connected system
FERMENTOR
sustainable approach for innovating small farms

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PIC4SeR

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Camilla Quarato

“Machines that fit the human environment, instead of forcing humans to enter theirs, will make using a computer as refreshing as taking a walk in the woods.”

M. Weiser

ABSTRACT

#agriculture4.0 #systemicdesign #viticulture #IoT #wineproduction #smallfarms

The topic chosen for my dissertation deals with the field of agriculture 4.0, an evolution of precision agriculture that incorporates the use of robotics and artificial intelligence, among other new technologies. This thesis has been developed in collaboration with Pic4Ser (Polito Interdepartmental Centre For Service Robotics) a research centre of Politecnico di Torino.

The first section is about future trends of agriculture and state-of-the-art new technologies. A categorisation was done among monitoring tools, operating tools and integrated tools.

In the second section, some reflections about agriculture 4.0 and its adoption are illustrated. The role of the farmer is changing, new skills and new job opportunities are emerging. Advantages brought by the aid of innovative methods are promising but great attention must be paid to the transition of family farms, referred to here as small agricultural holdings. Some design guidelines were developed with the aim of creating a sustainable path towards agriculture 4.0.

In the third section, small viticulture companies of Piedmont territory were investigated in order to explore the authenticity of local production. The analysis of a case study has been essential to get an overview of the context. Moreover, the relationships between actors and regulations were analysed in depth, considering the network of “Regione Piemonte”, consortia, agronomists and farmers.
From a deep analysis of wine companies, two main processes have been identified: viticulture and vinification. The first one regards the vine cultivation cycle, while the second one concerns the wine production process, from vintage to bottling. After a comparison between these two fields, the latter has been identified as a project area because of its higher percentage of human expertise, fewer variables and lower external constraints. In addition, the wine production process has become an intervention point for enhancing communication to consumers.
The cellar is the physical place where wine is processed. In small companies, it is a restricted area in which an oenologist and a few employees direct the entire process. The main problems encountered here are related to management and control over production. Indeed, when different wine typologies are produced at the same time, great attention must be paid to process overlaps. In addition, monitoring of chemical reactions and wine composition under the supervision of an expert is essential.
Therefore, the aim of my dissertation has been to develop a decision support system (FerMentor) to increase the oenologist’s control over winemaking processes, fermentation in particular. A real-time overview of the fermentation process can assist problem solving, decision-making and consequently increase output quality.
The system that has been developed consists of a network of connected sensors implanted on each fermentation tank. User Experience (UX) and User Interaction (UI) have been studied in order to make the oenologist feel in control of the process without interfering with the routine.
Moreover, a mobile app has been designed for the purpose of clearly showing information, suggestions and data history to offer remote control with notifications and alerts.
A functional prototype based on Arduino has been built. It gathers data and sends it to a web page, making a motor vibrate when problems are detected.
The prototype and the app mock-up have been tested on two wine farms. There, the focus of the test was the quality of the interaction between the oenologist and the system in order to verify whether it is fluid, natural and stimulating.

The scope of this project could be expanded and FerMentor could be tested long term to understand if it could bring effective advantages for small wineries’ management. In addition, the growing trust and interest towards new technologies should be verified after a familiarisation with the FerMentor connected system.

ABSTRACT

#agricultura4.0 #designsistemico #viticoltura #IoT #produzionevino #piccoleaziendeagricole

L'argomento di tesi scelto riguarda l'agricoltura 4.0, un'evoluzione dell'agricoltura di precisione che integra l'utilizzo di numerose tecnologie tra cui la robotica e l'intelligenza artificiale. La tesi è stata svolta in collaborazione con Pic4Ser (Polito Interdepartmental Centre For Service Robotics), un centro di ricerca interdipartimentale del Politecnico di Torino.

La prima sezione tratta i trend futuri dell'agricoltura ed offre uno stato dell'arte delle nuove tecnologie. Viene inoltre presentata una categorizzazione tra strumenti di monitoraggio, strumenti operazionali e strumenti integrati.

Nella seconda sezione sono illustrate alcune riflessioni riguardo all'agricoltura 4.0.
Il ruolo dell'agricoltore sta cambiando e nuove competenze e opportunità lavorative stanno emergendo. I vantaggi apportati dall'aiuto di metodologie innovative sono promettenti, ma una particolare attenzione deve essere posta sulle transizioni di aziende agricole di piccole dimensioni. Dunque, alcune linee guida sono state delineate al fine di creare un sentiero sostenibile verso l'agricoltura 4.0.

Il terzo capitolo analizza le piccole aziende vitivinicole del territorio Piemontese, allo scopo di esplorare la genuinità della produzione locale. L'analisi di alcuni casi studio è stata essenziale per acquisire una conoscenza generale del contesto. Inoltre, è stato possibile approfondire le relazioni tra gli attori e i flussi di regolamentazioni a partire dalla Regione Piemonte, dai consorzi e dagli agronomi, fino all'agricoltore.
Da un'analisi approfondita delle aziende vitivinicole, sono stati definiti due processi: la viticoltura e la vinificazione. La prima riguarda la coltivazione della vite, mentre la seconda consiste nella produzione del vino. Dopo un confronto tra i due campi, il secondo è stato selezionato come focus progettuale. La vinificazione infatti contiene una maggiore componente di competenza umana e meno variabili e vincoli esterni. Inoltre, il processo produttivo del vino può diventare un punto di intervento per migliorare la comunicazione al consumatore.

La cantina è il luogo in cui il vino viene lavorato. Nelle piccole aziende, essa è un'area ristretta in cui un enologo e pochi cantinisti dirigono l'intero processo produttivo. I principali problemi incontrati riguardano la gestione e il controllo della produzione. Infatti, quando diverse tipologie di vino vengono prodotte simultaneamente, grande cautela deve essere prestata per evitare sovrapposizioni. Anche il monitoraggio delle reazioni chimiche e della composizione del vino sono punti delicati.

Riguardo al processo produttivo, è stato progettato uno strumento per il supporto decisionale (FerMentor), al fine di aumentare il controllo dell'enologo sulla lavorazione del vino e in particolare sulla fermentazione. Una visualizzazione in tempo reale dell'andamento può infatti migliorare le capacità di problem solving e di decision making, provocando un miglioramento della qualità del vino e del lavoro dell'enologo.

FerMentor consiste in una rete di sensori impiantati in ogni vasca e connessi tra loro.
La User Experience (UE) e la User Interface (UI) sono state studiate in modo da offrire il comando del processo produttivo all'enologo, senza contrastare con la routine del suo attuale flusso di lavoro.
Inoltre, un'app mobile è stata progettata allo scopo di mostrare chiaramente le informazioni raccolte, suggerimenti, data history e la ricezione di notifiche in remoto.

Infine, è stato realizzato un prototipo funzionante basato su un Arduino. Esso raccoglie alcuni valori dal liquido, li invia ad una pagina web e causa una vibrazione su un motore quando rileva problemi tra i parametri.
Il prototipo e il mockup dell'app sono stati infine testati in aziende vitivinicole, per verificare la qualità dell'interazione tra l'utente finale e il sistema.

Un monitoraggio su lungo termine dell'applicazione di questo progetto sarebbe utile per verificare l'apporto di vantaggi significativi nella gestione di piccole aziende vitivinicole. Inoltre, a seguito di una familiarizzazione con FerMentor su lungo termine, bisognerebbe testare anche l'incremento di fiducia e interesse nei confronti delle nuove tecnologie.

1 CHAPTER
THE FUTURE OF AGRICULTURE

This first chapter illustrates the future trends and challenges of agriculture. Some initiatives between States are presented with the aim of showing the growing interest towards a more sustainable approach to agriculture.
A state-of-the-art review of innovative technologies is listed in order to help the reader to better understand the context of this research.

1.1 DEFINITION OF AGRICULTURE

Agriculture (from the Latin: *ager* meaning “field” and *cultura* meaning “growing”) is the cultivation and breeding of animals, plants and fungi for food, fiber, biofuel, medicinal plants and other products used to sustain and enhance life.
There are five main partitions of agriculture (Branches of Agriculture, 2013):

Crop production
Arable farming, field crop: annual crops like cereals, pulses (garden peas), perianal crops like coffee, tea, sugarcane.
Horticultural crops: pomology (fruits), olericulture (vegetables), floriculture

Livestock production
Cattle; poultry farming (chicken, goose, turkey, duck, pigeon etc.), pig farming; apiculture; aquaculture (fish).

Forestry

Agricultural economics
Use of scarce resources, maximizing output while minimizing costs.

Agricultural engineering
Use and maintenance of farm tools, machinery and structures.

From here on, the term agriculture will essentially refer to crop production, read as food and human livelihood.

Chapter 1. THE FUTURE OF AGRICULTURE

1.2
FUTURE TRENDS & CHALLENGES

Despite the past, in the last ten years agriculture has faced some changes that are conditioning its appearance as we imagine it in the near future. These changes are influencing food security, poverty and the overall sustainability of food and agricultural systems. Specifically, it is possible to identify three key forces: the increase of human population, consequent rising meat and dairy consumption and biofuel consumption.
As FAO (Food and Agriculture Organization of the United States) illustrated, some future trends have been identified and relative challenges have been analysed (The future of food and agriculture: Trends and challenges, 2017). Those which were found more relevant are set out below.

TRENDS

Population growth and dynamics

While today the world's population is 7.5 billion, in a future 2050 a rise of 25% is expected for a total of 9.5 billion people.
Recent studies have shown that global crop production ought to increase by 60%–110% by around 2050 to match the nutritional needs of the growing population (Bruinsma, 2012). This includes a 77 percent increase in developing countries and a 24 percent increase in developed countries.

Moreover, urbanisation has been accompanied by a transition in dietary patterns and has had a great impact on food systems. The world's average daily calorie availability is predicted to grow by about a 10 percent over its current level. In particular, diets are shifting towards more livestock products, vegetable oils, etc. and away from staples such as roots and tubers.
This prediction leads to three main consequences: more pressure exerted on natural resources; big portions of our actual arable land devoted to animal feed; fewer people working in agriculture and more in food processing and secondary sectors.

Another important aspect is that the world is likely to not only be more populous and urban, but also demographically older. This tendency could be unsustainable especially in low-income countries that may grow old before they can increase food supply, heathcare and other services.

Economic growth

The FAO report argues that, despite this rising demand, crop production growth is seen to decelerate in all regions and especially in developed countries. The events that are hampering this growth are several: food losses, food waste, the spread of diseases and pests as well as the degradation of natural resources.
Furthermore, the most valuable projected growth in crop production would come from intensification in the form of yield increases and higher cropping intensities.

Climate change

Natural resources for agriculture are expected to become even more scarce by 2050. An intensified competition for these resources could degrade the environment, leading to an overexploitation and unsustainable use and creating a loop that would trigger further degradation. Among the most visible manifestations of this degenerative trend are deforestation, water scarcities and land degradations. Indeed, almost 33 percent of arable land suffers from moderate to high degradation.
In this context, it would become harder and harder for farmers to improve their livelihood and escape poverty. Especially taking into account that the additional land available is not suitable for agriculture and expanding the agricultural area is not the right solution.

	1961-2007	1987-2007	1997-2007	2005/2007 -2030	2030-2050
World	2.2	2.3	2.3	1.3	0.7
Developing countries	3.0	3.1	3.0	1.4	0.8
idem, excl. China and India	2.8	2.8	3.2	1.7	1.0
Sub-Saharan Africa	2.6	3.3	3.0	2.4	1.9
Latin America and the Caribbean	2.7	2.9	3.7	1.7	0.7
Near East / North Africs	2.9	2.5	2.4	1.4	0.9
South Asia	2.6	2.4	2.1	1.5	0.9
East Asia	3.4	3.6	3.2	1.1	0.3
Developed countries	0.8	0.4	0.5	0.8	0.3
44 countries with over 2700 kcal/person/day in 2005-2007*	2.6	2.9	2.1	1.1	0.4

*Accounting for 57 percent of the world population in 2005/2007

Figure 1.1 Annual crop production growth (percent p.a.). (Data source: FAO)

CHALLENGES

All the quoted trends pose a series of challenges to the food system and agriculture.
Innovative systems and organisation are needed in order to enhance sustainability of food production and agriculture, while also increasing productivity. Indeed, intensive farming cannot be considered a solution any longer since sustainability is not taken into consideration.
On the contrary, opportunities do exist to increase production and respond to increasing food demand through a more efficient management of input and resources. Extensive solutions can preserve and enhance small-scale farms and their livelihood while, at the same time, avoiding exploitation.
These realities must be communicated in order to build resilience to future problems such as climate change. This can be done by transitioning towards a sustainable production system that is based on the principles of agriculture 4.0. A holistic approach is extremely important to guide this transformation.

Initiatives

Some worldwide initiatives have been started with the aim of preparing the ground for sustainable development.

For instance, the United Nations approved in 2015 the "2030 Agenda For Sustainable Development". This Agenda is described as a "plan of action for people, the planet and prosperity". Its goals regard a response to climate change, the ending of problems related to wellbeing, poverty and hunger, sustaining natural resources and supporting food and agriculture. The latter is one of the core ideas of the Agenda, that aims to develop a sustainable transition with particular attention for least developed countries, in order to double productive capabilities by 2030 (Transforming our world: the 2030 Agenda for Sustainable Development, s.d.).
All seventeen goals stated by this initiative are listed in the following infographic image.

Another initiative at European level is Horizon 2020, started in 2014. It is the "biggest EU Research and Innovation programme ever with nearly €80 billion of funding available over 7 years" as the European commission states on its website (Horizon 2020, s.d.).
The main goal of this initiative is to improve economics and create jobs, through the adoption and development of technological innovations. Horizon 2020 comprises seventeen thematic sections and its main focus areas are:

- Building a low-carbon, climate resilient future;
- Connecting economic and environmental gains – the Circular Economy;
- Digitising and transforming European industry and services;
- Boosting the effectiveness of the Security Union.

Specifically, a section of the programme concerns agriculture and environments with the scope of reducing environmental degradation and enhancing ecosystems.
The initiative work programme identified three priority areas that deal with preservation of biodiversity and traditional agricultural landscapes, management of water, reduction and reuse of waste, Bio-economy and sustainable food security (The European Commission's priorities, s.d.).

Figure 1.2 Sustainable development goals.
(Image: UNICRI)

1.3
AGRICULTURE DEVELOPMENT

This chapter presents a brief history of agricultural development and introduces the key concept of "agriculture 4.0", "precision agriculture" and "digital agriculture". The categorization described has been identified by CEMA, a Belgian company that works on legislation and regulatory frameworks for the European agricultural machinery industry (Digital Farming: what does it really mean?, s.d., p. 8 - 9).

AGRICULTURE 1.0

This first period in agricultural history goes back to the early 20th century. The situation was characterized by a labour-intensive system agriculture with low productivity. Essentially, the labour of several small farms was sufficient to feed the population, but it required a third of the population to be employed in the primary agricultural production process.

Figure 1.3 Rural Midwest farm life in the early XX century. (Image: Iowa Public Television)

AGRICULTURE 2.0

This second farming phase began in the late 1950s and it is commonly known as "The Green Revolution". In this period, new agronomic management practices were applied. Among them there were supplemental nitrogen and new tools like synthetic pesticides, fertilisers and more efficient and specialized machines. These innovations allowed the human workforce to be reduced by taking advantage of relatively cheap inputs.
As a result, yield potential increased significantly as well as returns to scale at all levels were registered.

Figure 1.4 Intensive crop production. (Image: H. Sarah, CC BY-NC-SA)

AGRICULTURE 3.0

The third phase is associated with the advent of "Precision Farming" and started once military GPS signals were made available for public use. This innovation led to an improved accuracy of all operations by managing in-field variations instead of considering the field as a whole. The aim was to provide exactly what a single plant needed, optimizing inputs and reducing wastes of time, efforts and substances.

The entailed solutions concern the following fields:

Guidance: since mid-1990s early adopters were using GPS-signals for manual guidance. One particular application has been aerial spraying technology. There, the first automatic steering solution appeared in the late 90s. From that moment on, several accuracy improvements have been made.

Sensing and control: From 1990s, yield monitors based on GPS location appeared on combine harvesters. The first automatic Variable Rate Application (VRA) started at the same time. Data began to be gathered by yield monitors, overcoming the previous method of soil sampling.

Telematics: The first technology for monitoring vehicle fleets appeared in the early 2000s. It is based on cellular technology and leads to an optimization of logistic farm processes.

Data management: Several farming software programs have become widely available since the early 80s, at the same time of the birth of Personal Computer.

AGRICULTURE 4.0

A new improvement in Precision Agriculture can be recognized around the early 2010s based on the evolution of several technologies: cheap and improved sensors and actuators, low cost microprocessors, high-bandwidth cellular communication, cloud-based ICT systems, Big Data Analytics, IoT and Artificial Intelligence (AI).

Agriculture 4.0 is more than just precision farming; it also involves digital evolution, robotics, artificial intelligence and machine learning. Moreover, it blends technology with other complementary social phenomena.
These phenomena can be summarised as follows:

Combination and coexistence of physical products and non-physical services: together with technologies and machinery, data and information gain more and more importance. In fact, algorithms can transform data gathered into valuable information, providing processes with a means of optimisation and reducing machinery vulnerability.

Emergence of agricultural ecosystems and holistic organisation: Digital platforms can now combine different information and data gathered in order to give the farmer a complete visualization of his/her field. Decisions are based on this new knowledge and choices are more accurate than ever. As a consequence, this support may bring financial advantages and improvements.

Cooperation among different actors in the same production chain: data and information can be shared among different actors in the same territory and production chain. This leads to a reduction of time and effort, while creating a strong network and added value.

1.3
AGRICLTURE 4.0: PRECISION FARMING, DIGITAL FARMING & SMART AGRICULTURE

The concept of Agriculture 4.0 is highly dynamic. While it is possible to define a starting point of this phenomena, it is impossible to know where it could lead and what innovations could be next. The potential is huge; applications are spread all over the world and guidelines for future developments are only beginning to take shape. In order to better understand what is meant for Agriculture 4.0, it is necessary to adopt some key concepts that are linked together under this big phenomenon. Presently, they occur in a sequence in which the previous concept is included in the subsequent one. In what follows, these concepts are listed and explained.

PRECISION AGRICULTURE

Precision Agriculture (PA, Precision Farming) has been a farming revolution triggered by the adoption of new technologies: satellites, high precision positioning systems, smart sensors and a range of IT (information technology) applications combined with high-tech engineering (Whelan).

All aspects of the environment such as soil, weather, vegetation and water change place to place, depending on their position, time and external agents. PA technologies allow for the precise management of all variations inside a defined area by understanding them and predicting future behaviours. In this way, it is possible to divide portions of a field with the same characteristics and to receive detailed information about all sections individually.

The following definition comes from the US House of Representatives (US House of Representatives, 1997) (Whelan, p. 2):
"Precision Agriculture is an integrated infor-

mation- and production-based farming system that is designed to increase long term, site-specific and whole farm production efficiency, productivity and profitability while minimizing unintended impacts on wildlife and the environment".

This definition explains that PA can be considered not only as individual field management, but also as a "whole farm" management system. Moreover, it can be applied in all kind of agricultural production systems, from crop production to livestock industries, forestry and so on.

The focus of Precision Agriculture is mainly on decision making, with the aim to provide economic, environmental and social benefits. The main objectives of this strategy are:

Optimisation of production efficiency: different management of field areas that have different characteristics and variables can optimize production quantities;

Optimisation of quality: site-specific data collection allows the farmer to treat plants or field areas optimally, giving exactly what each needs. Tailored inputs will impact quality as well as quantity;

Minimisation of environmental impact: when better management decisions are being made, there must be a decrease in the loss of any applied detrimental input to the environment. Moreover, since the amount and location of any input are mapped and recorded, compliance with environmental regulations could be more efficient;

Minimisation of risk: PA grants a precise response to environmental needs. Predictions are essential to minimise income and environmental risks;

Decrease costs: Tailoring inputs allow a better management of the economic flow and reduce wastes.

