps people understand the concepts and strategies outlined in the future vision, enabling them to apply these ideas effectively.
- **Community Building:**
  A well-designed toolkit can foster a community of users who share a common interest or goal related to your future vision. This community can collaborate, share experiences, and contribute to the evolution of the toolkit.
- **Feedback Loop:**
  A toolkit often allows for user feedback. Understanding how people are using the toolkit and what challenges they face provides valuable insights. This feedback loop can inform future updates to both the toolkit and the overall vision and roadmap.
- **Scalability:**
  Toolkits can be scaled easily. As more people adopt the toolkit, it can adapt to different contexts and needs, ensuring that the vision can be applied across various scenarios.
- **Innovation and Collaboration:**
  Toolkits can encourage innovation by providing a structured framework for experimentation. Additionally, collaborative toolkits can foster partnerships and collaborations among different entities interested in your vision.

The toolkit designed for the roadmap is a combination of speculative design and ORID method. The ORID method is very suitable due to its reflective characteristics.
Other possible considerations for integrating into the framework of the toolkit are methods like the c-box matrix, future cone model, future thinking canvas, futures wheel, 5D appreciative inquiry, De Bono's six hats or Socratic questioning.

Speculative design is a design approach that uses fiction and storytelling to explore possible futures. It is a way to think about and design for the future, even though we cannot know for sure what that future will hold. Is this the reality we want? How might we shape our future through the products and services we create?

Speculative design probes provide a tool for asking these critical questions. It allows people to imagine what the future might look like if different solutions were adopted. It provides people with the tools to speculate upon social, ethical, and political implications of new technologies. (Dunne & Raby)

The ORID method can be used to generate new ideas, to develop existing ideas, and to evaluate ideas. It can also be used to share ideas with others and to build consensus. (Liu, 2019). The ORID method fits well with speculative design because it provides a framework for involving objective, reflective, interpretive, and decisional dimensions that heighten the participants' awareness of how thinking can translate into action for the future. The toolkit's goals include facilitating the communication of opinions, critical thinking, finding a collective consensus, and spreading awareness. The intended outcome is the alignment or adjustment of roadmaps, reflecting the collaborative efforts of individuals working together towards shared objectives. Further development of the toolkit is needed for the actual practical use of validating the roadmap.



Is this the reality we want? How might we shape our future through the products and services we create?

Speculative design provides a framework for asking these critical questions. It allows designers to imagine what the future might look like if different solutions were adopted. It provides designers with the tools to speculate upon social, ethical, and political implications of new technologies.

H1

1. **Utopian Vision: The Garden of Symbiosis**
   Picture a world where robots and nature exist in perfect harmony. Farms are lush, biodiverse ecosystems where robotic bees pollinate, drones monitor plant health, and autonomous tractors till the soil. Through AI systems, farmers can wander through these automated gardens, understanding the beauty of seamless integration between technology and environment.
2. ***Dystopian Vision: The Disconnected Farmstead***
   In this scenario, fragmented automation leads to chaos. Disconnected robots operate independently, leading to inefficiencies, resource wastage, and crop failures. Farmers participate in a mixed-reality experience where they navigate through these fragmented farms, understanding the challenges of uncoordinated automation. Delving into the importance of seamless integration and unified strategies in agricultural robotics.