The most common technologies used in Precision Farming practices can be divided into these categories (Precision Farming: key technologies & concepts):

High precision positioning systems: like GPS, these technologies provide navigation and positioning capabilities. The system records the position using the geographic coordinates of latitude and longitude;

Geomapping: maps that show nutrient levels, water level etc. as graphic visualizations that give precise information about the field;

Sensors and remote sensing: they can collect different kinds of data locally or from a distance. They can be implanted on the soil or over machinery;

Integrated electronic communications: machinery and equipment can communicate and exchange data and information.

Variable rate technologies: adaptation on parameters on machinery or equipment depending on characteristic variations of precise spots of land.

This new farming system has brought several advantages to farm administration and has been considered an evolving reality for some time. PA has now reached a point in which it is possible to collect huge quantities of data, in an increasingly inexpensive way. Furthermore, now small processors can read and use this information to control equipment and machinery. This is the moment where we are witnessing a transition and upgrade to Digital Agriculture.

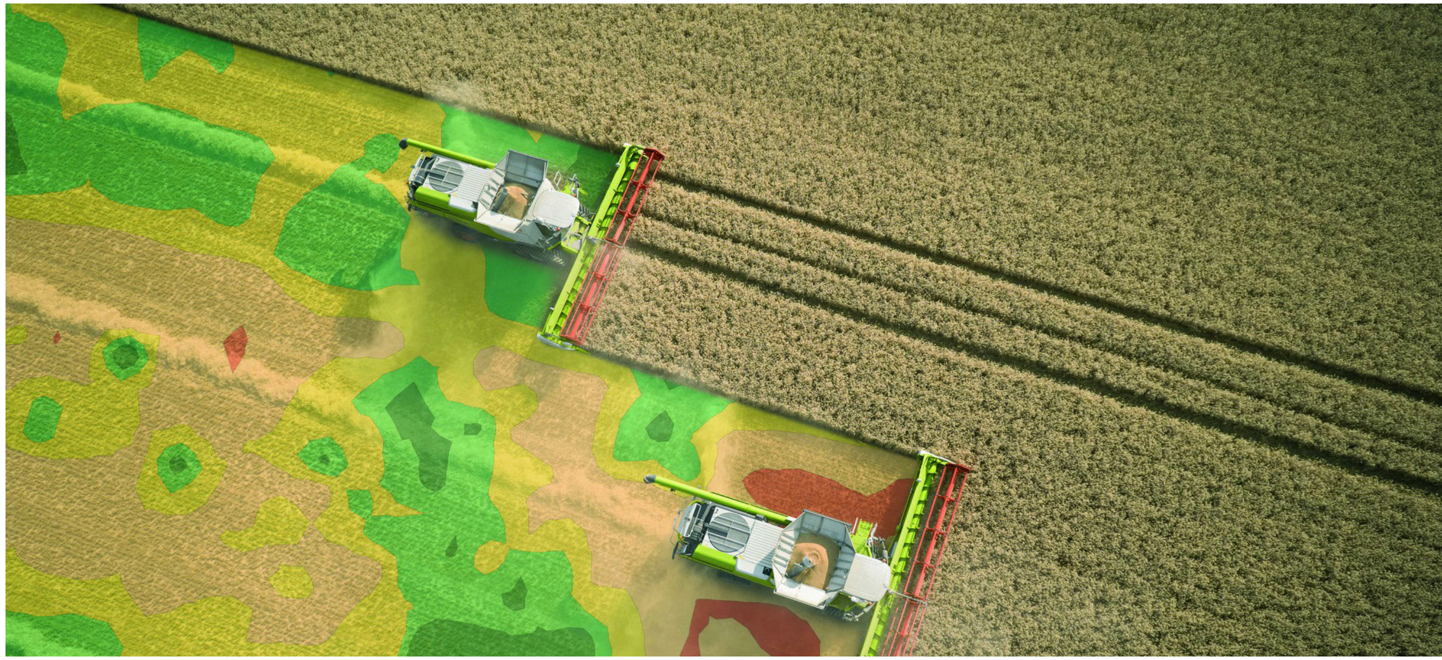

Figure 1.5 Precision agriculture, mapping field
(Image: Qaros)

DIGITAL AGRICULTURE

Precision Agriculture caused some implementations regarding site-specific monitoring, accuracy of operations, data management and understanding of in-field variations. Digital agriculture may be considered an evolution of PA, in the form of a connected, knowledge-based system. It makes use of its technologies and, in addition, employs intelligent networks and data management tools (Digital Farming: what does it really mean?, s.d., p. 1 - 2).
In Digital Agriculture, data is the key ingredient and its management is of a fundamental importance. In fact, the aim is to create considerable added value from data that is already available by combining them.
In this context, the Internet of Things (IoT) offers great opportunities to build knowledge-based systems. The term refers to a world of connected devices networked and equipped with sensors and software that allows connection, analysis and data exchange.
Data is gathered from this network, stored

in a cloud and accessed by the farmer via Internet or mobile app. In some cases, information is visualized remotely thanks to the system connectivity.
Since sensors may be deployed to the ground, in water, in vehicles etc., some IoT applications can be environment and soil monitoring, vehicle tracking, storage monitor and so on. (Christopher Brewster, 2017, p. 1 - 2)
The main advantages brought by data management are listed below:

Improvement of processes: analysing data and merging them allows us to gain a better comprehension of process management. The current operating situation can be evaluated and better controlled. Farm activities are better planned;

Optimisation of inputs and outputs: data knowledge and usage can enhance the performance of inputs and outputs. The organization of consumptions is improved and input and output losses are limited;

More decision support: data processing and analysis ensure more relevant decision making, especially when data gathered on the field is combined with external data (e.g. weather);

Data exchange: exchanging data also creates a network of external partners where knowledge is the sum of all data exchanged and compared.

Figure 1.6 Digital technologies and analytics insights.
(Image: Accenture)

The added value that Digital Farming brings to end customers is certainly the larger information- and knowledge-based data obtained from sensors, machinery and other sources. One of the most important benefit is that data can be gathered automatically and no additional efforts are required from users. Moreover, data mobility in increased since information is available everywhere and can be shared to other parties. Finally, decisions over daily activities or risky situations are better supported by consistent data and data portals, where all information is stored and ready to be visualized.
In the end, farmers will use equipment that is better suited to the job, more productive, provides optimisation, saves time and reduces input costs.

Nowadays a growing number of farmers are starting to adopt data-driven innovations including IoT and digital technology. More and more connections are beginning to take shape among parties and these connections are becoming smarter and branching. Machines and equipment can connect to each other and receive additional external information. Finally, all this data is then stored in cloud-based farm management software.
Digital Agriculture is paving the way for a further evolution of farming that faces the advent of unmanned operation, automated machines, robotics and artificial intelligence.

SMART AGRICULTURE

The boost of Digital Agriculture has opened up a wealth of new opportunities related to data and technology. Remote sensors, satellites and UAVs (unmanned aerial vehicles also known as drones) are now able to gather and collect a vast amount of data. Thus, this farm data is becoming both richer and more robust. Their availability and their recognised potential are paving the way to develop and deploy Artificial Intelligence (AI) in agriculture (Rakestraw, 2017).

As the Encyclopedia Britannica states, "Artificial Intelligence (AI) is the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings."

A machine that is powered by Artificial Intelligence can perceive its environment and, through a certain capacity of flexible rationality, act to address a stated goal related to that environment.
The next stage of AI is machine learning. The concept of machine learning simulates how the human brain actually works. The principle is to program software to recognise patterns so it can learn how to respond appropriately. It improves in its ability to address problems and goals as the amount of data it receives increases. Specifically, the software can categorise similar sets of data into precise protocols, increasing its rationalising ability with each iteration. In addition, it learns to better predict a range of events.
Both Artificial Intelligence and machine learning offer several advantages if combined and employed in the agricultural sector. Indeed, technologies can enable algorithms to interpret the amount of data gathered as statistical data, extremely useful for farmers'

decision-making. These algorithms process data, learn and adapt depending on the nature of information.
The aim is that farmers can take advantage of artificial intelligence and machine learning to achieve the goal of better managing their fields through better-focused decisions.

The most popular applications of AI in agriculture can be grouped into three major categories (AI in Agriculture – Present Applications and Impact, 2017):

Agricultural Robots: several companies are developing and programming autonomous robots to handle essential agricultural tasks, reducing efforts and time. For instance, an autonomous robot could harvest crops at a higher volume and faster pace than human labourers;

Crop and Soil Monitoring: Computer vision and machine learning algorithms are being leveraged in order to process data captured by drones, satellites and/or software-based technology in order to monitor crop and soil health;

Predictive Analytics: Machine learning models are being developed to track and predict various events and activities that can influence field management such as changes in weather.

Figure 1.7 Robotic arm in a greenhouse.
(Image: Foodtank)

To further expand the concept of Agriculture 4.0, a second classification concerning tools is needed. Among this category it is possible to distinguish between operational tools, monitoring and mapping tools, and integrated tools. The first two categories may operate either alone or paired in the latter one.

OPERATING TOOLS

Operational tools are those that can perform tasks. They can be either guided by the user or unmanned. Additionally, they can be autonomous and perform the predetermined task independently, or semi-assisted with less autonomy.
Robots applied in agriculture are also called "Agbot" and use specialised tools and accessories, arms and hands to perform agricultural assignments. For crop farming, robots need to autonomously navigate their environment and perform actions at set locations. For instance, they are able pick a fruit, spray a pesticide, plant a seed, photograph a plant, or make a measurement.
IntoRobotics has inspired the following Agbot partition (Robots in Agriculture, 2018):

Automated harvesting systems: picking ripe fruit/vegetables, using computer vision and other technologies to detect ripeness and position;

Robots for weed control: detecting and eliminating different kinds of weeds. These robots can take decisions on the use of herbicides, fertilisers and pesticides;

Robots with autonomous systems for navigation in the fields: moving around the crop to perform some tasks. They can adapt to uneven and inconsistent terrains;

Robots mowing, pruning, seeding, spraying and thinning: various features allow robots to perform several precise tasks as transplanting plants, mowing lawn and applying nutrients;

Robots sorting and packing: detecting different stored products thanks to computer vision, performing palletising tasks, moving vegetables and fruits;

Agricultural robot platforms: hosting different equipment for agricultural cores and performing delicate tasks due to numerous attachments.

Figure 1.8 Asterix Project, mobile robot for weed control.
(Image: IntoRobotics)

In addition to robots, drones play a major role among operational tools.
Thinking about drones often recalls military weapons or surveillance tools. Harriman and Muhlhausen state that “Commonly referred to as an unmanned aerial vehicle (UAV), unmanned aerial system (UAS) or remotely piloted aircraft (RPA), a drone can also provide a low-cost and low-impact solution to environmental managers working in a variety of ecosystems” (Muhlhausenb, 2013).

In the agricultural sector, drones can perform some tasks such as crop spraying. They can fly maintaining the right distance from the crops to spray the correct amount of liquid/fertiliser, modulating spraying in real time assuring even coverage. This application leads to more precise functioning, reduces the amount of excess chemicals and is up to five times faster than traditional machinery.

MONITORING AND MAPPING TOOLS

As the name itself states, the first role of this tools category is to observe and track the environment and the activities that occur in it.
Sensors play a leading role in this category, since they can be put everywhere and even on advanced machinery as robots and aerial platforms. The following table sets out the most important sensors for the agriculture sector (Schriber, n.d.).

Optical Sensors: they use light to measure soil properties and measure different frequencies of light reflectance in near-infrared, mid-infrared, and polarized light spectrums. This sensor class has been developed to determine clay, organic matter and moisture content of the soil. An example of variables that can be aggregated and processed are soil reflectance and plant colour data;

Location Sensors: they collect signals from GPS satellites to determine latitude, longitude and altitude;

Electrochemical Sensors: they provide key information about pH and soil nutrient levels. Sensor electrodes work by detecting specific ions in the soil and gathering chemical data;

Airflow Sensors: they measure soil air permeability. Measurements can be made either at singular locations or dynamically while in motion. Airflow sensors detect the pressure required to push an arranged amount of air into the ground at a recommended depth. Different types of soil properties, such as compaction, structure, soil type, and moisture level, produce unique identifying signatures;

Dielectric Soil Moisture Sensors: they check moisture ranges by measuring the dielectric constant inside the soil. This constant is an electrical property that changes depending on the amount of moisture;

Mechanical Sensors: they measure soil compaction or “mechanical resistance.” The sensors use a probe that penetrates soil and records resistive forces by using load cells or strain gauges;

Agricultural Weather Stations: they are self-contained blocks that are placed at various locations throughout the field. These stations have a combination of sensors appropriate for the growing crops and regional climate. These units gather information such as air temperature, soil temperature, rainfall, leaf wetness, chlorophyll, wind speed, dew point temperature, wind direction, relative humidity, solar radiation, and atmospheric pressure. They are measured and recorded at predetermined intervals. All the data recorded is sent to a central logger.

Sensors can be implanted on the ground or above equipment and machinery. Among these supports there are traditional machines, drones and robots.

Computer vision allows robots to detect some characteristics of plants and the environment. This feature, in addition to algorithms of machine learning, provide vigorous maps and a wide range of useful information to the farmer.

As well as operational tools, drones may be used for crop monitoring, health assessments and soil and field analysis.
Until recently, the most advanced form of monitoring used satellite imagery. Unfortunately, this technique has several limitations regarding low precision, low quality, high cost and malfunctions due to bad weather. On the contrary, drones’ costs are lower, the

Figure 1.9 Cluster of sensors at WCREC (West Central Research and Extension Center). (Image: Nebraska Farmer)

efficiency is higher and the result is more precise because of the bird's-eye view and of the possibility to make selective interventions. Furthermore, UAVs are able to produce precise 3D maps allowing early soil analysis.
Finally, drones can help to assess a plant's health and spot infections and diseases. Scanning a crop using visible light (VIS) and near-infrared (NIR), light shows which plants reflect different amounts of light and illustrates plants vigour (I. Colomina, 2014).

Monitoring tools may be considered decision support tools. Essentially, they show the status of a variable. The farmer's decisions and actions are then assisted and built upon the knowledge acquired by these tools.

INTEGRATED TOOLS

This category includes both monitoring tools and operational tools in a system.
Since field management requires a huge number of performances and checks to be done, sometimes it is useful to merge different features in the same tool or task.
In particular, some services that offer several performances regarding both monitoring and practical assistance do exist.
For instance, a machine harvester can offer its service of efficiently harvesting a crop, autonomously moving between rows, while at the same time analysing proprieties of the field thanks to its sensors.
Usually these services are connected in a system composed of different intelligent equipment in order to offer a complete management tool.

1.4 STATE-OF-THE-ART TECHNOLOGICAL INNOVATIONS

In order to better understand the pace and scope of technological advancement in the agricultural sector, some examples of state-of-the-art worldwide innovations are presented and explained in the following section. Since most of the equipment available falls within the category of integrated tools, another kind of categorisation has been chosen; Specifically, technologies are depicted in accordance with the partition of crop production practices from preparation of the soil, to harvesting.

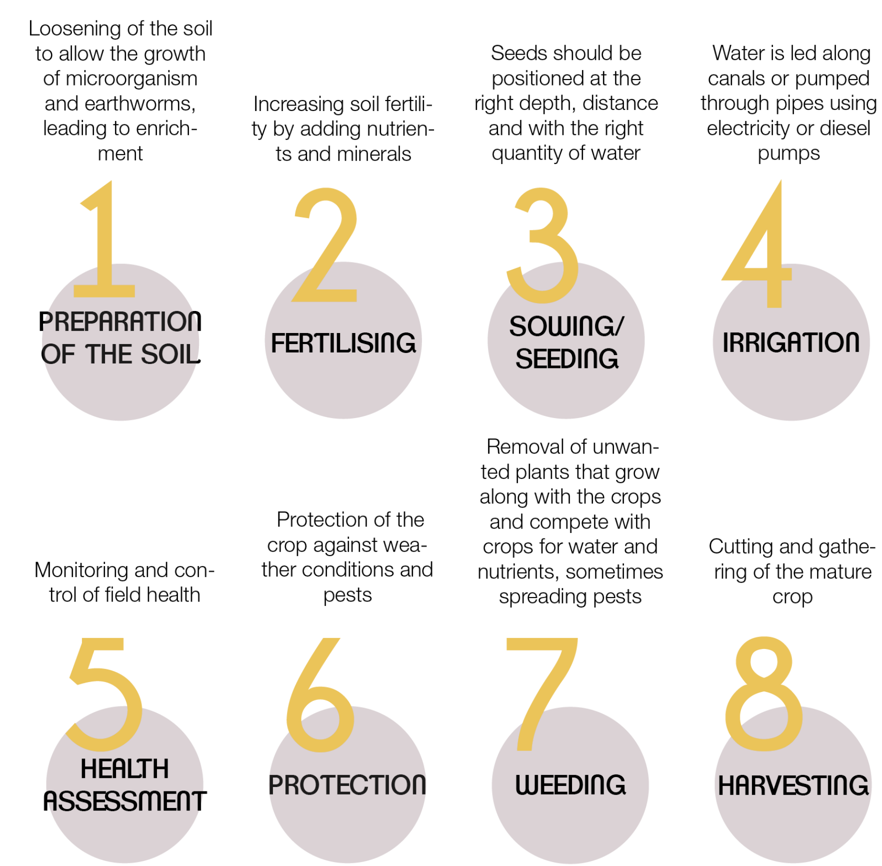

Figure 1.10 Crop production practices

PREPARATION OF THE SOIL-TILLING

Tilling operations consist of primary and secondary tilling. Primary tilling is a deep agitation of the soil that creates a rough surface, while secondary tilling is the opposite because it produces a smooth surface. A few examples of secondary tilling are: ploughing, harrowing, rototilling and cultivating. Soil preparation is a tedious and labour intensive process.

Trimble: Ag Field Solutions

Figure 1.11 AG Field Solutions for tilling. (Image: SITECH)

Trimble provides a full strip till/anhydrous solution to manage soil preparation and fertilizing. It is equipped with a system for automated guidance, software for creating prescription maps, and a variable rate application control system.
Steering solutions like Autopilot™ can be quickly installed from one vehicle to another, no matter which brand they are. Moreover, the system is equipped with T3™ sensors that calculate the position of the vehicle to help minimize skips and overlaps in areas characterized by rolling terrain, slopes, and rough ground (Tractor, Implement and Row Guidance Steering System, n.d.).

KUHN Farm Machinery: Smart Ploughing

This system uses a GPS-based feature that automatically lifts and lowers each individual plough into and out of the ground, aligned to each furrow.
KUHN filed a patent application for this system that won a silver medal for innovation at AGRITECHNICA 2017 thanks to its ability to ensure uniform ploughing across the full field width (Intelligent plough system brings precision farming to inversion cultivations, 2017).
The main advantages brought are a reduction of the number of times the tractor passes over the headland, reducing soil compaction, reducing jolts and bouncing as well as speeding the whole ploughing process.

Figure 1.12 Kuhn intelligent plough system. (Image: KUHN)

Case IH: Autonomous Concept Tractor

Figure 1.13 Case IH Autonomous tractor. (Image: Case)

This ACT is a cables tractor that offers more control, monitoring capabilities and cost savings while tilling, planting, spraying and harvesting. A remote supervision via tablet or computer is possible. Thanks to the use of radar and onboard video cameras, the vehicle can sense obstacles in its path and will stop on its own until the operator assigns a new path. In addition, the vehicle will stop immediately if the GPS signal or position data is lost, or if the manual stop button is pushed. All machine tasks can also be modified in real time with remote interface or automatic weather alerts (Bedord, 2016).

John Deere: Precision AG and automatic guidance

John Deere develops precision technology in the tractors, combines, sprayers, planters, hay, and tillage products the user already owns.
In field preparation, it controls input costs, reduces wastes and increases yield potential. The equipment needed consist of automatic command systems, machine vision and automatic guidance in defined paths.

Figure 1.14 John Deere AG tractor. (Image: Deere)

FERTILISING

Fertilising consists of the application of nutrients to the soil in order to set it up for seeding. Indeed, proper nutrition is essential for satisfactory crop growth and production. As Ross McKenzie states, the term fertiliser refers to “any compound that contains one or more chemical elements, organic or inorganic, natural or synthetic, that is placed on or incorporated into the soil or applied to directly onto plants to achieve normal growth” (McKenzie, 1998). The main plant nutrients include organic manures, plant residues, biological nitrogen fixation and commercial inorganic fertilisers.

Linak: Actuators for intelligent spreaders

Linak electric actuators can be integrated with almost any control system. Thanks to position feedback based on GPS tracking and soil quality data, the actuators allow the system to adjust spreading on the fly. This limits the pressure on the environment and saves money.
A close collaboration among LINAK and Sulky F&E has succeeded in automating all the control processes involved with fertiliser spreaders (Automation of Sulky fertiliser spreader, n.d.).

Figure 1.15 Linak actuators on a Sulky spreader. (Image: LINAK)

Smart: Fertilizer Management

Figure 1.16 Smart fertilizer management app. (Image: Smart)

This tool is a decision support platform for optimizing fertilizer use for agriculture. It enables growers to maximise crop yields, save costs and increase their profits. The platform supports over 250 different crops in a wide range of geography. Moreover, it is able to interpret soil test results to allow precise fertilizer application rates (Smart Fertilizer Management, n.d.).

Rauch: Agronator

Rauch (supplied under the Kuhn name outside Germany) has adopted the large eight-rotor drone developed by Agronator for spreading fertiliser. Flight time is up to 40 minutes using power from two lithium-polymer batteries. The weight is 80kg and it measures 4m in diameter. Furthermore, it can carry a payload up to 30kg. The main advantages brought are the ability to spread fertiliser regardless of ground conditions, following pre-programmed flight paths and the efficient working speed. Furthermore, the high degree of precision is claimed thanks to the global navigation satellite system (GNSS) guidance technology (Hill, 2017).

Figure 1.17 Rauch flying drone. (Image: Rauch)

IRRIGATION

The goal of intelligent systems that deal with the irrigation practice is to reduce water consumption and irrigate precisely in accordance with weather conditions and actual need.

Bosch: Aquazen smart irrigation controller

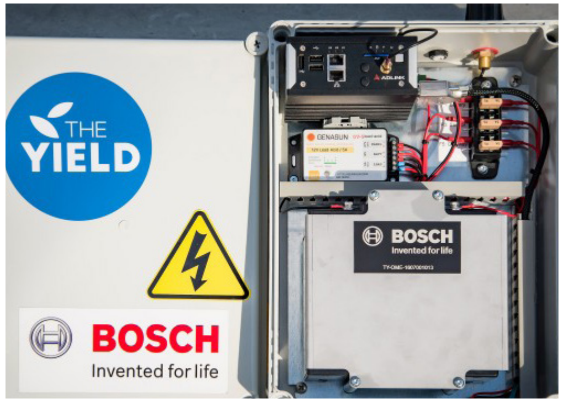

Figure 1.18 Bosch IoT platform measuring station (Image: Bosch)

Aquazen is an IoT-enabled, remotely controlled cross-platform system equipped with Big Data Analytics and Intelligent Irrigation Scheduling. It is accessible through both web and mobile applications.
The Bosch Internet Cloud (BIC) supports Big Data Analytics and aids lowering water consumption and energy consumption. On the other hand, the Intelligent Irrigation Scheduling collects and operates data through real-time sensors with the scope of increasing crop yield and decreasing fertiliser consumption. Furthermore, Aquazen has a large repository of data on models linked with on-

field irrigation water requirements that provides recommendations for efficient usage scheduling.

Cropx: Sensor set

CropX offers an integrated hardware and software system that tells when and how much to irrigate. Sensors are arranged in a station that measures soil moisture, temperature and electrical conductivity and sends that data to the cloud where it can be accessed from any mobile or fixed device. The installation of this station is “Do It Yourself” and the interface is intuitive (CropX, n.d.).

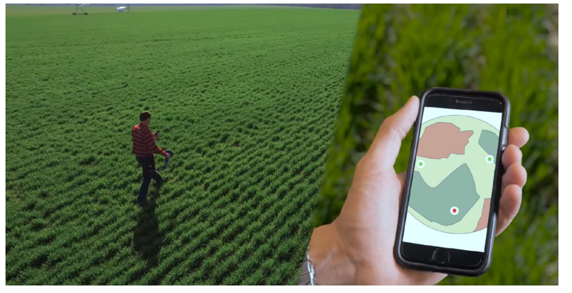

Figure 1.19 Cropx mapping field through app. (Image: Cropx)

PROTECTION

This category may be divided into two subcategories: protection against weather conditions and protection against pests. To address these two problems both weather forecasters and pest traps are illustrated.

Auroras: LoRaWAN

Figure 1.20 Weather station in a vineyard. (Image: Auroras)

The “WEATHER STATION LoRaWAN” is a versatile and rugged IoT (Internet of Things) device for continuous weather monitoring with long range data transmission. This weather station incorporates numerous sensors: rain sensor, to detect rainfall; anemometer, to measure wind speed and direction; air temperature sensor; air humidity sensor; dew point software sensor; wet leaf software sensor. The electronic components are protected in a waterproof box (IP65), resistant to weather conditions. Moreover, it is completed by a sun screen.
The weather data can be viewed via the web from any computer. A software application

can also analyse the data and send text messages or emails to alert the user of the occurrence of certain conditions. (Giordano, 2016)

Bosch, Deepfield Robotics: Sensor system

The system is composed of sensors that measure the amount of moisture in the soil and inform the grower if it is too dry. They also measure air temperature and humidity in order to calculate wet-bulb temperature. “If this temperature is zero degrees Celsius or below when the plants are beginning to flower, the grower has to cover the plants or take other steps to protect them from frost,” says Christian Glunk from Deepfield Robotics. (More sleep for growers: Bosch helps optimize the strawberry crop, n.d.)
Growers themselves can set the threshold values that will trigger an alert. For instance, in case plants are too warm, growers can remove the coverings to ensure the plants are properly ventilated.

Figure 1.21 Bosch Deepfield robot. (Image: Research Gate)

Bosch: Plantect

Figure 1.22 Bosch Plantect. (Image: Bosch)

Plantect is able to forecast plant diseases with 92-percent accuracy. The sensors are installed in the greenhouse in order to measure temperature, leaf moisture, sunlight, and carbon dioxide. Artificial intelligence analyses these values, combines them with weather forecasts, and sends warnings to farmers via mobile app.

Farmobile

Farmobile is a subscription service equipped with a small device (PUC) that can be installed on farm machinery. Once installed, it automatically collects real time data that can be visualized on the Dashboard, on desktop or mobile, anywhere, anytime. This makes it easy to share one's data with trusted partners, such as insurance agents or agronomists to get them the information they need, when they need it. (FarmMobile, n.d.)

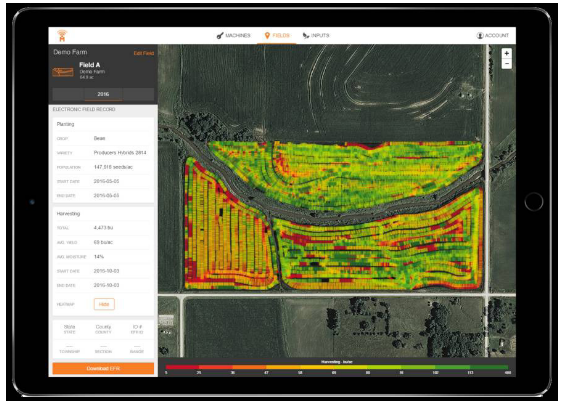

Figure 1.23 Farmobile dashboard heat map. (Image: CropLife)

FarmX

Figure 1.24 Farmobile visualisation tools. (Image: Farmx)

Service that helps growers avoid damage to their crops caused by frost. It includes local micro-climate sensing, leaf and bud frost, AI predictive software and mobile phone alerts. When an alert is sent, the grower can take preventative measures.
Some of the data measured includes: changes in canopy and identification of anomalies through GPS satellite; weather data with frost warnings; evapotranspiration; direct plant health; soil nitrate variances through Hi-Res Soil Sensors; flow and pressure.
Moreover, an advanced AI software allows to examine and solve inconsistencies in irrigation, control water pump, schedule irrigation (Farm(x), n.d.).

With regards to pest protection, most advanced technologies are about insect traps, insect previsions and monitoring.

Trapview: Insect trap

Figure 1.25 Trapview automated pests components. (Image: Trapview)

This trap design enables effective catching of targeted insects and automatically takes pictures of the captured pest. Each trap can cover 1 to 5 hectares completely autonomously without the need to refuel as it is powered by a solar panel and battery. Integrated GPRS and 3G connectivity allows automatic data collection without field visits from the farmer. The main advantages of this technology are the effectivity of capture, durability and resistance to light and water, and high resolution of images (TrapView, n.d.).

Spensa: Z-trap

Trap system composed of different units that can communicate with a cell tower, thanks to the integrated cell module.
Z-traps are equipped with the bio-impedance sensing technology that detects distinct insect species. It works thanks to electrical properties of biomaterials that measures how well the body impedes electric current flow. Every disruption in the electronic current means that an insect has entered the trap, attracted by a pheromone lure. Then, this disruption is analysed and used to evaluate which species came in contact with the device. Cellular communication technology is then used to count the number of insects in all units. Finally, all data collected is sent to an app for an easy viewing and reporting (Spensa, n.d.).

Figure 1.26 Spensa Z-trap pests trap. (Image: Spensa)

HEALTH ASSESSMENT

Health assessment is usually done with the NDVI (Normalized Difference Vegetation Index) equation and analysis. This method is applied to satellite imagery. The equation (NDVI = (NIR — VIS)/(NIR + VIS)) tracks the ratio of near-infrared (NIR) to red reflectivity of a plant. NDVI works because when light reaches a plant, certain wavelengths are absorbed while others are reflected. When a plant becomes dehydrated or affected by some disease, it absorbs more NIR rather than reflecting it. Then, looking at how NIR varies compared to red light provides an accurate indication of plant health.

Sentera: Integrated service

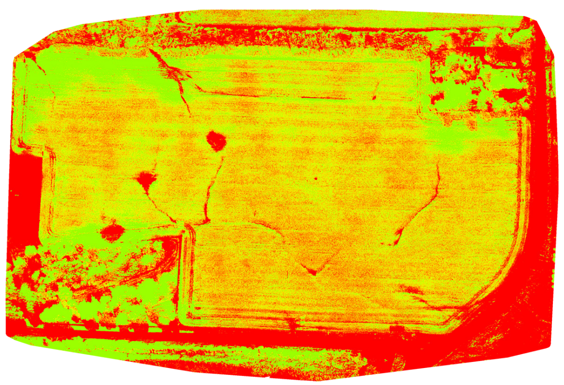

Figure 1.27 NDVI vigorous map.
(Image: Sentera)

Sentera drones, sensors, software and analytics allow farmers to see NDVI plant health values in real time. By flying the drone, data is gathered and uploaded to AgVault which supplies instant plant health maps. After recording data, ranges of NDVI values are mapped to a set of colours and the result is a visualization map: the "red-green" NDVI colour map. Since there isn't a standard colour map, it is possible to personalise, recolour, adjust, and change the palette dynamically (Taipale, n.d.).

The Copernicus Global Land Service (CGLS)

This service is a component of the Land Monitoring Core Service (LMCS) of Copernicus, the European flagship programme on Earth Observation. It produces a series of bio-geophysical products on the status and evolution of the land surface, at global scale, at mid- and low- spatial resolution. The outputs of this tool are used to monitor vegetation, water cycle, energy budget and the terrestrial cryosphere. Among all these applications, it provides a NDVI service used principally by the European institution

Figure 1.28 NDVI service.
(Image: CGLS)

for global crop monitoring and research institutions (Copernicus Global Land Service: Providing bio-geophysical products of global land surface, n.d.).

Agribotix: Drone NDVI service

Figure 1.29 eBee drone for Agribotix.
(Image: Agribotix)

Agribotix is an agriculture data-analysis company in Colorado that provides drone-enabled technologies and services for the agricultural sector. "Drones use near-infrared images to map patches of unhealthy vegetation in large fields, in order to reveal potential causes, such as pests or problems with irrigation" (King, 2017).
Agribotix is based on FarmLens™ NDVI Software Platform for monitoring crop health and supporting precision decisions in the field. Visualizations of the field health status are provided to the user in the form of colour mapping. All data is available on a digital report, readable on smartphone, tablet or computer. The company is now using machine learning to train its systems to differentiate between crops and weeds (Agribotix, n.d.).

WEEDING

Weeding innovations rely mostly on site-specific weed control techniques. To manage weeds on a subfield level, it is essential to measure their density variation. Once weeds are detected, control can be done either with herbicides or mechanically. With both techniques, site-specific control aims to reduce consumptions and augment adaptability to every crop.

John Deere: Blue river technology

This technology uses computer vision & machine learning to power the See & Spray equipment. Every plant is scanned to determine appropriate treatments for each. Moreover, machine learning is trained over massive libraries of plant images in order to teach the machine how to distinguish subtle differences between plants and weeds. When weeds are detected, robotic nozzles automatically target them as the machine passes by and they apply herbicides only where needed. Finally, the technology includes a second set of cameras and the ability to automatically check its work as it operates, gathering data so that its software can continue improving itself (Blue River Technology, n.d.).

Figure 1.30 BlueRiver seeing technology. (Image: TrattoriWeb)

University of Sydney's Australian Centre for Field Robotics: RIPPA

Figure 1.31 RIPPA weeding robot. (Image: Farmonline)

RIPPA (Robot for Intelligent Perception and Precision Application) is a prototype that aims to reduce pesticide use by delivering it only to the right spot in the quantity needed rather than spraying the entire field. Mounted on RIPPA is VIIPA™ (Variable Injection Intelligent Precision Applicator) used for autonomous spot spraying of weeds at high speed using a directed micro-dose of liquid.

HARVESTING

Harvesting is one of the most critical points for farmers. Indeed, speed, accuracy, and timing determine whether the harvest will be successful or not. Until recently, harvesting was the most burdensome and laborious activity of the entire growing season. Today, however, the task is being taken over by some of the most sophisticated farm machines that aim to save labour and time in addition to increasing efficiency.

Chapter 1. THE FUTURE OF AGRICULTURE

Claas: Combine Harvester Lexion 600

This combine harvester features a Telematics and telemetry system equipped with a receiver satellite plus module that gathers data from the machine and transmits data to a remote server. This data can then be consulted by the user, in order to know the harvester functional state and its position on the field. Consequently, the user can analyse data and make improvements concerning processes, harvesting techniques and logistics. A crop monitoring system, a position receiver, a volumetric sensor for grain flux and a capacitive moisture sensor are also provided. This sensor combination enables the farmer to know the precise quantity of grain and its moisture and the overall quality of the crop.
Additionally, this harvester may be combined with the AUTOpilot system, which allows the machine to operate autonomously (Advanced automation for LEXION 600, n.d.).

Figure 1.32 Claas harvester. (Image: Farm Trader)

Kormann et al.: Harvesting machine

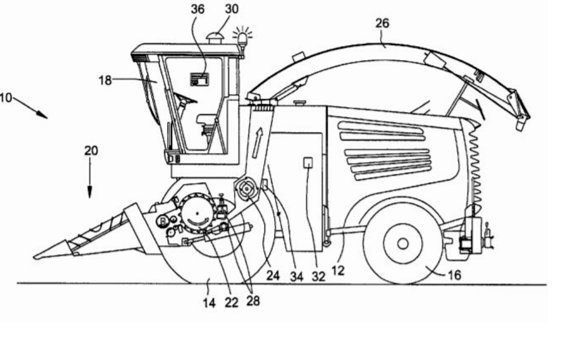

Figure 1.33 Harvesting machine drawing sheet. (Image: German Patent)

Combined with a measuring device for capturing the throughput of collected crop material (Germany Patent No. US 7,430,845 B2, 2008).
"It is proposed to make available a measuring plate having a surface disposed for being engaged by crop material, with the plate being supported by a solid body articulation." First, crop material is picked up and processed by the harvester, then the machine exerts a force and some torque on the measuring plate. A "laser interferometer or another optical absolute or incremental

distance measuring system" can then analyse the plate and grains above it. With this invention a mass flow rate can be captured with high resolution.

Sweeper: Sweet pepper harvesting robot

In the EU-FP7-project CROPS started in October 2010, extensive research has been performed on agricultural robotics (Intelligent sensing and manipulation for sustainable production and harvesting of high value crops, n.d.). The sweet pepper picking robots SWEEPER is one of these projects. It involves 6 partners from 4 different countries: The Netherlands, Belgium, Sweden and Israel.

This harvesting machine is equipped with a colour camera and a Time of Flight camera. The images of both cameras get recorded to have full information on colour combined with 3d data, so that the machine can recognise the state of ripeness and the exact position of the fruit.

With respect to end-effectors to detach fruits from the plant, two methodologies were developed and analysed: a gripper with an integrated cutting tool with fingers and a guide, and a cutting tool approaching the fruit from below (WP5: Sweet pepper – protected cultivation, 2015). Some further improvements are coming especially regarding this functionality.

Figure 1.34 Machine vision to regognise ripe peppers. (Image: Sweeper-robot)

Figure 1.35 Picking robot. (Image: Sweeper-robot)

2 CHAPTER

REFLECTIONS UPON AGRICULTURAL INNOVATIONS

This second chapter presents some reflections on how future agricultural trends are influencing farmers and their livelihood.
Some design guidelines have been researched in order to provide a sustainable approach for leading the transition towards agriculture 4.0.
Particular attention is paid to small realities, with the aim of respecting their traditions and values.

2.1
AGRICULTURE 4.0 ADOPTION & BENEFITS

According to a 2017 study by Maximize Market Research, the Smart Agriculture market is expected to reach $22.8 billion USD by 2026 up from USD $5.1 billion USD in 2016 at a CAGR of 18.2% (Smart Agriculture Market – Global Industry Analysis and Forecast (2017-2026), n.d.).

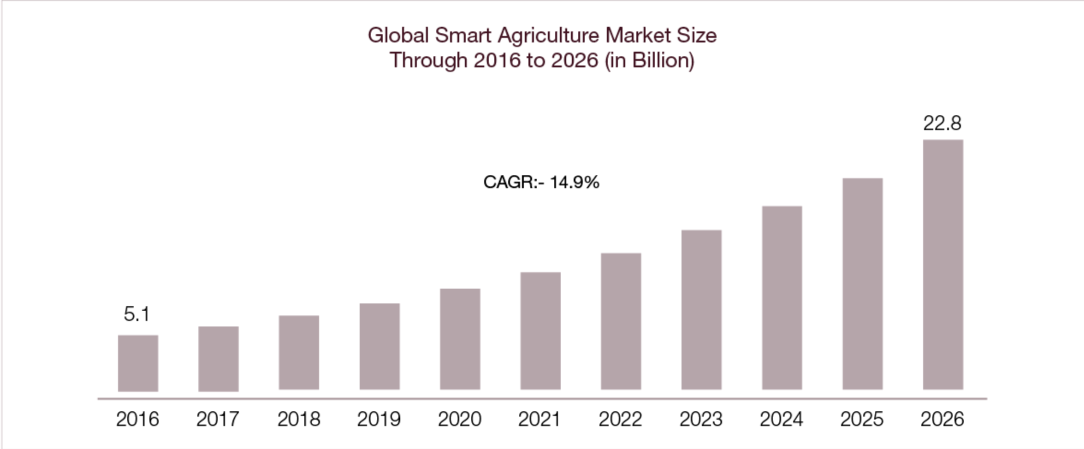

Figure 2.1 Global smart agriculture market size through 2016 to 2026.
(Data source: Maximize Market Research)

As the graph in Figure 36 demonstrates, the adoption will be massive especially in North America, Europe and the Asia Pacific region. Undeniably, farmers in developed countries are rapidly adopting smart agricultural practices and equipment with the aim of boosting their yield productivity and reducing agricultural losses (Smart Agriculture Market, n.d.).
Given all present technological innovations from unmanned monitoring drones to “seeing” harvesters, potential technical advantages can easily be imagined. The following list illustrates all potential benefits:

- Tasks may be less time consuming, less laborious and less repetitive;
- Energy consumptions may be reduced;
- Farmers' knowledge may improve thanks to data support;
- Farmers' quality of life may increase due to less physical effort needed and more free time;
- Food safety and plant health may augment.