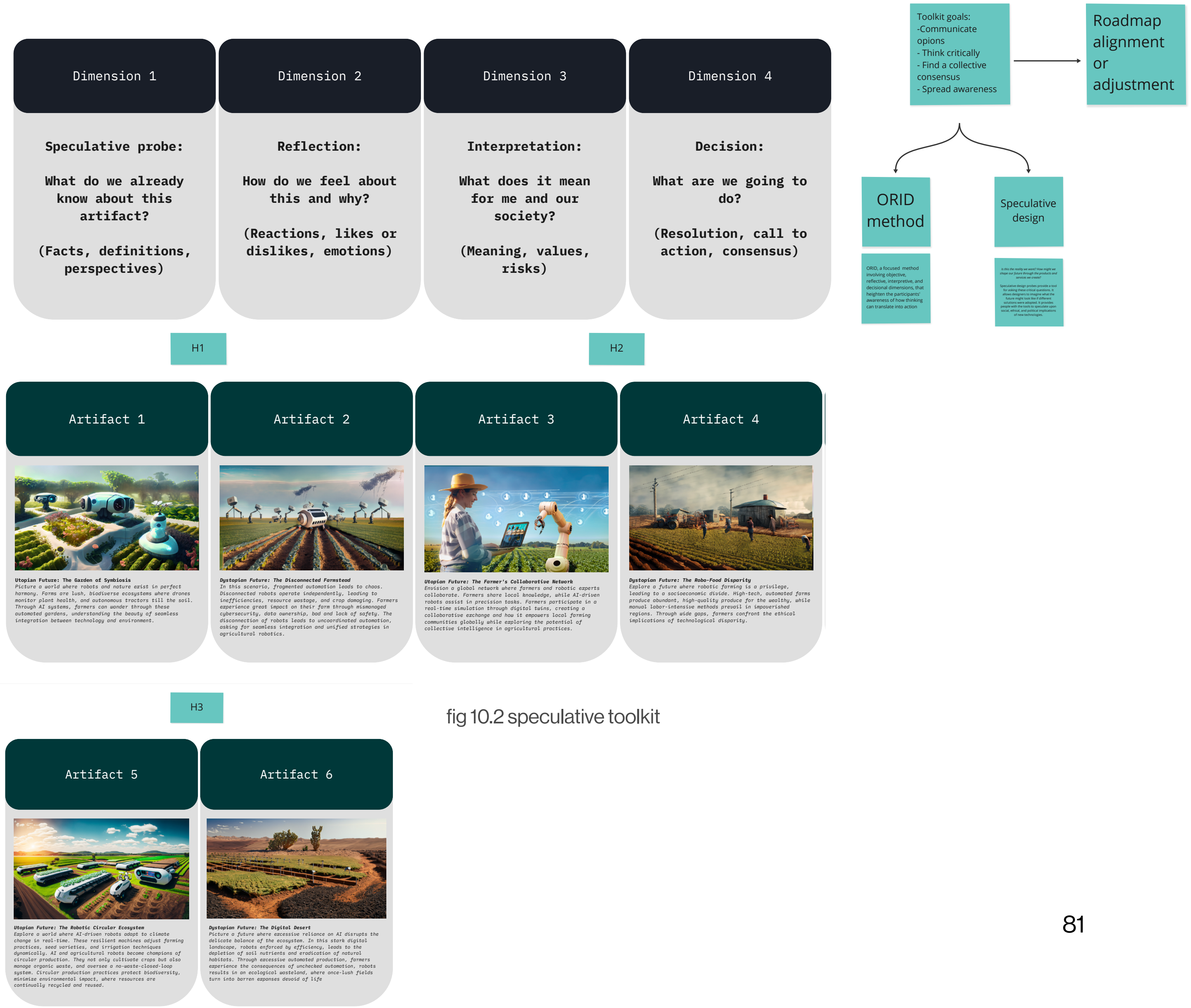
H2

1. **Utopian Vision: The Farmer's Collaborative Network**
   Envision a global network where farmers and robotic experts collaborate. Farmers share local knowledge, while AI-driven robots assist in precision tasks. Farmers participate in a real-time simulation, observing this collaborative exchange and how it empowers local farming communities globally. Exploring the potential of collective intelligence in agricultural practices.
2. **Dystopian Vision: The Robo-Food Disparity**
   Explore a future where robotic farming is a privilege, leading to a socioeconomic divide. High-tech, automated farms produce abundant, high-quality produce for the wealthy, while manual labor-intensive methods prevail in impoverished regions. Through wide gaps, farmers confront the ethical implications of technological disparity.