However, despite all these opportunities, these technologies cannot be implanted overnight in the agricultural sector without reflecting on the ramifications. Specifically, considerations are needed in relation to the changing role of the farmer and the divergent impact over small and big companies.

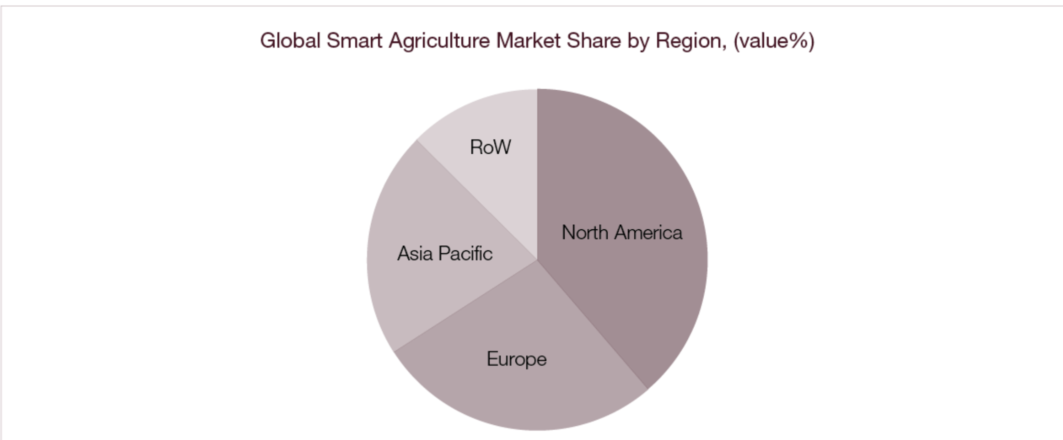

Figure 2.2 Global smart agriculture market share by region.
(Data source: Variant Market Research)

CHANGING ROLE OF THE FARMER

Analysing the Agriculture 4.0 trend from the point of view of the farmer sets out some food for thought. Key concepts are: the decreasing number of people employed in the sector, the ratio between young and old employers and the new skills required in order to accommodate the change.

Decreasing employment in agriculture

Max Roser states that "as countries develop, the share of the population working in agriculture is declining. While more than two-thirds of the population in poor countries work in agriculture, less than five percent of the population does in rich countries. It is predominantly the huge productivity increase that makes this reduction in labour possible" (Roser, 2018).

Graphs below illustrate the total number of people employed in the agricultural sector across selected European, American and Asian countries. Two range periods have been selected in order to better visualise the information: 1991-2017; 2006-2017.

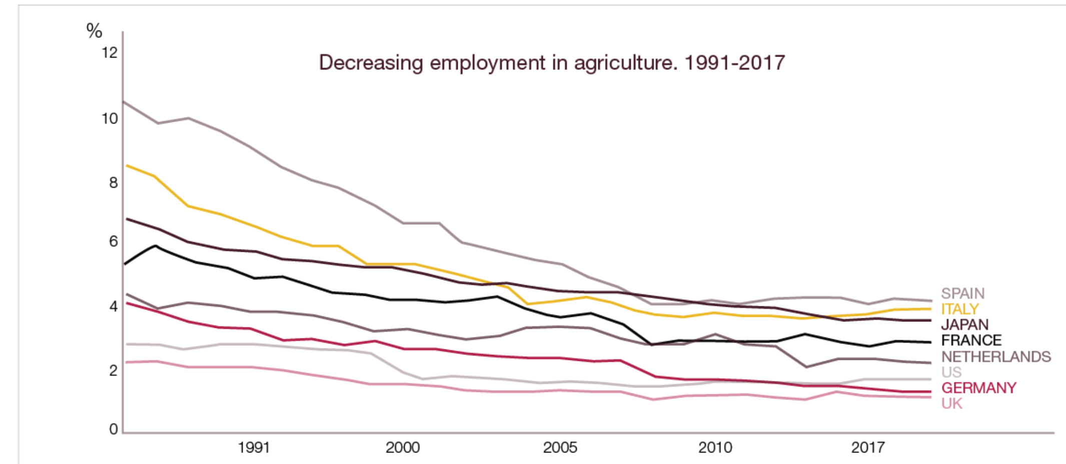

Figure 2.3 Decreasing employment in agriculture. 1991-2017.
(Data source: Our World in Data)

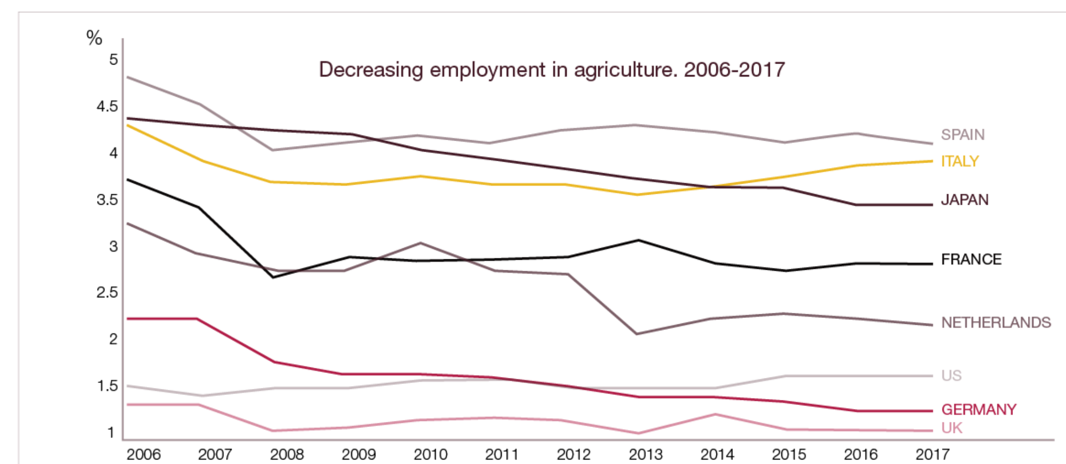

Figure 2.4 Decreasing employment in agriculture. 2006-2017.
(Data source: Our World in Data)

The World Bank claims that the total percentage of employers in agriculture has decreased from 43.28 percent in 1991, to 26.48 percent in 2017.

The promise of young employers

In addition to considering the number of farmers, it is important also to take into consideration the age of these employers and the proportion of young and old people in the sector.

The European Commission has stated in 2017 that “only 5.6% of all European farms are run by farmers younger than 35, while more than 31% of all farmers are older than 65” (Young farmers in the EU – structural and economic characteristics, 2017).

For the EU as a whole, the ratio of young (below 35) and old (above 65) stands at 0.18, indicating a rather old farming community. In fact, among the so-called market-oriented farms that are included in the FADN (thus excluding the smallest farms in each country), the average age of farmers is of 51.4 in 2013 in EU and even higher (58.3) in US.

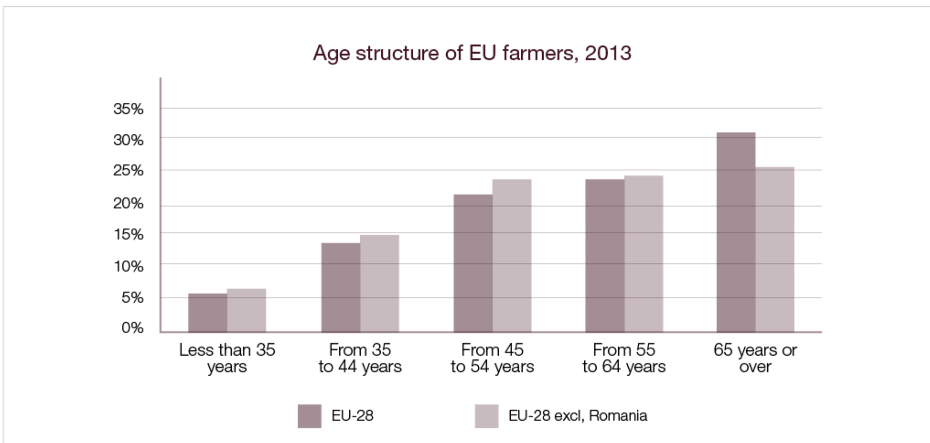

Figure 2.5 Age structure of EU farmers, 2013.
(Data source: European Commission)

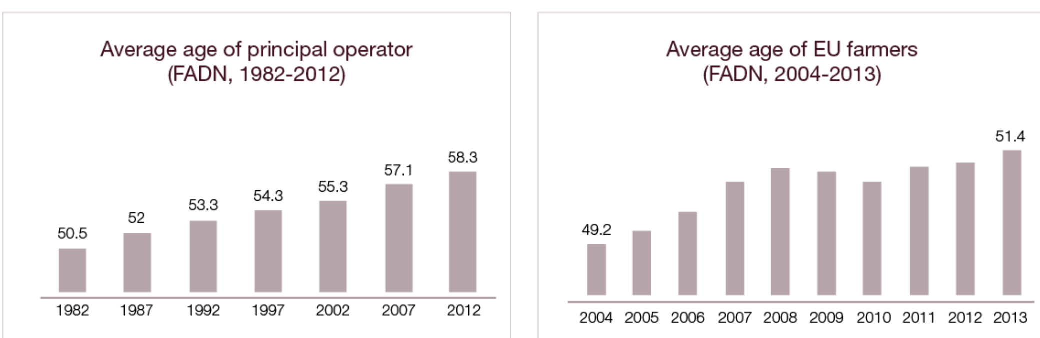

Figure 2.6 Average age of EU farmers and pricipal operators.
(Data source: European Commission)

Despite the low young-old proportion, it has been calculated that young employers' average farm size is higher that of the old employers and even 3 times bigger in economic terms. Moreover, young farmers have higher professional qualification in terms of full agricultural training, though less practical experience.

Looking at the next 30 years, the proportion

of young farmers cannot be expected to rise as quickly as the proportion of older farmers decreases, to respond to the increasing food need. Thus, it is possible to make optimistic projections, if analysing the growing interest of young people in agriculture and comparing it with the past.

In 2014, Eurostat suggested that many young people no longer saw farming as attractive profession. Moreover, young people have become even more alienated from the way in which food is produced and from its roots. In a report published in 2010 by Mark Shucksmith, this general tendency was called “the exodus of young people” (Shucksmith, 2010).

In order to attract young people into the agricultural sector, some institutions started introducing incentive measures. For instance, the reformed CAP (Common Agricultural Policy) of 2014-2020 established various forms of financial support.

Because of these among other measures, a return of young people towards agricultural employment is anticipated. Young people may also be tempted by the tangible technological evolution of the sector and by the adopted global sustainability strategy. The youth of today in general are showing an increasing interest in careers based on agriculture and the number of students studying agriculture and related subjects is growing.

In terms of future competitiveness, a rising interest towards innovations, new technologies and an adoption of smart agriculture principles is likely though, as demonstrated by the previous points, not necessarily guaranteed.

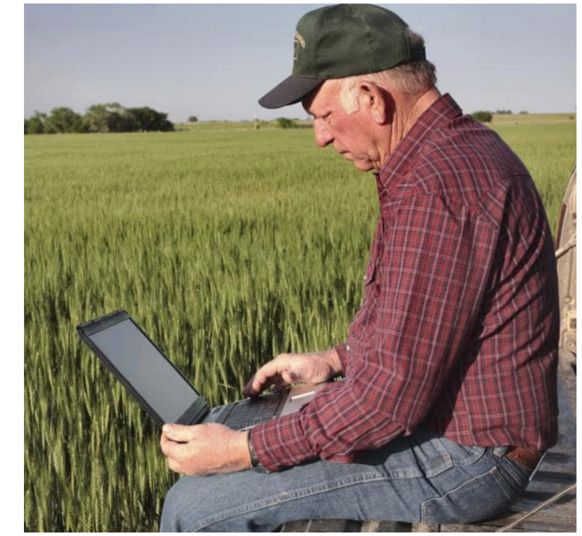

Figure 2.7 A farmer checking on a computer monitoring data.
(Figure: International Food Information Council Foundation)

New skills and professional figures

Agricultural development and changes over the farmer's professional figure are proceeding in tandem. As a matter of fact, new digital skills are required to face the adoption of incoming innovations.

A report by the Scientific and Technological Options Assessment (STOA) committee of the European Parliament highlighted the need for a substantial “education push” focused on high-tech skills (Schrijver, 2016, p. 27).

This report defines three main key areas of expertise: technological, environmental and managerial skills.

Environmental skills: understanding legislations, laws; expertise in circular agriculture; knowledge of local ecosystems; genetics expertise; knowledge of regional potential and regional growth.

Technological skills: notions of robotics and automation with their relative technological applications; notions of data science in order to work with data and understand them; ability to choose the appropriate technology or solution to solve a problem; concepts of low waste production; diverse high-tech production skills related to advanced machinery; notions of computer science.

Managerial skills: Knowledge of business management; knowledge of innovation management; entrepreneurship; marketing skills; ability to communicate with consumers and the market.

In order to fulfil the endorsement of these skills, a reflection must be done over education and new forms of learning.

This report states that "a continuous and life-long learning would be necessary to keep up with the speed of expected technological developments" (Schrijver, 2016, p. 25). This learning may include new programs as virtual and blending learning, online courses and peer-to-peer learning where anyone can teach topics within the personal area of expertise.
Access to this vocational training could be encouraged by targeted incentives and support programmes.

According to STOA report, as well as new skills are required, new business models are emerging, driven by new technologies.

A list of possible professional figures that are ready to be born is presented:

The Geo-Engineer: specialised in carbon sequestration alongside a food production business;

The Energy Farmer: specialised in renewable energy production and management for the farm area;

The Web Farm Host: specialised in the outside context and its trends;

The Animal Therapist: specialised in management of farm animals and on the communication of information about their wellbeing to the market;

The "Pharmer": specialised in biotechnologies used to grow and harvest plants that are able produce pharmaceuticals;

The Insect Farmer: specialised in growing insects for use as natural predators to control the new pests coming with climate change.

The consequences of the so-called "education push" may be numerous.
First of all, it can build a more interesting image of jobs in farming for young people: they might be more attracted to diverse interests such as technology, business and the environment.
Moreover, it could redefine the farmer's role as an expert on sustainability and "expert of local ecosystems" because of the higher level of competence in the field.
Finally, the new teaching methods may be particularly useful for the management of smaller farms, where farmers often find it challenging to participate in costly and time-intensive traditional training forms.

2.2 DESIGNING AN INNOVATION PATH FOR ALL

The analysis of Agriculture 4.0 sets out the tendency of companies to provide ready-to-use smart machinery and equipment to the market. Sometimes, employers in the agricultural sector find out about these innovations through specialised events and trade shows. Eventually, the more industrialised a farm is, the more easily it can access innovations and purchase technology.

What is lacking in this interaction flow between technology providers and end users is a mediation figure who could select and address the correct solution where needed. Indeed, it might be beneficial to provide users with tailored solutions, based on appropriate tools and proportioned to farmers' reality.
This foresight may be particularly useful concerning small farms, which are more reluctant late adopters and may be left aside by the system.

In this section, a strategy for easing a transition towards Agriculture 4.0 is presented. Moreover, some design guidelines addressed to small realities are shown and described.

FOCUS ON SMALL FARMS

From the picture just described, it appears that the road towards the large-scale adoption of Agriculture 4.0. must address some sensitive issues in order to prove its benefits. Specifically, the smallholders' transition warrants further analysis.
Small farms are struggling to keep up with new technologies because of a lack of knowledge, scarcity of investment capital as well as the "large digital divide" compared to

big farms. In order to maximise benefits, it is needed to think from a small company perspective. Indeed, the potential of this agricultural evolution is enormous for them too, even though the uptake tends to be higher among larger realities.
Great attention needs to be paid towards the elderly who could encounter more problems in gaining e-skills and consequently neither understand nor reap the benefits, in comparison with young employers.
Moreover, in order to achieve a successful and inclusive agricultural transformation, the digital gap between rural and urban areas and big and small companies has to be filled. According to the European Agricultural Machinery Industry Association (CEMA), adequate broadband infrastructure is lagging behind and it is essential to get rural areas quite literally up to speed in order to compete (Michalopoulos, 2017).
In conclusion, solutions are required to sustainably support all companies, especially the more vulnerable small ones. For the reasons set out above, further work examines in-depth precisely small realities. A design method has been chosen and explained accordingly.

Figure 2.8 Small scale farm worker.
(Image: Cristiano Spadoni - AgroNotizie)

DESIGN METHODOLOGY AND GUIDELINES

Co-Design

There is currently an increasing disconnect between those creating new innovations and those who should utilize them: the farmers. Pete Nelson, president and executive director for the Memphis-based AgLaunch Initiative, states that "this gap is dramatically lowering the probability of success for new agricultural ventures, which is in turn giving investors pause and is certainly not accelerating adoption quickly" (Michalopoulos, 2017).
A co-design process can be helpful in this context in order to bridge this gap. In this process, three key figures work together: the user, the researcher and the designer. Farmers (user) who will eventually be served are given the position of "expert of their expertise" and play an important role in knowledge development, idea generation and concept development. The researcher (who 42may also be the designer or service/tool provider) also changes role from translator to facilitator. Indeed, he/she analyses the user and the context and helps to express needs. Finally, in a co-design process the designer (who develops new tools/services and their experience) provides expert knowledge and translates users' needs shaping tailored solutions (Stappers, 2016).

The Farm Centric Innovation model follows this train of thought of participatory design and aims to augment farmers' role in the creation and refining of new ideas. With this approach, farmers are actively incorporated in the innovation system early as full participants and not just customers. In fact, what usually happens is that new technologies are not investigated in real farm conditions, nor early enough to contribute towards make-or-break decisions on whether or not to pursue new concepts.
Therefore, the farmer's role within the Farm Centric Innovation model is to run field tests at farm scale and to provide related feedback or suggestions on how to improve the product. Another key role for farmers is helping to develop new concepts and solutions (Changing the Farmer's Role in AgTech Commercialization, 2017).
Thankfully, some applications of this model have already been experimented, as in the case of start-up accelerators and incubators. One example is a start-up called AgVoice which uses a voice recognition technology with the aim of simplifying crop scouting and other recordkeeping efforts. The validation took place in Mississippi, Tennessee and Arkansas in 2016 with the cooperation of Ritter Agribusiness and Mid-South Family Farms. It included interactions, user experience and ergonomics. Finally, all results and feedbacks of these tests were incorporated by AgVoice.
The AgVoice start-up is just one of the existing examples of this approach whose effectiveness has already been tested.
To sum up, according to the Farm Centric

Figure 2.9 AgVoice fileld tests in the Midwest of US.
(Image: AgVoice)

Innovation model, farmers and scientists play different roles in the innovation process, although the best results can only be achieved if both sides work closely together.

Systemic design

Systemic design is a holistic approach that states that sustainable economic and social development comes from the connections and relationships between resources, producers and society. According to this approach, the economy should work as a system in which realities are connected and material and energy flows are designed so that waste from an activity (output) is converted to resources for another activity (input). This system aims to reduce wastes and emissions and augment wellbeing of each actor. The new economic-productive model is called Blue Economy and transforms the community into a network characterised by strong, equal and conscious relationships (Bistagnino, 2009). Systemic design generates autopoietic networks that are self-sustaining and resilient.

The most important aspect is that this approach enhances and supports the development of local realities, respecting and safeguarding territory and habitat. The goal is to support local resources, traditions and values that depend on the territory in which the system occurs.

This attention towards the wellbeing of both society and the environment must be kept in mind in order to achieve the purpose of this dissertation of helping the transition of small farms toward innovations.

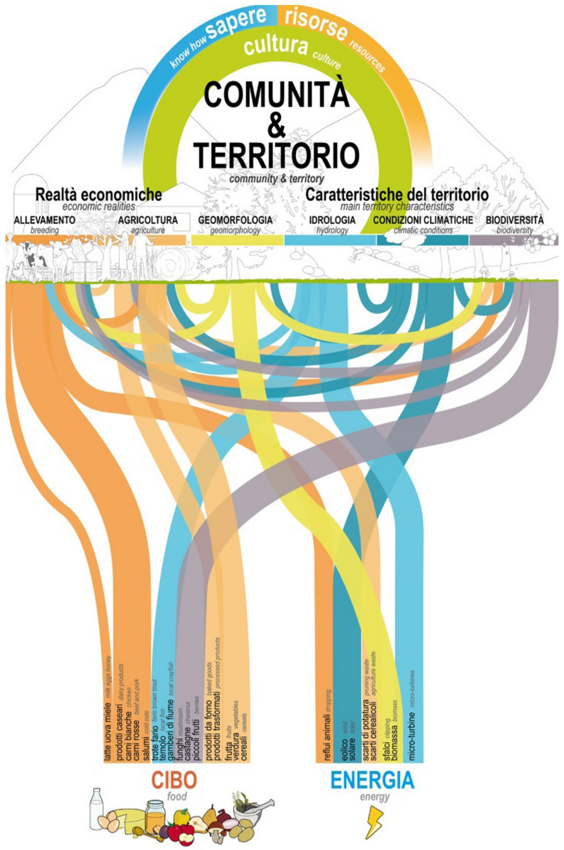

Figure 2.10 How systemic design works.
(Image: Design Sistemico - Luigi Bistagnino)

Design guidelines

During their life, traditional small farms have developed specific methodology, knowledge and workflow that ensure their survival and wellbeing. In contrast to the situation of big farms with their global reach, competitiveness is scaled down to a regional-local market.
In this context, the benefits that new innovations could cause are slightly different than ones for bigger realities. Co-design approach can help identifying the specific needs for each farm, in order to ensure all possible benefits. Moreover, during this design process, some other concerns have to be considered

in order to foster small farms' growth, following Systemic Design principles.

It is essential to ensure that new technological tools and machinery **do not cause a replacement of workforce**; they merely help employers solve their tasks more efficiently.

Attention must be paid to **traditional routine and workflow**: specific innovations should be carefully weighed up to avoid upheavals and alienation. Furthermore, it is important to consider current farms' internal relationships.

It must be kept in mind that small farms are usually family businesses and their **know-how** and **traditions** have been passed down over generations. Preserving these values and knowledge is mandatory for a sustainable adoption of innovative solutions.

Figure 2.11 Know-how passed down over generations.
(Image: Donavan Whyte)

3 CHAPTER

CASE STUDY: VITICULTURE AND WINE PRODUCTION

This third chapter deals with the wine growing sector, with a focus on wine production. After a review of the state-of-the-art of new technologies, a study of the Piedmont territory in Italy allowes us to focus on a specific context. Small agricultural holdings are the target of the project and their production processes are described in order to show critical points and design opportunities.

3.1
VITICULTURE AND WINE PRODUCTION

The following project phase of this dissertation started with the choice of a context, in which all insights and design guidelines are applied.
Viticulture has been selected among all agricultural branches especially because of the great attention towards its output quality. In fact, wine producers have to cope with several regulations and practices in order to obtain high quality wine. As a consequence, since the wine sector requires very high standards of the finished product, the quality of harvest is essential as well. Indeed, it is important to pay attention to both the grape vines' cultivation and vineyard management.

Another reason for choosing viticulture as a case study was the high variability of the soil depending on its altitude that makes the plants' treatment and harvesting challenging.
Moreover, both wine grape cultivation and wine production require a huge amount of expertise and creativity. Either wine grower or oenologist has a personal methodology, based on know-how passed on through generations and continuous improvement. The human factor is high and traditions play a key role in farm management.

Piedmont, in Italy, has been chosen as the context research area, since viticulture and wine production are two leading sectors of the economy of not only this region but also the entire country. Specifically, several small farms are devoted to viticulture for generations and this situation has been considered optimal for the experimentation of designing a path towards the adoption of innovative viticulture.

3.2
VITICULTURE 4.0 STATE-OF-ART

Principles of precision agriculture, digital agriculture and smart agriculture can also be adopted in viticulture, with the aim of maximising the oenological potential and achieving high quality standards of vineyards. The introduction of new technologies for supporting vineyard management allows for the improvement of efficiency and production quality while simultaneously reducing the environmental impact. Innovations grant a more efficient use of production inputs such as energy, fertilisers and chemicals and a minimisation of input costs, while preserving the environment.
Moreover, vineyards are highly heterogeneous fields due to structural factors such as pedo-morphological conditions and crop practices. These different characteristics cause diverse vine physiological response and varied grape quality with direct consequences on wine quality. In this sense, innovative technologies help manage spatial variability within the vineyard in order to respond to the real needs of the crop (Matese A, 2015).
Useful tools may be applied in monitoring and control of many aspects of vine cultivation and wine production. Indeed, these tools can observe spatial variability with high resolution, provide suggestions and solve some site-specific tasks.

This section presents a brief outline of state-of-the-art technologies in viticulture 4.0.
The review is divided in three parts: the first one focuses on operational machinery and agriculture robots (agbot); the second one deals with monitory machinery; the third one focuses on monitoring software.
To preface this review, it is important to recognize the technologies developed by companies, university research and projects made with the collaboration of several partners and countries.

OPERATING MACHINERY: AGBOTS

Vitirover

Vitirover is a mini solar-powered lawnmower robot, developed in France. It can mow wild grasses that prevent the growth of grapevines. Its application can reduce the use of pesticides and herbicides, which are dangerous for human health and whose application, carried out by human employers, is energy-intensive.
This robot uses GPS signals to find its way. Additionally, it is programmed by a smartphone and can work autonomously among vine stocks for several weeks (Niedercorn, n.d.).
The use of this robot can be seen in some prestigious vineyards, such as Château Ausone in France, and Cousino Macul in Chile.

Figure 3.1 Operating robot inside the vineyard. (Image: VitiRover)

Wall-Ye

Figure 3.2 Christophe Millot stands with his Wall-Ye prototype. (Image: The Atlantic)

The Wall-Ye V.I.N. robot is a brainchild of Burgundy-based inventor Christophe Millot. Thanks to a monitoring system based on optical sensors, this robot can not only perform correct displacements within the vineyard, but also carry out precision pruning, respecting the specific structure of each individual vine.
Wall-Ye draws on tracking technology, artificial intelligence and mapping to move from vine to vine. Moreover, it can recognise plant features, capture and record data, memorise each vine, synchronise all six cameras and guide its arms to wield tools (Wrenn, 2012).

VineGuard

VineGuard is a prototype designed for foliar applications by Ben-Gurion University of the Negev, in Beer Sheva, Israel (Matese A, 2015, p. 5). This robot can move on rough terrain using a complex set of sensors. A robotic arm for grape harvesting is going to be developed, using artificial intelligence to guide the robot in a series of operations: localization, assessment of ripeness, selection and detachment of grapes.

Figure 3.3 VineGuard spraying with its nozzle and camera. (Image: Tuvie)

Selectiv

Figure 3.4 Machine sorting ripe berries. (Image: Pellenc)

This is a mechanical harvester produced by Pellenc. It is combined with a roller sorting table that destems and removes other waste material while leaving the grapes intact. This machine is able to sort 2000 items per second and drastically reduces labour costs. Quality values may be set through a touch interface in order to obtain the desired level of selection.
Finally, an artificial intelligence vision block is needed in order to operate the sorting activity berry by berry (Perfect sorting for exceptional quality wines!, n.d.)

MONITORING MACHINERY

Vinbot

"VINBOT is an all-terrain autonomous mobile robot equipped with a set of sensors capable of capturing and analysing vineyard

images and 3D data by means of cloud computing applications" (Powerful precision viticulture tool to break traditional yield estimation in vineyards, n.d.). This is a Precision Viticulture tool that allows winegrowers to accurately assess the yield, without basing their knowledge on visual inspection of small samples which can lead to error and low-quality wines.
Computer vision, colour cameras and 3D range finders allow Vinbot to estimate the amount of leaves, grapes and their health, with the scope to help winegrowers in blending grapes with the same ripeness state. Then, the farmer receives vigorous maps based on the NDVI value, useful in order to optimise the management of his/her vineyard.

Figure 3.5 Vinbot monitoring grapes on vines. (Image: VINBOT)

VineRobot

Figure 3.6 VineRobot II. (Image: Televitis)

VineRobot is an UGV (unmanned ground vehicle) that measures and gathers data on grape yield estimation, plant growth monitoring, water status and berries composition assessment. This robot is a project that involves eight partners from four different vine-growing and winemaking European countries (France, Germany, Italy and Spain).
The use of VineRobot is able to provide key information about vineyard parameters much faster and with higher resolution than manual solutions.
Final users are able to visualise maps of all gathered information through software applications (Wilson, 2016).

Precision Vine

Precision Vine is a remote sensing company that provides aerial decision support and mapping using drones. Vineyards may be scouted several times during the wine-growing season. Rich amounts of data can be gathered during these monitoring flights, using a multi-spectral imaging technique. Consequently, data is analysed, interpreted, collected and shared with the end user, who can develop precise, cost-effective, in-field plans. The aim is to allow winegrowers to segment harvesting and take specific corrective measures.
This drone service is now already active in fifteen vineyards (Using drone-based Technologies to inform Winemaking decisions, n.d.).

Figure 3.7 William Metz and a PV drone. (Image: PrecisionVine)

Chouette

Figure 3.8 Drone assembly before its monitoring flight. (Image: Chouette)

Chouette is a drone service and analysis solution for winegrowers. It provides precise maps of vines' state of vigour, diseases and dynamic state evolution, thanks to an artificial intelligence. Its use is particularly effective in identifying and locating vines affected by diseases such as Mildew, ESCA and Flavescence (La surveillance quotidienne des vignes, n.d.).
Subscription is needed for flight and analysis. With this subscription, the winegrower becomes the owner of the drone and has unlimited access to the number of flights and the number of returns of analyses throughout the season.

MONITORING SOFTWARE

Algo Wine

In the field of software an example is Algo-Wine, developed by the Italian-German Ors Group, led by Fabio Zoffi who, in Roddi, near Alba, has been developing software based on Big Data for about ten years. Moreover, the collaboration with Italian and American universities, including Cornell University, the University of Turin - Faculty of Agriculture, and the Umberto I Wine Institute in Alba, has been vital for the success of the study.
The solution offered is called Algo-Wine and it has already been adopted in some wineries of Monferrato, such as Noceto Michelotti. It was born from the aim to help the wine grower in the processing of large amounts of data collected in the vineyard. In a few seconds, Algo-Wine allows you to analyse thousands of figures on different parameters (amount of light, heat, altitude, type of soil, orientation of the rows of vines in the sun, water, precipitation, dew) and, depending on the wine to be produced, the software divides the vineyard into blocks of ripeness. This is crucial to know harvesting times in order to develop a rational organization of the harvest and a better selection of grapes to be vinified. It prevents, for example, that excessive harvests degrade the quality of wine, or that the delay in harvesting would affect the chemical parameters necessary to maintain structure and aromas (Ors Goup: È nato Algo-Wine, un alleato prezioso per viticoltori ed enologi, 2015).

Figure 3.9 Bottle of wine with AlgoWine certification. (Image: Noceto Michelotti)

Smart Vineyard

Figure 3.10 Internet of wine station.
(Image: Fine Dining Lovers)

Monitoring station that includes precision sensors capable of capturing weather and soil parameters, locally. Each station has to be installed in a micro-zone of the vineyard in order to provide precise disease predictions, alerts, forecast. Moreover, all information can be monitored via charts and graphs on computers or smartphones (Smart Vinwyard System components, n.d.).

Vinifica!

Since wine cellars are dominated by mechanical technologies, 2.0 innovation in these area is based on the concept of the “Internet of things”, the study of the interactions between machine and machine in order to harmonize and coordinate the entire process.
VINIFICA! is a system of mechanic and software developed by Winer of Casale Monferrato. It is an integrated winemaking system with precision sensors controlled by artificial intelligence software that can not only monitor and regulate the various processes but also “learn” from the practices and errors of winemaking to act in the case of accidents.
Through VINIFICA! it is possible to program the wine production cycles according to the decreasing density curve or to the succession of the fermentation days, activating an automatic self-adaptation control that precisely follows the variations of density and temperature. All this can be controlled remotely with a handheld or laptop (VInifica, sistema di vinificazione integrato, n.d.).

Figure 3.11 Vinifica control monitor and data visualisation.
(Image: Winer)

Chapter 3. CASE STUDY: VITICULTURE AND WINE PRODUCTION

Viticanopy

Figure 3.12 Viticanopy mobile app.
(Image: Plantransig)

Free app funded by the Australian Grape and Wine Authority that helps growers, irrigation practitioners and scientists to reliably asses spatial and temporal growth and canopy architecture dynamics. The system estimates grapevine canopy size (Leaf Area Index and Plant Area Index), canopy porosity, canopy cover and clumping index, by using the front camera and GPS capabilities of smartphones and tablet PCs.

SiGeVi

The growth and development processes of plants are influenced by environmental factors such as temperature, solar radiation, humidity and precipitation. Thermal variations affect all the physiological processes that govern phenological and physiological development. In this field of interest, SIGEVI has been created with the aim of developing, testing and implementing an innovative decision support tool, or decision support system - DSS - based on the principle of wireless sensor networks (SIGEVI SIstema di GEstione del comprensorio VIti-vinicolo, n.d.).
The system has a wireless network architecture that collects data gathered by sensors, which are transmitted via the Internet to a processing centre, open to consultancy by operators through user friendly interfaces and accessibility from mobile devices. Thanks to the data collected in the field with the

Figure 3.13 - 3.14 SIGEVI weather station.
(Image: La Nuova Provincia)

collaboration of the professional partners of the project, the information system provides support for decisions on several issues such as water balance, use of irrigation, management of the canopy, harvesting time, productivity and related considerations related to pathophysiology and vine diseases.
Finally, 3D maps made by satellite and high-resolution multispectral images taken by the drones, give real-time information on the topography of the places, the biochemical and physical composition of the soil, the indices of vegetative vigour and the water stress of the plantations.

3.3 VITICULTURE 4.0 GOALS

According to a 2018 report, “the Precision Viticulture market is projected to reach $1,546.6 million USD by 2022 from $1,014.0 million USD in 2017, growing at a CAGR of 8.81% during the forecast period” (Precision Viticulture Market worth 1,546.6 Million USD by 2022, n.d.).
The adoption of new technologies will be wider in the Asia Pacific region (40%), compared to North America (20%) and Europe (also 20%). The reason for this discrepancy can be found in the high variability of soil types in the countries, in which several dryland farms depend on variable rainfall.

Worldwide governments are largely supporting the adoption of modern viticulture techniques and several cross-country projects are being developed. For instance, with respect to digital viticulture, The Horizon 2020 Framework Programme of the European Union founded The Internet of Food and Farm 2020 (IoF2020).
This project has started on January 1st 2017 and “investigates and foster a large-scale implementation of Internet of Things (IoT) in the European farming and food sector”. Moreover, it presents a series of case studies for each agricultural branch.
Among all examples, the use case 3.2. “BIG WINE OPTIMIZATION” focuses on viticulture (R. Tomasi, 2017, pp. 76 - 87).
Several partners from different countries, including Italy, are participating in the project:

- STMicroelectronics (technology provider);
- Denis Dubourdieu Domaines (wine grower);
- Bordeaux INP-IMS Laboratories (research);
- CEA – LETI (research)

- VINIDEA and ISVEA (research and analytic support);
- Process 2 Wine (software provider).

The domain model of "BIG WINE OPTIMIZATION" is designed to handle the following objectives in four years:

- Monitoring of real time weather conditions monitoring at parcel and vineyard level;
- Optimization of potable water resources during vinification;
- Reduction of production and commercialisation costs by increasing inputs efficiency;
- Frequent and inexpensive monitoring of key indicators of wine quality in the cellar, in order to avoid technological accidents during winemaking;
- Continuous checks and controls of wine conditions throughout transport, storage and distribution, to preserve best wine quality to the final consumer.

Figure 3.15 IoF 2020: Internet of Food and Farm.
(Image: IoF2020)

ITALIAN FOCUS

Thus far, the Italian wine sector is the field in which the greatest development of Agriculture 4.0 in the country has been recorded. The reasons for this progress are several, from the technical-cultural vivacity and research system, to the related characteristics of Precision Agriculture itself.
In fact, viticulture has a lot to do with quality values, since maximum income is generated by augmenting grapes and therefore wine value. Moreover, the components of the soil are sometimes different within the same vineyard, regarding moisture, structure, microclimate, and this generates different physiological expressions, depicted in complex vigour maps. These vigour maps are useful to solve some tasks at particular locations wherever and whenever needed instead of uniformly in a field. Furthermore, these maps can be focused on a single point of interest such as components of the soil for fertilising, irrigation, ripeness values for harvesting and so on.

The greatest development expected for Viticulture 4.0 involves high definition sensors that can be applied on aerial devices, such as manned or unmanned vehicles. All data gathered could be then analysed by an Artificial Intelligence that can process all information, select values that are considered the best, learn from them and decide on actions to take that can ensure similar results in the future. Later, the result of these analyses leads to some territorial interventions, solved either with robots or with traditional human actions, but targeted on a specific surface/plant/leaf. Another important step towards the adoption of Viticulture 4.0 concerns data communication: all information can be stored in "the Cloud" or online servers in order to let experts read and analyse them.

In Italy, some directives have been developed to face the adoption of new technologies and the farm conversion towards sustainable viticulture. An example is the Viniveri Italian Project, founded upon the initiative of the Viniveri Association, that went through the adoption of technology for vineyard management (Il progetto Viniveri: innovazione tecnologica per la gestione del vigneto, 2012). The project attempted to develop a system of information which could be easily used by producers for the purpose of:

- Optimising the defence against fungal diseases;
- Modulating fungal treatments;
- Monitoring the water status of soil and plants;
- Improving workers' safety conditions;
- Starting the innovation path;
- Ensuring transparency for clients.

In 2017, the Italian Ministry of Agricultural, Food and Forestry Policies forecasted some goals about the development of other systems as follows:

- Daily monitoring of crop water status and targeted intervention through new parcelled irrigation systems, only in the portions with the first symptoms of water scarcity;
- Checking the state of ripeness of the grapes for large areas or farms. Possibility of differentiated harvesting in time and space;
- Production forecasts (this is a very useful service for large companies, consortia). All models used so far have given error results of around 10%, not acceptable for marketplaces;

- Health status of the vineyard (it allows intervention at the first symptoms of diseases of the wood, yellowish, by eradicating infection-bearing plants. For fungal diseases the effectiveness of targeted and timely interventions in the vineyard must be verified;
- Damage caused by adverse weather conditions (e.g. hail, sunburn);
- Crop nutrient status and targeted crop and mineral specific fertilisation interventions.

Chapter 3. CASE STUDY: VITICULTURE AND WINE PRODUCTION

3.4 THE CHOSEN CONTEXT: PIEDMONT REGION

Wine grape cultivation plays a fundamental role in Piedmont agricultural context; so much so, in fact, there are 44,200 hectares of vineyards, (about 7% of the total Italian vineyard) and 18,000 wine-growing holdings. In 2017 wine production of this region was estimated at 2.043 million hectolitres out of 38.9 million hectolitres at national level. Among all wine typologies produced, 18 wines have DOCG certifications and 42 have DOC ones: the highest number between Italian regions. Moreover, they are produced from almost all historical autochthonous vines (Regione Piemonte, 2017).