H3

1. **Utopian Vision: The Robotic Resilience Alliance**
   Explore a world where AI-driven robots adapt to climate change in real-time. These resilient machines adjust farming practices, seed varieties, and irrigation techniques dynamically. Through a collaborative online platform, stakeholders engage in scenario planning, foreseeing how adaptive technology can ensure food security even amidst changing climates.
2. ***Dystopian Vision: The Digital Desert***
   Picture a future where excessive reliance on AI disrupts the delicate balance of the ecosystem. In this stark digital landscape, robots dominate to high yield production, depleting soil nutrients and eradicating essential insect populations. Through excessive automated production, farmers experience the consequences of unchecked automation, emphasizing the necessity of ecological mindfulness.

fig 10.1 toolkit frame work



ORID, a focused method involving objective, reflective, interpretive, and decisional dimensions, that heighten the participants' awareness of how thinking can translate into action

Is this the reality we want? How might we shape our future through the products and services we create?

Speculative design probes provide a tool for asking these critical questions. It allows designers to imagine what the future might look like if different solutions were adopted. It provides people with the tools to speculate upon social, ethical, and political implications of new technologies.

Utopian Future: The Garden of Symbiosis
Picture a world where robots and nature exist in perfect harmony. Farms are lush, biodiverse ecosystems where drones monitor plant health, and autonomous tractors till the soil. Through AI systems, farmers can wander through these automated gardens, understanding the beauty of seamless integration between technology and environment.

Dystopian Future: The Disconnected Farmstead
In this scenario, fragmented automation leads to chaos. Disconnected robots operate independently, leading to inefficiencies, resource wastage, and crop damaging. Farmers experience great impact on their farm through mismanaged cybersecurity, data ownership, bad and lack of safety. The disconnection of robots leads to uncoordinated automation, asking for seamless integration and unified strategies in agricultural robotics.

Utopian Future: The Farmer's Collaborative Network
Envision a global network where farmers and robotic experts collaborate. Farmers share local knowledge, while AI-driven robots assist in precision tasks. Farmers participate in a real-time simulation through digital twins, creating a collaborative exchange and how it empowers local farming communities globally while exploring the potential of collective intelligence in agricultural practices.

Dystopian Future: The Robo-Food Disparity
Explore a future where robotic farming is a privilege, leading to a socioeconomic divide. High-tech, automated farms produce abundant, high-quality produce for the wealthy, while manual labor-intensive methods prevail in impoverished regions. Through wide gaps, farmers confront the ethical implications of technological disparity.

Utopian Future: The Robotic Circular Ecosystem
Explore a world where AI-driven robots adapt to climate change in real-time. These resilient machines adjust farming practices, seed varieties, and irrigation techniques dynamically. AI and agricultural robots become champions of circular production. They not only cultivate crops but also manage organic waste, and oversee a no-waste-closed-loop system. Circular production practices protect biodiversity, minimize environmental impact, where resources are continually recycled and reused.

Dystopian Future: The Digital Desert
Picture a future where excessive reliance on AI disrupts the delicate balance of the ecosystem. In this stark digital landscape, robots enforced by efficiency, leads to the depletion of soil nutrients and eradication of natural habitats. Through excessive automated production, farmers experience the consequences of unchecked automation, robots results in an ecological wasteland, where once-lush fields turn into barren expanses devoid of life

fig 10.2 speculative toolkit

10.2. Stakeholder validation

Through three feedback moments with industry experts, validation on the roadmap was gained. After these sessions, multiple insights were derived from going through each section of the roadmap. The experts agreed with most of the content in the roadmap, providing some points of interest and considerations in addition.

1. Feedback from innovation developer Topsector Agri & Food and business developer at Pixelfarming Robotics

The learning points from this session are based on a wide array of comments.

Innovation and digitalization in agriculture:
He emphasizes the importance of innovation and digitalization in the agricultural sector. He talks about the challenges of adopting new technologies and how this affects the transition from early adopters, around 25% of the farmers, to the early majority. He suggests a separate timeline for early adopters from 2025, 2030 to 2035 a timeframe.