TERRITORY OF WINE

Piedmont is a region located in the north-western corner of Italy, at the foot of the Western Alps. Of Italy's twenty major wine regions, it ranks 6th in highest production volume.
There are three wine areas in the Piedmont region: North Piedmont, Monferrato and Langhe-Roero. Respective provinces and produced wines are listed below (Panoramica dell'enografia Italiana, 2014).

North Piedmont

This district is divided in two by the Sesia river. The most widespread grape variety is

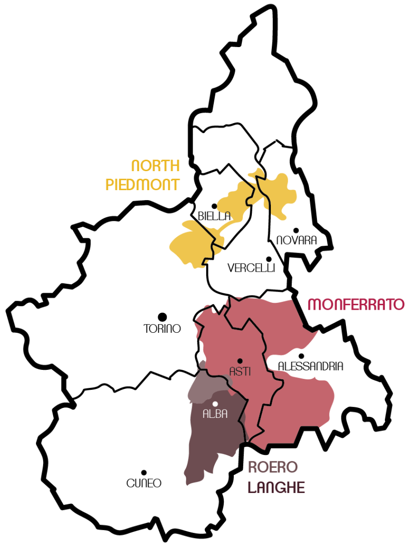

Figure 3.16 Piedmont map: main wine areas.

Nebbiolo, locally called "Spanna", that gives a fresher and more robust wine than the one produced in Langhe region.
The soil of this district is particularly acidic, rich in iron and poor in limestone.
The most produced wines in these regions are: "Gattinara" (DOCG), "Ghemme" (DOCG) and "Erbaluce di Caluso" (DOC).

Monferrato

This area is located further south of the Sesia river, between the two provinces of Asti and Alessandria.
The soil of this district is calcareous and rather rich in silt and clay and carbonates.
The most produced wines are based on Barbera, Freisa and Grignolino. Among the many denominations, it is important to mention the DOCGs: "Barbera del Monferrato Superiore", "Dolcetto di Ovada Superiore" and "Gavi" or "Cortese di Gavi", a white wine made with Cortese grapes.

The Astigiano region, provice of Asti, is characterized by the production of famous sparkling wines, usually refermented with the Charmat method. They are based on "Moscato Bianco" grapes, which fall under the name "Asti DOCG".
Astigiano district includes the production area of "Brachetto d'Aqui DOCG", a red sparkling wine based on Brachetto grapes, as well as that of "Ruchè di Castagnole Monferrato DOCG", from grapes of the same name.

Figure 3.17 Nizza Monferrato hills and Barbera vines. (Image: Associazione per il patrimonio dei paesaggi vitivinicoli di Langhe-Roero e Monferrato)

Chapter 3. CASE STUDY: VITICULTURE AND WINE PRODUCTION

Langhe-Roero

This district includes the province of Cuneo and it is one of the most suitable wine areas and most famous ones in Italy.
In the Langhe district soil is generally calcareous and morainic but in the Barolo zone a distinction is made between Elvetiano soil and Tortonian soil. The first typology is composed of grayish-yellow compact sands and dark soil: this type of soil gives life to more robust and tannin-rich wines, particularly suitable for aging. The second typology is composed of light soil and bluish-gray marls: this type of soil contributes to the creation of perfumed, velvety and elegant but less long-lived wines.
In this regions, the most famous wines are the DOCGs: "Barolo" and Barbaresco", made with Nebbiolo grapes; "Dogliani" and "Dolcetto di Diano d'Alba", both made with Dolcetto grapes; "Roero" based on Nebbiolo grapes, which becomes "Roero Arneis" with white Arneis grapes.
Also important are the DOCs: "Barbera d'Asti" and "Barbera d'Alba".
Moreover, in a larger area of the traditional Langhe, which borders in the provinces of Asti and Alessandria, some white and rosè sparkling wines are produced under the denomination "Alta Langa DOCG".

Since June 2014, Italy has a new site declared as a World Heritage Site by UNESCO. This site celebrates the Italian Cultural Landscape: a huge expanse of vineyards, hills,

Figure 3.18 Barbaresco and its vineyards. (Image: Tom Hyland)

farmsteads, small villages, churches and castles.
Specifically, the site includes the areas of Langhe-Roero and Monferrato, about a hundred municipalities with the best grape varieties and the most famous wines of Piedmont, from Barolo to Moscato, from Barbaresco to Barbera.
The so-called core zones are five and among them we can find some representative areas of each individual territory: Barolo with its noble castles, Barbaresco with its red tower, Moscato in Canelli with its cathedrals of the historical cellars of sparkling wine, Barbera in Nizza Monferrato with the Ethnographic Museum Bersano and Vignale with the circuit of Infernot (wine cellars dug into the tuff).
In every area, a Regional Wine Cellar has been active for decades to represent, inform and promote their respective great wines. Moreover, a network of facilities is dedicated entirely to wine.
Finally, the sixth zone is the castle of the Conti di Cavour with the Piedmont Regional Wine Store. It was here that experimentations with the best techniques for making Barolo wine started.

The following table shows vines surfaces divided by province and altitude zone:

Province	Mountain	Hills	Plane	All the rest	Ha
Torino	428.33	667.89	171.69	49.55	1317.46
Vercelli	0.00	156.93	8.90	3.48	169.31
Novara	0.00	495.74	20.98	4.80	521.52
Cuneo	700.20	14218.47	333.62	60.46	15312.76
Asti	1427.51	14909.73	226.50	231.50	16795.25
Alessandria	1232.72	11449.23	249.04	132.48	13036.46
Biella	21.62	218.44	1.68	1.92	243.66
Verbano c-o	25.83	0.00	0.00	9.17	35.00
Total Region	3836.21	42116.43	1012.40	493.37	47458.41
Relative Contribution	8.08	88.74	2.13	1.04	100.00

Figure 3.19 Vines surfaces divided by province and altitude zone.
(Data source: Regione Piemonte)

WINE CERTIFICATIONS

The European Union assigns the DOP protection label – "Denominazione di Origine Protetta" (Protected Designation of Origin) to those food products whose peculiar characteristics depend essentially or exclusively on the territory in which they were produced, with regards to natural factors (for example soil, climate, etc.) and human factors (production techniques handed down over time, craftsmanship, know-how, etc.).
Combined together, these characteristics enable an inimitable product outside a specific production area, since the regulations concern as well product specification, transformation and processing stages.

In Italy, the DOP label is classified in the oenological field in DOC and DOCG, the highest recognitions traditionally attributed to Italian wines to control and protect the consumer, which attest to its origin and good quality.

Consortia

Consortia are voluntary associations, without lucrative purposes, promoted by the economic operators involved in the supply chains. The purpose of these associations is the function of protecting wine products with designation of origin certification.
Essentially, the role of a Consortium is to carry out protection, promotion, enhancement, consumer information, certification management, and supervision in order to avoid commercial frauds.
In Piedmont there are 14 Consortia of Protection that deal with all DOCGs and DOCs wines, 2 big producers associations and a consortium of promotion: "Piemonte Land of Perfection".

Figure 3.20 DOCG wine bottle label.
(Image: Cultura - Biografieonline)

WINERIES IN PIEDMONT

As stated before, in Piedmont there are 44,200 hectares of vineyards.
On this land, wine-growers can be distinguished in terms of size, production and organization.
A distinction concerning these terms has been made and is described below. However, in doing so, single producers have not been considered. Indeed, since their production is extremely limited, this users group does not fall within the purpose of this dissertation.

Agricultural holdings

In Piedmont, these wine-growing holdings are 18,000.
They are farms of small dimensions with less than 12 ha of vineyards and most of the time they are family businesses, handed down over generations, with traditional methodologies and machinery. Most phases of the production process, such as harvesting, are done by hand. Also, the process may be considered sustainable and with low chemi-

cal consumption.
A few people work there all year long while the rest are employed seasonally, only when tasks become more tiresome and time consuming. These agricultural holdings produce about 20,000-40,000 wine bottles a year (10,000 bottles a year is the average expected from one full time employer).
Agricultural holdings produce their own wines, but assistance is needed from external analysis laboratories in order to perform expensive and complicated tests.
With respect to the market, these farms produce and sell their own wines in an internal point-of-sale (direct selling), since direct contact with consumers is preferred. Other sales channels are predominantly specialized local fairs, local restaurants and local specialized markets. Occasionally there is a tendency to export wine abroad, thanks to its high quality.

Industrial enterprises

There are 280 Piedmont industrial enterprises with more than 3,300 employers.
They can be divided into both wine-growers and wine producers or wine producers only. In the first case, industrialists own or rent vineyards from which producing wine; in the second case, they are confined to buy grapes from other producers and vinify them. On average, their territories comprise of vineyards from 20 ha to 95 ha and production can be around 350,000 bottles a year with a maximum of 600,000 bottles (50 - 65 employers).
In an industrial enterprise, it is possible to face the adoption of more advanced technology compared to agricultural holdings. Indeed, financial investment is high in order to accelerate processes, decrease setback risks and increase quality.

Figure 3.21 Fontanafredda and its 100 Ha of vineyards. (Image: Repubblica.it)

Moreover, industrial enterprises rely on experts in agronomy, oenology and their own internal analysis laboratories that can conduct all vinification tests rather than relying on external labs.

Cooperatives

In Piedmont, there are 54 social wineries and number about 12,000 partners.
The interview conducted with Salvatore Giacoppo, member of the "Cantina Sociale dei Sei Castelli del Barbera di Agliano" has been extremely what to understand how cooperatives work.
They are similar to social organisations, in which job and profit are shared. More specifically, a cooperative exists when a group of partners, mostly producers, choose to combine their resources and all their means to reduce the costs of producing wine.
In order to become part of one of these organisations, it is necessary to ask for and receive approval, following the proper statute and regulation. Indeed, social wineries follow some rules, imposed by administrators.
Members of social wineries are usually small wine-growers that chose not to produce their own wine, but just to cultivate vines. Therefore, harvested grapes are brought each vintage to the receiving cellar, where wine is produced and sold to the market. Since producers are several, organisation and a lot of vintage planning is needed, in order to allow each member's grapes to be vinified.
Once the grapes of all the members have been deposited, it is necessary to move on to the actual processing phase. In the winery, the vinification is made by working the grapes of all producers. To do so in the best way, quality and typology classification of grapes is essential, with the aim of producing blended wines that meet the cooperative requirements.
In order to get the profit from the sale of the bottle of wine, there are several variables that are taken into consideration. Essentially, the income from the sale of the wine produced must be divided by the number of members. The division will be carried out on the basis of the quantity of grapes brought by each individual producer.
Usually, wine cooperatives offer assistance to each member with regards to vine illness detection and vineyard treatments with the aim of guaranteeing holdings' wellbeing and to assure high output quality. Sometimes they also rely on an internal analysis laboratory.
Concerning machinery and technological innovations, it is possible to find advanced machinery for vinification in the cellar, while vine cultivation itself is still traditional.

Figure 3.22 Grapes reception at the cooperative Cantina Sociale dei Sei Castelli del Barbera di Agliano. (Image: Repubblica.it)

3.5

DEFINITION OF THE TARGET

The previous overview has been followed by a comparison of values and goals among small and big wineries, with the aim of choosing the target for the design project.
The category of the cooperatives has been left aside in this phase, since Consortia are already positioned in a middle ground between agricultural holdings and industrial enterprises and further discussion would lead to a lot of overlap. Indeed, the cooperatives are organizations of small realities with traditional wine-growing methods, but they are more technologically advanced concerning the wine production process. It can be said, then, that the goals of the cooperatives are a combination of those of small and big holdings.

Industrial wineries' main goals are increasing profit and production while augmenting output quality. Looking forward to doing so, they do not mind increasing vineyard extension since they have enough capital for investments. At the same time, industrial enterprises aim to reduce consumption and waste. Sometimes, manpower is reduced and replaced by new technologies that can speed up practices and ease management.

On the contrary, agricultural holdings have different and sometimes opposite purposes. Indeed, small wineries' main goal is to maintain traditional values, handed down from previous generations. In doing so, workforce is essential and the improvement of work conditions is constantly kept in mind. Moreover, the high respect of the territory and vineyard rates cannot lead to an increase of production. On the other hand, great attention is paid to the increment of output quality, coming from sustainable practices.

This values and goals comparison has confirmed the purpose of designing a path for small realities towards the adoption of new technologies. Indeed, as has already been said in chapter 2, small farms are struggling to keep up with technological innovations, while industrial enterprises are more advanced.

However, in order to start the project phase, more information about the target is needed. The following section analyses in depth agricultural holdings' relationships inside Piedmont territory. In addition, viticulture and vinification processes are compared in order to choose the project focus.

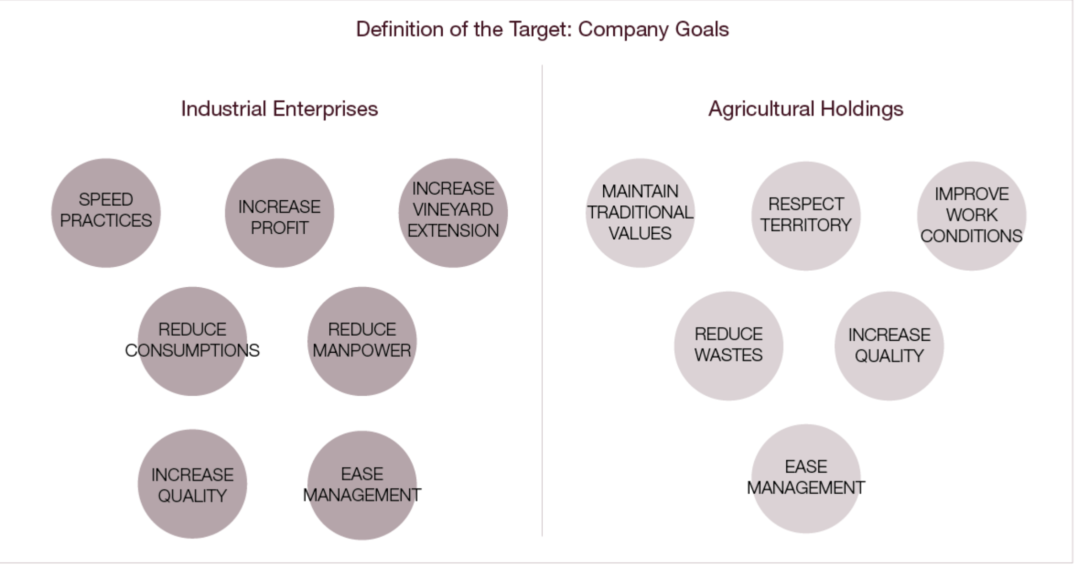

Figure 3.23 Big vs.small wineries: company goals.

THE TARGET: AGRICULTURAL HOLDINGS

Network of relationships on the territory

An agricultural holding is not an isolated reality but integrated in a network of relationships inside the Piedmont territory.
These relationships are structured in two flows: an "information flow" and a "goods flow". The "information flow" concerns regulations, certifications, policies and support services. On the other hand, the "goods flow" deals with the production process, technologies, machinery and the market. Furthermore, several actors interact with each other in this network, generating nodes where the two flows intersect with each other.
Some actors are grouped together inside the network, depending on their characteristics.
To begin with, it is possible to recognise the government group that unifies policy suppliers, certification servers and the entity Regione Piemonte. The latter defines and adapts regulations in its territory and offers support in the form of research and testing.

The second group is composed of technicians (agronomists, meteorologists etc.) and laboratories for analysis that exchange knowledge and provide technical assistance to holdings.
The next big group concerns industry: technology providers, telecommunication and connectivity suppliers, manufacturers (who build and sell machinery and equipment) and chemical providers, who produce fertilisers and reagents. Water and energy suppliers and packaging producers are also included in this set.
Halfway between industries and government, university and private researchers are mentioned, because they innovate and implement new technologies for Agriculture 4.0.
The market constitutes the fifth group and includes also wine customers, who may have a direct connection with the agricultural holding as well.
Finally, it is essential to mention the connection with other wineries, distilleries and

NETWORK OF RELATIONSHIPS

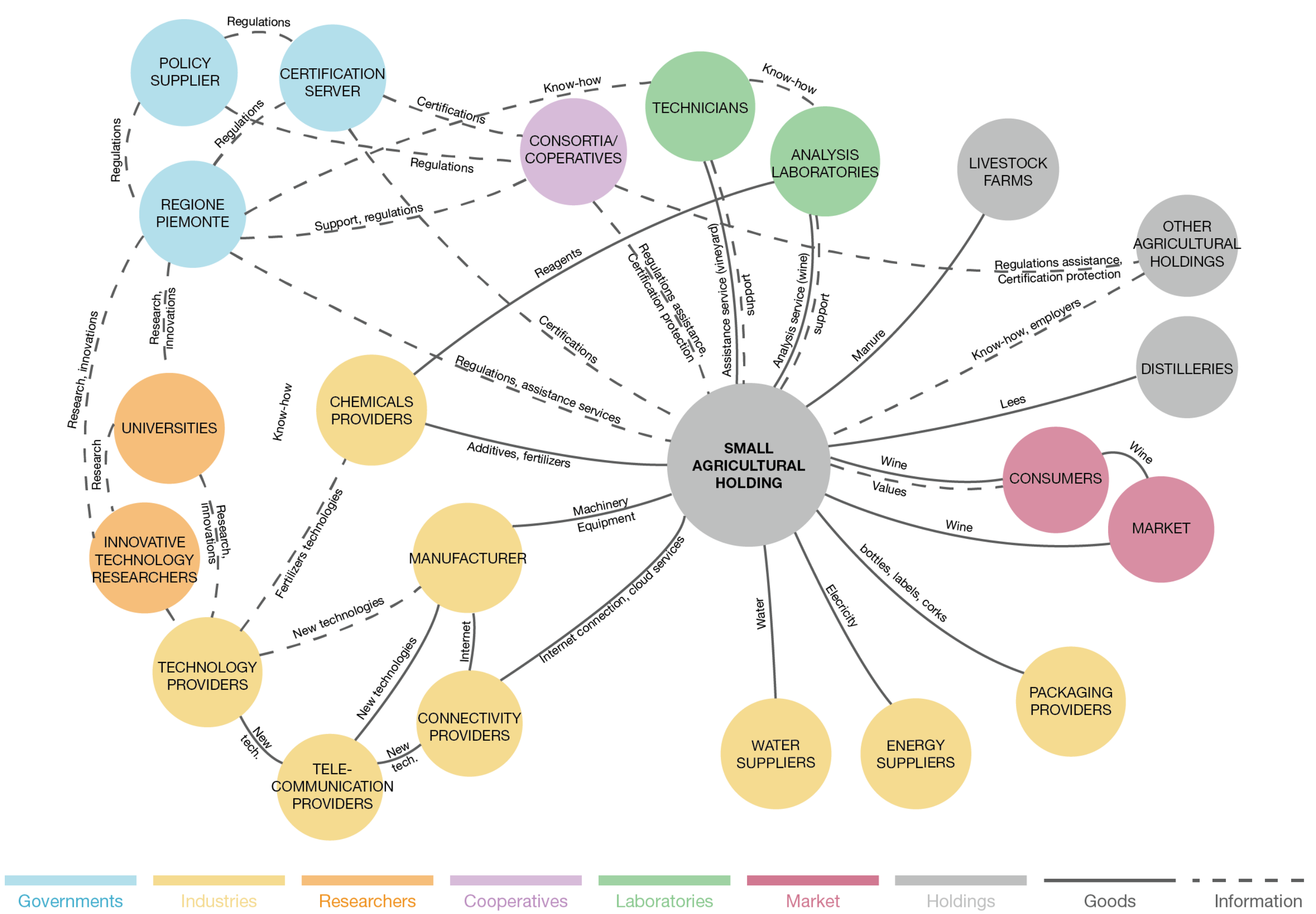

Figure 3.24 Network of relationships of agricultural holdings on the territory.

livestock farms into this network of relationships. Distilleries produce grape spirit from wine lees, while livestock farms provide manure for vine cultivation.
Consortia and cooperatives form a solo group, since they are the linking point between agricultural holdings and the Government group.
The definition of this network was done following an encounter with Federico Spanna, agronomist and plant protection researcher for Regione Piemonte. An interview was conducted about viticulture in Piedmont and holdings' attitude towards Viticulture 4.0. The insights obtained have led to the generation of the scheme in Figure 3.24.

FAMILY WINERIES CASE STUDY

At the early stage of the context definition, three agricultural holdings have been analysed and interrogated. The scope was to understand their values and approach towards technologies. Information about production processes, their management and their critical points have been gathered through observation and interviewing taken in a real context.

Azienda Agricola Chiesa Carlo

Family agricultural farm located in Santo Stefano, heartland of the Roero region. Six members of the family are now working for the business that has been in operation for five generations. The farm produces about 35,000 bottles a year and the vineyards extend for 9 ha. The most produced wines are Roero, Roero Arneis, Barbera and Nebbiolo. In the vineyard, almost all operations are done manually, and the farmer's expertise and creativity are supported. Chemical treatments are avoided as much as possible. Indeed, the aim of Chiesa agricultural holding is to produce high quality wine sustainably, respecting tradition and the territory.

Figure 3.25 A bottle of Roero, Azienda Agricola Chiesa. (Image: Vinichiesa)

Figure 3.26 A bottle of Barbera d'Asti Superiore, Azienda Agricola Poggio. (Image: Vinipoggio)

Azienda Agricola Poggio

Family winery founded in 1899 and located at 350 meters above sea level, in Castel Boglione, a small village close to Nizza Monferrato and Acqui Terme in the Monferrato region. Ten people work in this agricultural holding which produces 38,000 bottles a year and has an extension of 10 ha. Here, the most produced wines are Barbera, Barbera Superiore, Dolcetto and Moscato.
This farm follows the principles and regulations of integrated production, a methodology that aims to minimise the use of synthetic chemicals and rationalising fertilisation, in compliance with the ecological, economic and toxicological principles. The goal is to lower the impact on man and the environment, allowing economically sustainable productions to be reached and maintained (Norme tecniche di produzione integrata, 2018).

The analysis of these case studies was essential to understand both cultivation processes and wine production process in particular. Furthermore, it has led to the definition of some critical situations that may occur and affect vineyards and cellar management.
In reference to vineyard management, the most critical activities are related to physical variability of the territory and to weather conditions. Some vineyards are positioned on steep slopes (Figure 3.27) and this gradient could keep workers from optimally performing their tasks, not to mention the risk of erosion. For instance, it becomes difficult to weed, apply treatments and eliminate pests, since walking and equipment handling are limited.
On the other hand, weather conditions may be dangerous for the performing of planned activities, such as applying fertilizers to combat the spread of diseases and pests. For instance, heavy rain can prevent harvesting and wind can disturb the distribution of substances, causing waste.
The last critical point of the cultivation process is disease prediction. Vines are threatened by some moulds that may arise with increasing humidity content and by some bacteria such as the Flavescence Dorée (Figure 3.28). This bacterial disease is carried by an insect, but it is hard to understand precisely when preventing treatments have to be done.

As well as vineyard management, the vinification process may be marked by weaknesses too. Specifically, the most critical moment is fermentation, one of the first steps in which sugars are transformed into alcohol. In this phase, several tests must be done but most of the time support from analysis laboratories is required.
Control over oxidation and over wine inputs and outputs is also essential.
Constant monitoring and great attention are needed during wine production steps, especially when several wine typologies are produced simultaneously.
More broadly, it can be concluded that major issues do not concern the amount of work that has to be done both in the vineyard or in the cellar, but rather the need for monitoring and preventive care.

Figure 3.27 Chiesa's vineyard positioned on a steep slope. (Image: Vinichiesa)

Figure 3.28 Vine affected by Flavescence dorée. (Image: Pest Tracker)

Chapter 3. CASE STUDY: VITICULTURE AND WINE PRODUCTION

3.6
FOCUS OF THE PROJECT: VINIFICATION

Vine cultivation and wine production processes are equally important to get high quality output. In order to decide where to focus the design project, a comparison was done concerning the nature of the critical points previously highlighted.

Viticulture depends on external and less controllable variables than wine production. Indeed, vineyards are wide open fields that depend on unforeseeable climatic conditions that change year by year. On the contrary, a cellar is an enclosed and limited space where the oenologist governs each step of the process. It is the oenologist who decides the methodology and timing of each step, in order to produce the chemical composition of wine, which otherwise couldn't exist in nature.
Furthermore, viticulture copes with several actors and professional figures on the regional scale, such as agronomists and meteorologists. They provide regulations and assistance in the form of prediction of treatments, weather forecasts and so on. In wine production, on the contrary, knowledge is already possessed by employers, who can rely on external laboratories to perform additional tests. The organization of relationships in viticulture is hierarchical like a pyramid, while in wine production it is circular and more fluid.

Finally, a comparison must be made about human expertise. In viticulture, the way in which pruning and defoliation are conducted is important for grape quality and vine health and growth. In wine production, the oenologist's decision-making and know-how affect the output quality considerably, even more than what happens for vine cultivation. In fact, all decisions taken over wine adjustments and production steps make the difference between each winery.

For all the reasons just described, vinification has been chosen as project focus. It is

expected that the introduction of new technologies in this phase could increase the oenologist's control over production, lower setbacks and, as a consequence, augment wine quality. Moreover, the wine production phase is the last step before the market and this characteristic may offer an opportunity for gathering consumers' feedback over the application of new technologies and its result.

WINE PRODUCTION PROCESS

The process for vinification differs slightly between white wine and red wine. The differences regard above all the presence or absence of grape marc (grape skins) during fermentation, its temperature and some subsequent treatments.
The main steps of winemaking are as follows.

Vintage/Harvesting

Grapes must be harvested at the precise time, depending on the ripeness of the grapes and the oenological objective set (between August and October). During ripening, grapes' acids decrease and sugar and aromas increase. From the sugar content value, it is possible to obtain the probable alcohol content of the future wine (0.6 coefficient).
Therefore, some measurements are needed in order to decide when to harvest.
Generally, the vintage starts first for white wines, continues with red wines, and finishes

Figure 3.29 Moscato grapes vintage.
(Image: Ilcorriere)

with red wines for aging and raisin wines. The grape bunches harvested are then sorted at the winery and rotten bunches are removed.

Crushing and pressing

After the reception of harvested grapes, they are crushed. Red wine is made from must and the fermentation occurs together with the grape marc. The red skins give the wine its colour because of the tannins. White wine is made by pressing crushed grapes to extract the juice and grape skins are removed before fermentation.

Fermentation

Fermentation is the process where sugars are transformed into alcohol (ethanol). The process lasts about two weeks and starts when selected yeasts are added to must. The alcohol level can vary depending on the wine typology produced. For instance, sweeter wines are produced by stopping the fermentation phase when some sugar has not been converted in alcohol yet.
Red wines ferment with grape marcs, which release tannins and provide the darker colour. On the other hand, white wines fermentation occurs after grapes are destemmed, when peels and pips are eliminated.
The fermentation phase is extremely important because it determines wine flavour and characteristics. For this reason, the entire process must be carefully controlled by the winemaker, who has to test wine values constantly. The most important values to be monitored are: temperature (25-30°C for red wines and 18-22°C for white wines), sugar content, alcohol level, acidity, pH and sulphur.
Since some of these tests must be made with chemical reagents, wineries collaborate with specialised laboratories which perform them. Moreover, some additives may be added in order to adjust the process.

Racking (red wine)

Operation that consists of the separation of wine from the marc after fermentation. Several techniques may be used, depending on the tank type, like siphoning or tapping the wine from one tank to another. The aim is to draw the free-run wine from solid residue that generates on the bottom of the tank, pouring the liquid into another container. In most cases an oenological pump is used.

Malolactic fermentation (red wine)

In this fermentation phase no alcohol is produced. Instead, selected lactic acid bacteria are added in order to convert malic acid into lactic acid.
This process works anaerobically (without oxygen) and it is done to augment wine stability and reduce acidity. Even in this case, several tests are needed such as temperature and sulphur monitoring.

Clarification (white wine)

This process is another filtering technique, usually adopted for white wines. Once the fermentation process is completed, the winemaker removes the solid sediment from the wine. The aim is to remove the suspended particles that make wine cloudy.
Filtering agents such as betonies (volcanic clay) are sometimes used in order to bond with particles and to make them settle down. This and other filtration techniques are also used to accomplish microbial stabilisation, removing organisms such as yeasts and bacteria, that can affect wine stability.

Figure 3.30 Stemmer crusher crushing red grapes. (Image: Pinhead Studio)

Figure 3.31 Oak barrels for wine aging. (Image: Niagara Vintage Wine Tours)

Aging

Aging of wines can be done in stainless steel tanks, wooden barrels or ceramic tanks. The duration and the container features depend on the wine typology that has to be produced and its desired characteristics.
Wines can also age in bottles.

Bottling

During this phase, the winemaker adds sulphite to help preserve the wine and prevent further fermentation. Traditionally, cork is used to seal wine bottles.

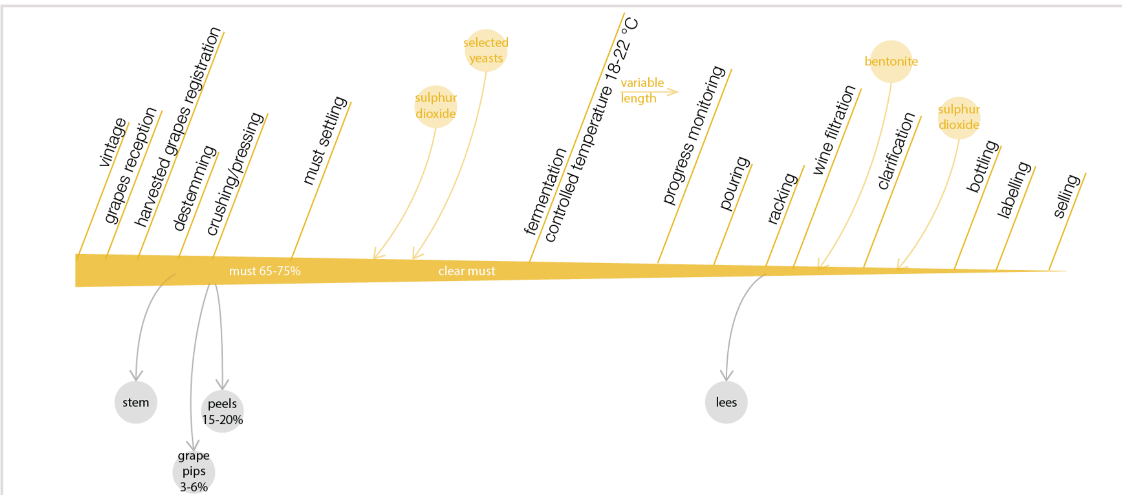

Figure 3.32 White wine vinification process main steps.

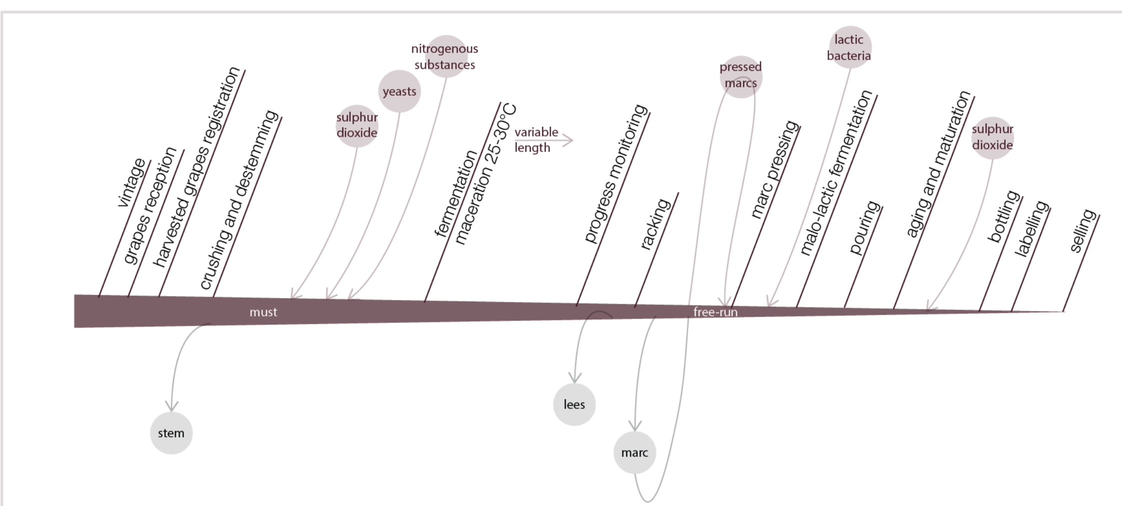

Figure 3.33 Red wine vinification process main steps.

Chapter 3. CASE STUDY: VITICULTURE AND WINE PRODUCTION

CRITICAL POINTS: FERMENTATION

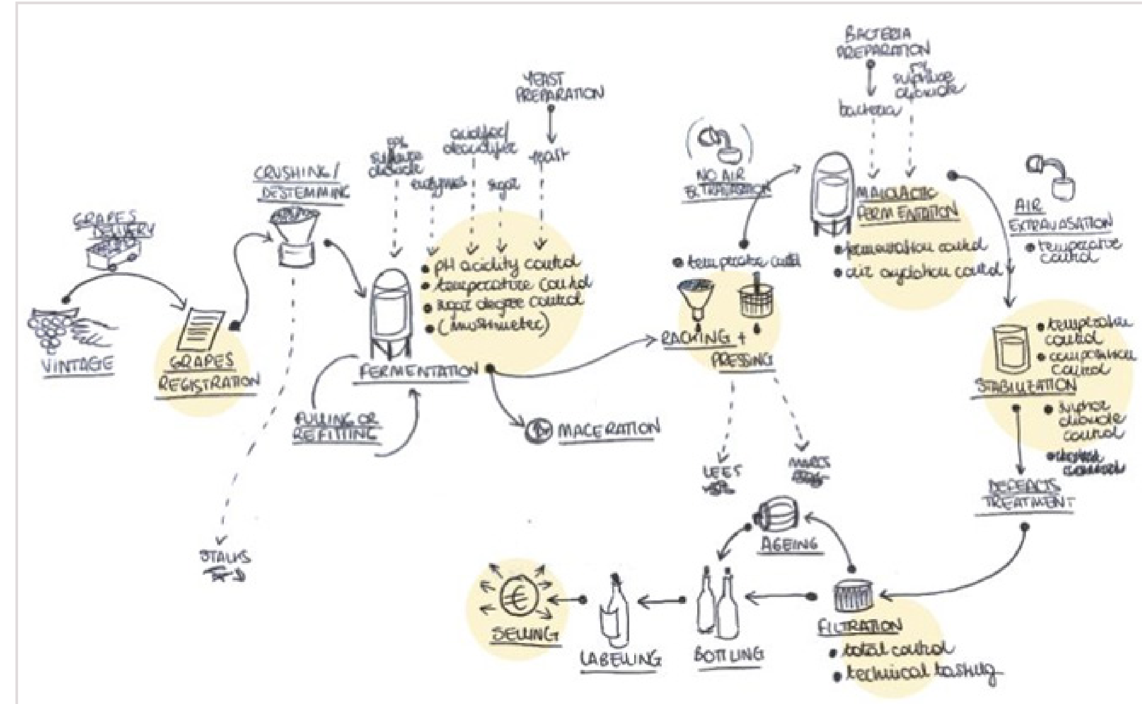

Figure 3.34 Critical points of wine production.

The production process of a red wine has been analysed in order to understand critical points along each phase.
Interviews have been conducted and timelines filled together with the oenologists of the two case study agricultural holdings.

The first observation done regards the management of wine production inside the winery. Since different grapes are cultivated, several wine typologies are produced. Each grape type has a respective ripening timing. Therefore, harvesting doesn't occur simultaneously for all vines. This means that inside the cellar the winemaker has to manage several uncoordinated processes.

Another problem deals with the need to monitor a huge number of parameters at different frequencies. Seeing as how the management is discontinuous, this task requires a lot of time and attention.

Also, chemical tests over wine during fermentation are critical. Indeed, the oenologist must monitor each tank more than once a day. Furthermore, samples have to be brought to laboratories that perform analyses and return results long after the period in which corrective action could have been taken.

Finally, another tipping point is the dosage of additives and inputs. The decision making

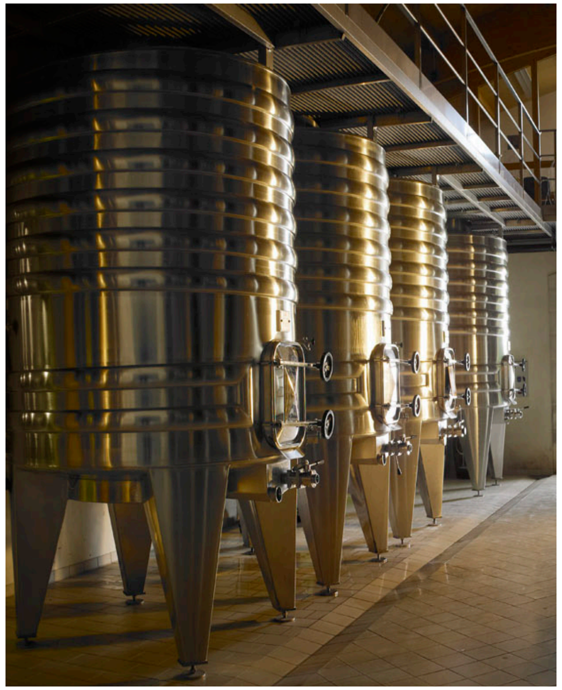

Figure 3.35 Wine stainless steel tanks.
(Image: Bordeaux Tourisme)

regarding how to adjust wine requires a lot of time for comparing values and analysing developments. These choices must be prudent in order to solve the problem without wasting substances.

After the analysis of winemaking critical points, it became clear that the most perceived problem is monitoring the simultaneous processes. Among all production phases, fermentation has been chosen because it is the key point of the winemaking process.

Right now, several manual tests and laboratory analysis are conducted for each tank, as well as taste and nose examinations. Work can be done for increasing the oenologists' control over the process, for its optimisation and for supporting decision making.

Figure 3.36 Red wine fermenting with peels and grape pips.
(Image: Stefano Lubiana Pinot Noir)

4 CHAPTER
WINE FERMENTATION MONITORING TOOL: FerMentor

This last chapter illustrates the entire design process, the study of the final user (oenologist), the definition of his User Experience, User Interaction and the project features.
Components of the designed connected system are described carefully and a prototype of the system is presented. Finally, testing results and future developments are listed.

4.1 IMPLICATIONS OF THE DESIGN PROJECT

The goal of this project is to show the validity of applying the design discipline as a guide for helping the transition of small farms towards agriculture 4.0 and its technologies.
The design project developed for this dissertation focuses on the fermentation phase of wine production: FerMentor is a technological tutor that has been developed specifically for small realities, thanks to a deep analysis of target and context.

Before starting with the explanation of the design path that has been followed, it is essential to draw attention to the implications that FerMentor aims to bring in the context where it is supposed to be applied.
These consequences are either technical improvements or social and human advantages. Above all, the second category is extremely important, because small farms are teemed with genuine values and traditions, which are meant to be supported.
First, this monitoring tool could ease and speed up tests and analysis, boost the oenologist's problem solving and decision making and improve treatments validity. Due to these technical advantages, output quality is increased as well as financial benefit.
At the same time FerMentor could sustain users' know how and expertise and lighten workflow. Traditional values and methodologies are enhanced, since the oenologist's routine is not altered by the adoption of new technologies. Moreover, relationships on the territory are strengthened, especially the existing connection between winemakers and technicians from analysis laboratories. As a consequence, the process appears more sustainable as regards either consumptions and wastes or human relationships.