Financial resources and support:
He argues for the need for financial support for farmers to stimulate new developments. He suggests that government incentives and targeted subsidies are needed to promote innovation. He discusses the possibility of collaboration between farmers and industries, whereby farmers are given facilities to try out new machines before investing, thereby helping them reduce risks.

Collaboration and knowledge sharing:
He emphasizes the importance of cooperation between farmers, research institutes and technology companies. He encourages knowledge sharing to work together on solutions.
He points out the importance of further training for farmers, especially with regard to operating and maintaining new technologies such as robots. He proposes creating investment programs that support farmers in training their workforce.

Biodiversity and sustainability:
He discusses the importance of biodiversity in agriculture and how crop diversity and cooperation between different crops can lead to better soil health and less dependence on chemical pesticides. He shares his vision of the future, in which plants become self-regulating and machines can work at plant level. He believes that technological developments will lead to a more holistic approach to agricultural practices. Regarding regenerative agriculture, he thinks stricter requirements should be defined.

2. Feedback from biodynamic farmer at Stadsboerderij Almere

The farmer has a biodynamic farm and sees people as leading in her work, not technology. She is careful about the use of new techniques, which must really have a serving function. She uses technology in some places, such as GPS systems for sowing and weed control. This saves time and labor, making work more enjoyable and supports her wellbeing.

Sustainable agriculture
She aims for agriculture in balance with nature, where the soil and crops remain healthy for the long term. Important aspects are biodiversity, circular agriculture through organic fertilizer and planting useful crops. She wants to prevent monoculture and dependence on fertilizer.

People as a guiding principle
People are central and not profit or technology. She wants to make her own decisions about her company and crops, tailored to nature. She also finds the welfare of animals important. Technology should not dominate the human dimension and relationships with animals and nature.

Careful use of technology
She looks critically at every technological innovation and considers whether it is really useful without disadvantages. She wants to avoid autonomous systems in order to maintain control. GPS and robots can help as long as they do not alienate her work. Costs and dependence on suppliers must also be taken into account.

Collaboration and knowledge sharing
By talking in vision groups, she can learn from other farmers and test ideas. This prevents one-sided choices. She also wants to share her knowledge about biodynamic agriculture. Joint thinking is essential for sustainable solutions, emphasizing decision making through community in the second horizon is a great focus point.

The future as a joint task
She sees the future of the sector as shared responsibility. Farmers, governments and tech companies must work together and avoid one-sided dependence.Her concerns also extended to the reliability of the technology and relation with nature becoming weakened.

3. Feedback from agrifood expert and projectmanager at ZLTO (Zuidelijke Land- en Tuinbouw Organisatie/ Southern Agriculture and Horticulture Organization)

With the feedback provided, several considerations emerge. Starting with refining the roadmap requires a meticulous examination of how robotics align with circular agriculture, a thorough exploration of the business economics for farmers, clear differentiation between trends and goals, an emphasis on integrated crop management, a precise discussion on crop protection, clarification on soil erosion, and a more sector-specific approach to products and services. This nuanced approach will enhance the roadmap's relevance and effectiveness in guiding the integration of robotics into Dutch agriculture.

Horizon 3 and Fostering Wellbeing:
The integration of robotics into agriculture, particularly within a circular framework, requires a more explicit link to the enhancement of wellbeing. It is essential to articulate how robotization contributes to circular agriculture specifically. While acknowledging that circular systems can exist independently of autonomous robots.

Autonomous agriculture for resilient food systems:
A significant aspect absent from the roadmap is an analysis of the business economics associated with autonomous agriculture. Recognizing that farmers prioritize functionality, reliability, and financial viability, the discussion should address the pragmatic concerns of the agricultural community. It is crucial to explore the reliability and failure susceptibility of robotic systems, comparing their accuracy to existing practices, and evaluating the financial feasibility and cost-effectiveness of their implementation, including payback time considerations.

Trends and desired uutcomes:
The relation between trends and desired outcomes or goals is significant for a nuanced discussion. The roadmap should clarify the nature of identified elements trends and desired outcomes. Additionally, the integration of Integrated Crop Management as a significant trend should be highlighted. Robots should be positioned as part of an integrated system encompassing soil health, nutrient management, natural pest control, and biocontrol, acknowledging that they are not a universal solution but a crucial component.

Crop protection and soil erosion:
Acknowledging farmers' preference for the term 'crop protection' over pesticides is relevant. The discussion should delve into the nuances of crop protection within the context of robotics, addressing the advancements in

disease and pest identification in protected crops. Furthermore, clarification is needed on the concept of soil erosion in relation to crop protection and a detailed exploration of how robotics can play a role in mitigating this challenge.

Products/Services and Sector Specificity:
A more sector-specific approach is warranted when discussing products and services related to robotics in agriculture. Recognizing the diversity within agricultural sectors, the roadmap should highlight the sector-specific advancements and challenges. For instance, while greenhouse horticulture has made strides in disease and pest identification, other sectors may undergo through different developments. The discussion should aim to provide a more nuanced exploration of sector-specific applications of robotics in agriculture.

Overall, the feedback from industry experts provided valuable validation. The comments reinforced the need to directly address financial viability, reliability concerns, and well-being objectives for farmers. Incorporating these complimentary perspectives through an iterative refinement process will help evolve the roadmap for future adjustments.

CHAPTER 11

Conclusion

The goal of this thesis is to research "How can robots and technology be integrated into agriculture in the Netherlands that is beneficial to the stakeholders?", and to develop a roadmap for this.
To answer the main question, an analysis was done to research the "key challenges and opportunities in the transition of robotic implementation", followed by identifying "How can this transition of robotic agriculture benefit all stakeholders".

The insights gathered from the research underline the key challenges that agriculture faces when integrating robotics, for which an opportunity and beneficial practice is presented per challenge.

Structured Approach for Implementation:
There is currently no definitive focus in place for the development and implementation of robotics as subsidies are being granted all over the place. This leads to a need for a structured approach in the implementation of robotics in the agricultural sector.
Developing a roadmap encompasses various phases, including awareness, community building, and wellbeing promotion. Such a structured framework will guide industry stakeholders, ensuring a systematic and efficient adoption of robotic technologies.

Government Support and Regulation:
A significant barrier to the widespread adoption of agricultural robotics is the lack of reliable regulation and financial support from the side of the governmental body. Adequate subsidies are crucial to incentivize farmers to invest in robotization and sustainable agricultural practices. A supportive regulatory environment can encourage and provide the necessary confidence for farmers to embrace new technologies, fostering growth and progress in the sector.

Change in Perception:
Farmers have currently no widespread trust in the technology that powers robotics in agriculture. Addressing the perception surrounding robotics in agriculture is necessary, as there is a need to foster a positive perception among farmers and the wider public. Widespread awareness needs to be created about the benefits of robotics, both in terms of resilience and environmental sustainability. By positively influencing public opinion, the agricultural sector can attract new generations of farmers willing to invest in technological advancements, driving the industry forward.

Education and Training:
As technology has advanced rapidly in the past decade, there is still a knowledge deficit among farmers, regarding the possibilities with technology. Education plays a major role in preparing the agricultural workforce for the future. Integrating robotics and precision agriculture into the curriculum is needed to grow farmers' knowledge and skills. By providing relevant education and training, farmers can optimize the potential of robotics in agriculture, making informed decisions and maximizing the benefits offered by these advanced technologies.

By adopting a structured implementation plan, garnering strong government support, reshaping perceptions, and prioritizing education and training, the agricultural sector can pave the way for a sustainable and technologically advanced future. The result is a roadmap with three horizons, that envisions a future where the synergy between robotics and agriculture transforms the Netherlands into a global leader in resilient and sustainable farming practices.

The roadmap envisions autonomous agriculture empowering resilient food systems through three horizons of Raising Awareness, Community Building, and Fostering Wellbeing, towards the future vision:
The future of agriculture is an automated and sustainable system which enables farmers to sustain the longevity and resilience of their

farming business.

By embracing innovation, fostering collaboration, investing in education, and prioritizing environmental stewardship, the integration of robots into agriculture will not only improve productivity and economic growth, but also pave the way for a more environmentally friendly and socially responsible agricultural sector in the Netherlands. This leads to the long-term viability and resilience of Dutch agriculture in the face of evolving challenges and opportunities.

In conclusion, the integration of agro-robots in the Netherlands presents a transformative opportunity for the agricultural sector. Through careful planning and strategic implementation, the proposed roadmap envisions a future where robotics play a central role in sustainable agricultural practices, enhancing productivity, efficiency, and environmental conservation.

CHAPTER 12

Discussion

12.1 Implications of roadmap method
12.2 Implications of robotics
12.3 Implications of research
12.4 Recommendations

This discussion section reflects on challenges that may hindered the research. It will evaluate the research methods and findings, approach to uncertainty and other considerations. The aim is to better understand limitations through a critical lens to make recommendations for improving the roadmap and further research.

12.1. Implications of roadmap method

The roadmapping process of this research applied a strategic planning approach inspired by Lianne Simonse's design roadmapping method to structure the creation of implementation plans. While this provided a coherent framework, shortcomings like dystopian futures were recognized in considering uncertainties inherent to the agriculture sector. To address these limitations, elements of speculative design were integrated into the roadmapping process.

Speculative design was utilized early on through envisioning multiple future scenarios. This helped surface additional pathways for robotics and digital technology adoption that may not have been identified through a purely incremental, top-down approach. For example, scenarios exploring the impacts of rapid climate change and diversification that could strengthen the roadmap.

Speculative artifacts were also created to visualize abstract concepts in ways that stimulate concrete futures. While speculation strengthened engagement and future-proofing, some limitations were also recognized. An overemphasis on highly hypothetical futures distracted from short-term implementations needed for roadmap. Maintaining feasibility among pioneering ideas also posed challenges to more incremental steps. Overall, the speculative techniques added value when combined with the design roadmapping method.

The incorporation of speculative design thus served to both stimulate innovative thinking around uncertainties in the roadmapping process. However, moderation was necessary to balance the future vision with practical outputs. The approach aimed to future-proof technology strategies while still providing clear direction of the future.

Overall, combining strategic foresight tools like speculative design with a structured roadmapping process can stimulate divergent thinking and make strategic plans more robust for uncertain technological change.

12.2. Implications of robotics

It is important to oversee discussion about implications concerning robots in agriculture in order to judge the viability of the roadmap, regarding ethical, social, political, and security implications.

The use of robots in agriculture raises ethical questions about the environmental impact of industrial farming, and the fair distribution of wealth. It can also be an issue to weigh the preference of traditional farming and choosing robotic alternatives, as well as to consider the ethical implications of job replacement.
Robots may lead to job displacement in the agricultural sector, which could have a negative impact on rural communities.

In terms of security, farms and production facilities that are highly reliant on automation and robotics will become more vulnerable to hacking and sabotage. There is also a risk that agricultural systems that rely heavily on robotics and automation might become vulnerable to cyber operations, possibly suffering big losses.

Furthermore, robots at large scale could lead to the concentration of power in the hands of companies or government, outside the control of farmers.
The gap between small farms and big farms might grow bigger. Governments should prioritize the development of robots that are sufficiently flexible to allow their use on small properties and with a wider range of crops and livestock.

They should also invest in research into the applications of agricultural robotics, and perhaps subsidies for their early adoption, to reduce the risk that small farms would miss out on the benefits of robotics.
Finally, legislators and policy makers should address the legal uncertainties surrounding the use of autonomous robots sooner rather than later for clarity on regulations.

12.3. Limitations of research

The findings of this research provide insight on the integration of robotics and technology into agriculture in the Netherlands. However, it is necessary to acknowledge the limitations encountered during the research process.

This study faced some time constraints. The research had to be conducted within a set timeframe, posing challenges in conducting extensive field research and engaging with a wide array of stakeholders. This lead to adapting and balancing the time for traveling to poorly accessible areas, finding the right person to talk to in a limited amount of time or long response time. In a similar fashion, a stakeholder workshop was not realized, as stakeholders had their own time constraints.

Connecting with stakeholders proved to be a challenging aspect of the research process. Stakeholders need to allocate time to participate in this research. Even with references from my network, reaching stakeholders to contribute to the research posed some challenges. Using different methods like flyering, emails, cold-calling, visits were not always leading to the desirable result to connect with stakeholders. Limited availability and the need for stakeholders to dedicate time to participate in the research possibly hindered the depth of engagement, potentially limiting the diversity of perspectives included in the roadmap development.

Validation through policy makers is an aspect that could elevate the roadmap on a political level but was not reached within this study.

Overall, the complexity of the agricultural ecosystem was challenging during the research process. Involving multiple stakeholders with varying accessibility levels and understanding their perspectives within their world added another layer of complexity, while maintaining a focused research approach.

In conclusion to these limitations, acknowledging these constraints allows for a realistic assessment of the roadmap's scope and the adaptability in its implementation.

12.4. Recommendations

The proposed roadmap for implementing robotics in agriculture contributes a certain direction to the field, but it is important to recognize that there are some limitations and implications that need to be addressed. It is recommended to revise these in further roadmap research. All of the following statements are based on the feedback during the stakeholder validation from chapter 10.

The roadmap provides an overview of robotics solutions for agriculture, but the advancement of robotics within the agricultural sectors are not at exactly parallel speed as different technologies are better applicable for different sectors. Some technologies, such as those for identifying diseases and pests, are particularly well-suited for protected crops (greenhouse horticulture). Others, such as weeding robots, may be more applicable to open-field agriculture. Similarly, some of the trends identified in the roadmap may not be directly aligned desirable for every stakeholder or sector.

In relation to horizon 3: Fostering Well-being, one of the limitations of the roadmap is that the claims on how robotization achieves the goal of a sustainable agriculture system need more scientifically proven results. The consequences of using robotics and its impact on nature needs to be measured to prove long-term effects. If there is proven evidence that a circular system is successful without autonomous robots, there is no guarantee that robots will automatically lead to improved environmental outcomes. It is important to carefully consider how robots can be deployed in a way that aligns with the broader values of sustainability and environmental impact.

Another limitation of the roadmap is that it should address more in depth business economics of robotics in agriculture. Farmers need to be able to justify the cost of adopting robotics by understanding the potential economic consequences and benefits. This includes abstract economic consequences such as improved product quality on how much can be additionally earned in numbers compared to conventional farming methods. It is important to provide transparent information about the costs and benefits of different robotics solutions to help farmers make informed decisions about whether or not to adopt them.

Furthermore, the roadmap could give more clarification on desired outcomes outside robotic technology, which rather require a combination of technological and other interventions. For example, integrated crop management is a broader approach to sustainable agriculture that includes not just robotics but also other practices such as soil management and natural pest control.

Building upon the insights gathered and the roadmap developed, several areas have emerged, needing further research to facilitate the successful integration of robotics and technology into agriculture in the Netherlands. While the roadmap provides a structured framework, the limitations can be addressed through recommendations. Based on the limitations and feedback received, the following recommendations can be made for further research and improvement for the roadmap.

Clarity about how robotization will help with circular agriculture needs to be emphasized. While robots can potentially play a big role in circular agriculture, it is important to recognize that a circular system is also possible without autonomous robots. Robots should be seen as one tool in a larger toolbox of sustainable agricultural practices.

A different aspect is greater emphasis on business economics. The roadmap should provide more information about the costs and benefits of different robotics solutions, including factors such as reliability, susceptibility to failure, accuracy compared to current practice, and the potential for cost savings.

Another element is more sector-specific information about robotics solutions. The roadmap should provide more information about the applicability of different robotics solutions to different agricultural sectors, such as horticulture and open field agriculture.
Accordingly, an in-depth analysis of the Technology Readiness Level (TLR) of existing robotic systems and emerging technologies should be conducted. The maturity, reliability, and scalability of these technologies concerning agricultural applications should be evaluated. This analysis can help identify gaps, guiding research efforts, and informed decision-making when selecting suitable technologies for integration.

All in all, by addressing the limitations and implications, the roadmap can be further developed into a more actionable plan for implementing robotics in agriculture. By adhering to these recommendations, a revised roadmap could further advance the integration of robotics and technology into agriculture in the Netherlands.

CHAPTER 13

Reflection

This section further details my personal reflection on the design process undertaken for this research project. Further recommendations on this study are described as well.

The project began with a literature research to understand the context of the agriculture industry. However, farm operations are complex systems affected by many variables. Conducting visits and interviews with so many people provided invaluable insights, gaining practical understanding that theories alone could not provide, which offered many lessons.

This roadmapping project allowed me to apply my education and skills at the intersection of design, strategy, and futures thinking. As the designer of this roadmapping process, my role was to be a facilitator that explores the integration of robotics in a neutral, open-minded manner while being empathetic to diverse perspectives. With an affinity for food production and sustainability, I sought to identify approaches that could benefit all stakeholders and the environment. Positioning myself as a designer without any prejudice required cultivating a shared understanding. This approach opened doors for me to explore new methods.

Adopting a helicopter view from above the individual interests, my role involved synthesizing perspectives from farmers, researchers, policymakers and more to envision balanced pathways forward. Active listening was needed from my standpoint as a designer outside any particular agenda to understand the real problems. Translating complex issues into visualizations helped me in my role as interpreter between specialized domains. It would have been nice to have been a facilitator for a workshop with a large amount of participant, however, that was something not possible during the project.

Overall, taking a human-centered approach asks for a responsible designer, seeking the future through critical thinking. While technologies will progress regardless, my aim as designer was to shape outcomes towards mutual benefit through participatory design.

Further reflection on my findings and interests, for future research it is possible to conduct continuous monitoring and adaptation of the roadmap. A robust monitoring and evaluation system could be implemented to assess the impact of robotics integration. Feedback from farmers, stakeholders, and end-users could be regularly gathered to evaluate the effectiveness of robotic systems and the implemented roadmap. Based on this feedback, strategies should be adapted and refined to address emerging challenges and seize new opportunities. Continuous monitoring keeps the roadmap dynamic and responsive to evolving agricultural landscapes and technological advancements. More in depth stakeholder involvement would also provide more clarity within the roadmap.

Further development of speculative toolkit can be done, the speculative toolkit introduced in this research could be further refined and expanded. The toolkit could serve as a dynamic resource, allowing for the exploration of various scenarios, critical thinking, and their implications for agricultural practices. Regular updates and improvements can lead to its relevance and applicability as technology evolves. In future works more validation of various stakeholders could be gained with the toolkit that could not be completed within the scope of the project.

Moreover, research on the dynamics of innovation systems within the agricultural sector should be conducted. The role of roadmaps in shaping these systems, along with their reliability as guiding frameworks for technological advancements, should be explored. This research will provide valuable insights into the effectiveness of roadmaps and their impact on fostering innovation within the agricultural domain.

Following, in depth business models tailored to the integration of agricultural robotics should be explored and developed. Various economic factors, such as cost-benefit analyses, return on investment (ROI) calculations, and market dynamics, should be considered. On the other hand, flexible business models that account for different agricultural sectors, scales of operation, and technological complexities should be developed. These models will assist farmers and investors in making strategic decisions related to the adoption of robotic technologies.

Lastly, further research should be allocated to relevant elements for sustainable agricultural practices. The dynamics of soil health, water management, and energy concerning robotic integration should be researched to understand the relationship between sustainability and automation. Additionally, the role of contractors in the adoption of robotic systems should be explored, examining their influence on technology uptake, operational efficiency, and collaborative opportunities within the agricultural ecosystem.

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