4.2
ANALYSIS OF THE USER

The user of the design project of this dissertation is the oenologist, the winemaker that leads the entire process and makes decisions over it. Specifically, he is a member of the family who owns and manage the agricultural holding.
A Persona has been designed considering the oenologist' skills, personality, goals, frustrations, preferred channels and motivations. Personas, also known as "portraits" are fictional characters expressing proprieties of a target group. They are "synthetized from recurring patterns and compelling stories found in research" (Elizabeth Goodman, 2015, pp. 189 - 190) and are particularly useful as references during the project development.
Hereby, the Persona of the users of this research is described point by point.

PERSONA

Skills

Essentially, the user received a training on oenology, vinification and tasting. He has some technical skills concerning chemical tests and analysis, but he prefers to delegate this task to more specialised laboratories. In addition, the user knows agronomy, since he not only works inside the cellar, but also in the vineyards.

Personality

The user is very passionate about his job and thoughtful about his tasks. Although the oenologist is set in traditions concerning wine growing and wine production, he is not excessively conservative; rather, he is curious about future developments and creative about new methodologies. Finally, he is organised in his job, but some improvements may be made.

Goals

The first goal of the winemaker is to increase wine quality. He would also like to preserve family and activity traditions, as well as manual operations. Indeed, performing tasks manually is an added value for the

Figure 4.1 Persona.

production of high quality wine. Moreover, the user looks forward to improving work conditions, easing tasks, but not reducing workforce.
Finally, the oenologist would like to open up to new markets, while increasing his customers' affection.
Since the user doesn't want to extend his vineyards or overexploit them, the interest towards increasing the number of customers is limited.

Frustrations

The main frustrations of the user deal with the management of the wine production process. As has already been said, technical analysis is unfeasible inside the winery and external help is needed. Basically, this is because of the early expiry date of chemical reagents and the expertise needed in performing these tests. Also, many time-consuming, repetitive manual tests are needed. Great attention has to be paid to each step

to avoid spreading wine defects and this invokes stress for the user.
Finally, another important frustration concerns the high price of innovative machine and equipment, that may provide advantages in the wine making process, but are inaccessible.

Preferred channels

The user prefers a traditional form of communication, such as phone calls and emails. The reasons for this preference may be found in the nature of his work routine, which leaves little time for interactions and for immediate response.

Sales channels are mainly direct sale, specialised wine shops and local restaurants. Sometimes the winery participates in fairs because of its high quality and traditional wines. Direct contact with the consumer is preferred and large-scale distribution is avoided.

Motivations

To summarize, the user's motivations may be divided into two categories: achievement and growth. In this case study, achievement is the most important one, regarding better output quality, work conditions and management results.

4.3 JOURNEY MAPPING

The creation and the consequent study of the user journey mapping has been extremely useful for the definition of opportunities for design-led changes of the fermentation process. Furthermore, it has led to the definition of the desired user experience and interaction.
A journey map represents how the user interacts with a product or service during a period of time (Elizabeth Goodman, 2015, pp. 193 - 194). It includes key locations, events and activities that occur, timing, touchpoints and interactions, users' feelings and opportunities.

In this section, the journey mapping of a typical fermentation day is illustrated and described.
The fermentation process is quite complicated for someone who is not in the wine business. Technical steps slightly differ wine by wine and depend on the oenologist's methodology. For these reasons, a red wine was chosen as case study to facilitate the understanding of the journey map.
Moreover, it was not possible to display the entire fermentation journey in just one representation. Indeed, different visualisation layers are needed regarding the key moments of fermentation: the initial phase, the intermediate phase and the final phase.

INITIAL FERMENTATION PERIOD

At the beginning of the fermentation period, just a few tanks are filled with must that is being processed. Some grapes are not ripe enough to be harvested and vintage is still going on.
The first part of a typical day takes place inside the cellar, where tests and every-day activities are performed tank by tank. Each morning, the winemaker measures density and temperature, tastes the must and performs the remontage (also known as "pump-over"). The latter consists of stirring the

must with a pump from the bottom of the tank over the top, in order to submerge grape skins and release carbon dioxide.
If some anomalies are detected, either some adjustments may be done immediately or a sample is taken to the analysis laboratory to be tested.
For the rest of the morning, during fresher hours, the oenologists need to work in the vineyard, helping to harvest.
In the early afternoon, he comes back to the cellar, where he has to prepare machinery for the reception of harvested grapes. Later, grapes are pressed and destemmed and new tanks are filled in order to start fermenting. During these processes, results of analysis may be received from the laboratory; the oenologist can then decide how to behave in order to solve the detected problems.
Again, at the end of the day, tests and remontage are performed tank by tank and eventually those musts that were adjusted in the morning are tasted.

Emotions – stressful points

In this initial phase of the fermentation period, the most stressful moments of the day are when the user has to interrupt his tasks in the cellar, move to the vineyards and vice versa. Besides the fact that harvesting is a tiresome and long task, the user experiences a growing concern regarding the adjustments he has just made. Moreover, he is still waiting to receive tests results from the laboratory. The decision-making process about fermentation is disturbed by these physical and mental interruptions.

Opportunities

A way to reassure the user may be to offer the possibility of monitoring the fermentation process remotely. This could return concentration and control to the oenologist.
In addition, remote alerts could be useful to understand when problems occur inside the cellar so that the user can promptly make adjustments.

INTERMEDIATE FERMENTATION PERIOD

During the intermediate phase of the fermentation period, more tanks are fermenting wine and fewer grapes need to be harvested. This means that more time is spent in the cellar during the morning, less time is spent harvesting in the vineyards and preparation and final tests happen earlier in the afternoon.

Emotions – stressful points

Moving from the cellar to the vineyards and vice versa is still a painful moment, when concentration is lost and stress arises. In addition, more time is needed to check each tank and perform all tests.
The user's problem solving and decision-making are intense and take more time

than during the initial fermentation phase.
Since more processes are initiated, a larger number of technical analyses is expected. The increment of information received from laboratories makes it difficult for the winemaker to manage data and compare values.

Opportunities

In addition to the opportunities mentioned earlier for the initial phase, a new design opportunity emerges regarding the management of analysis results. A direct connection between laboratories and cellars may accelerate and facilitate the comparison of values and decision-making.

Figure 4.2 Remontage of a red wine during fermentation. (Image: Carpe Vinum)

FINAL FERMENTATION PERIOD

The final phase of the fermentation period is characterised by the continuous presence of the oenologist in the cellar. Indeed, all grapes have been harvested, several tanks are hosting fermenting must and some wine is proceeding to the final production steps.
Sample tasting, tests and remontages are numerous and take several hours to be completed. Must adjustments require more effort as well.

Emotions – stressful points

The final period is considered less stressful than the previous ones because the user can focus entirely on his tasks. On the other hand, the amount of actions and tests the winemaker has to perform is huge. Moreover, he must deal with more typologies of wine, each one requiring different management.
This phase requires a higher level of concentration and problem solving.

Opportunities

Relieving the user from some tests he has to carry out may be a promising design opportunity to reduce the repetitiveness of checking values. Also, suggesting some adjustments to the oenologist may aid his concentration when he's comparing values and making decisions.

SINGLE TANK TESTS

The cycle of tests that the user has to conduct for each tank consists of three actions sequentially: sampling must, performing the test and transcribing results and comments. For instance, density analysis is usually conducted by dipping a hydrometer (saccharimeter) in a must sample, taken from the tank.
Consequently, transcribed values are compared and decisions are taken regarding the current situation.
The same sequence of actions occurs during the tests conducted at the end of the day. In addition, the oenologist must transcribe the results of the laboratory analysis as well.

Emotions – stressful points

The most stressful point of the single tank tests is the comparison of all data about fermentation. The previous adjustments and measurements have to be taken into account for the decision making.
The stress is magnified when managing several tanks one after the other.

Opportunities

A design opportunity in this case may be the digital transcription of gathered values and of wine treatments. Data history visualisation may be useful to ease and speed user's decision making.

Figure 4.3 Sampling white wine for tasting it. (Image: Samsung Maestros Academy)

Figure 4.4 Specific Gravity analysis with Babo Hydrometer. (Image: Samsung Maestros Academy)

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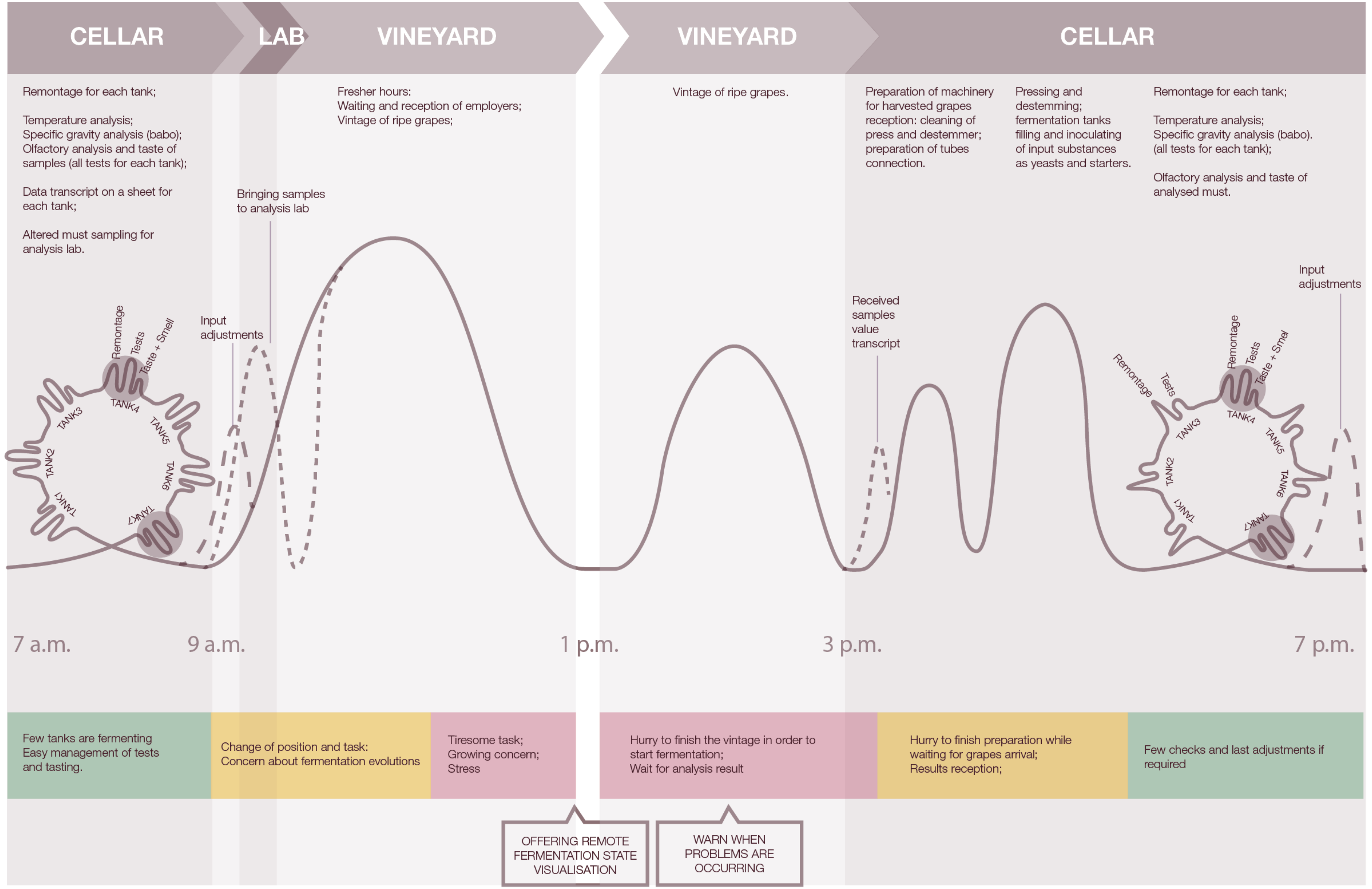

Figure 4.5 Initial Fermentation Period Journey Mapping.

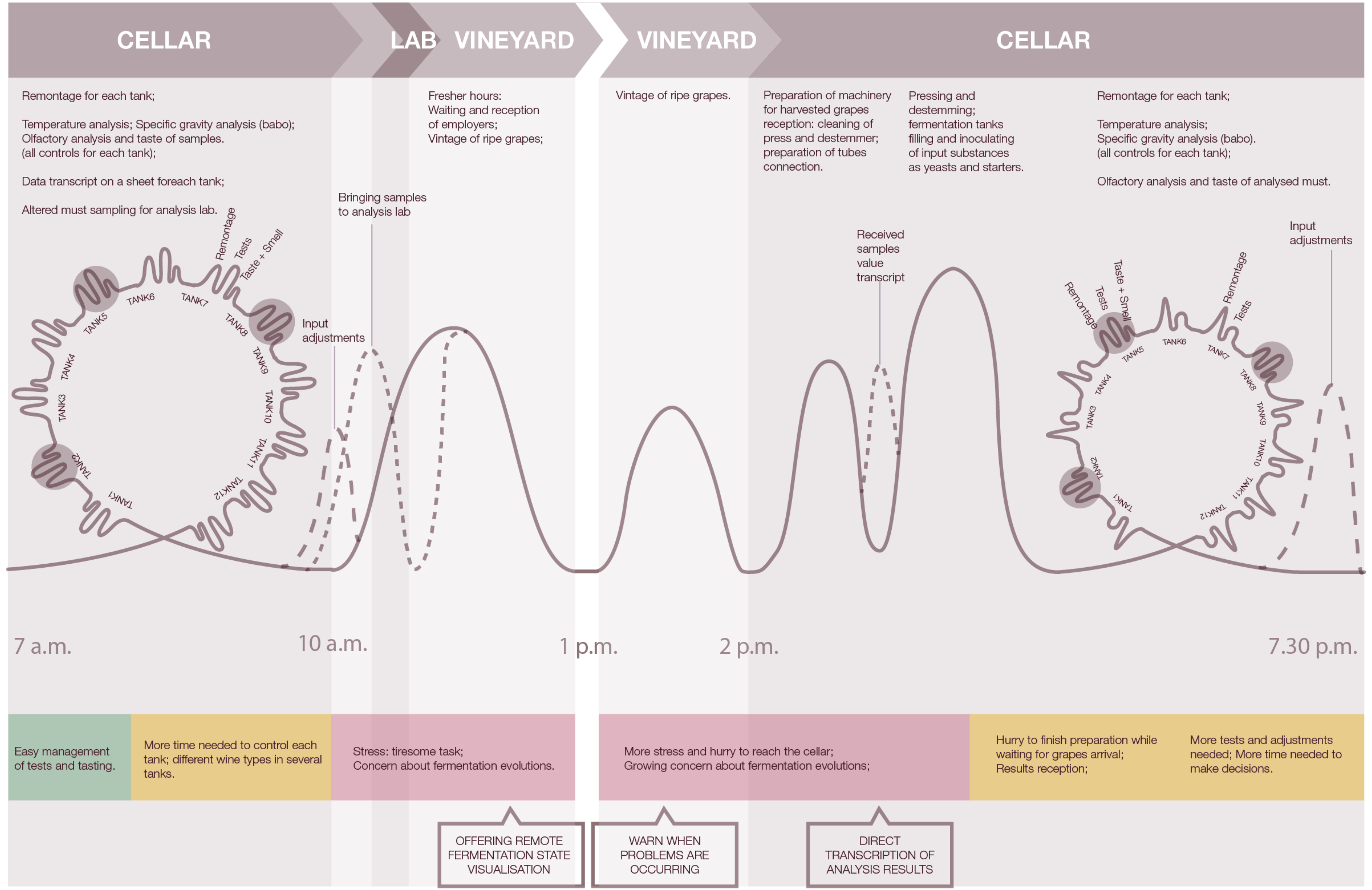

Figure 4.6 Intermediate Fermentation Period Journey Mapping.

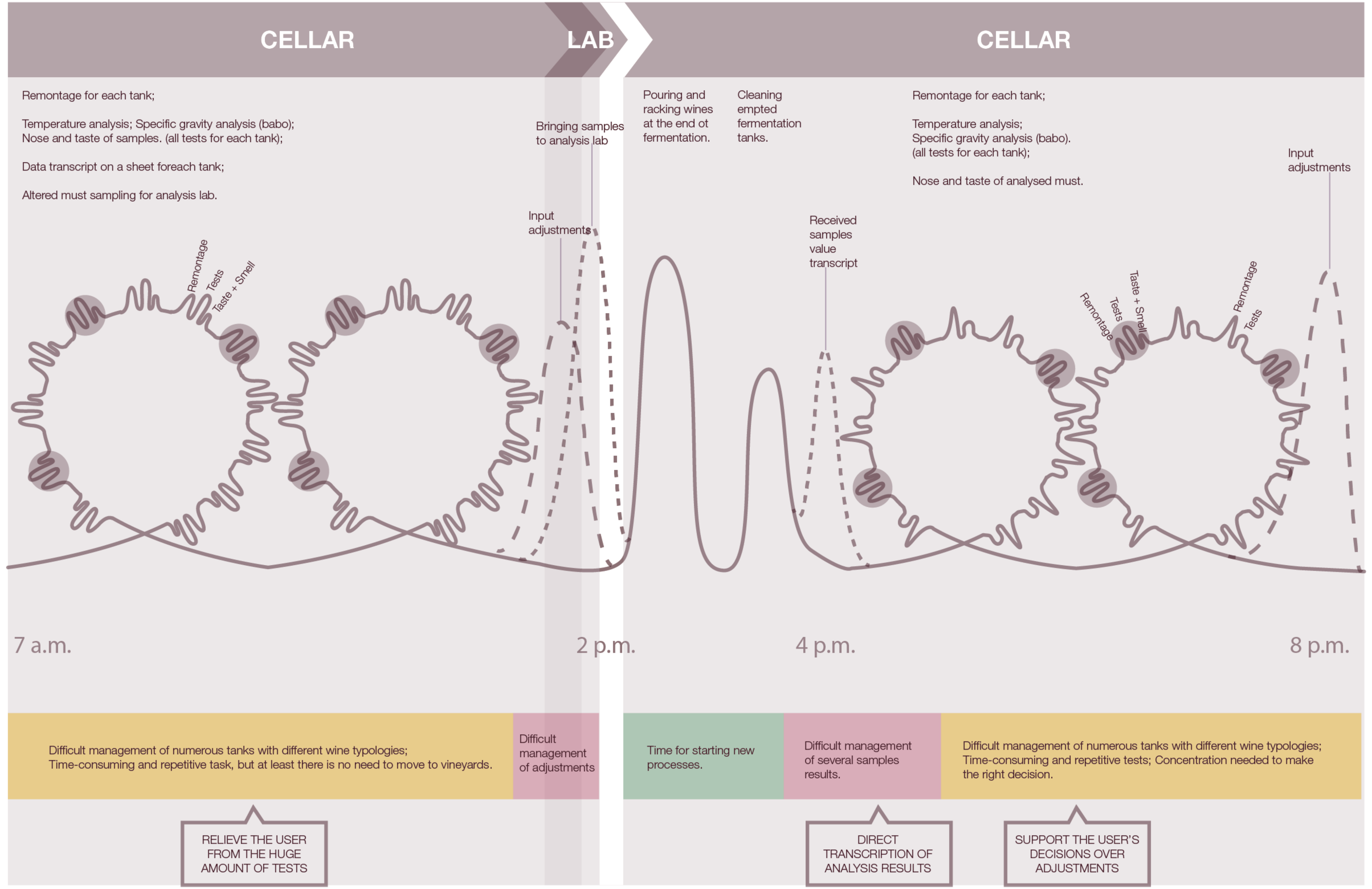

Figure 4.7 Final Fermentation Period Journey Mapping.

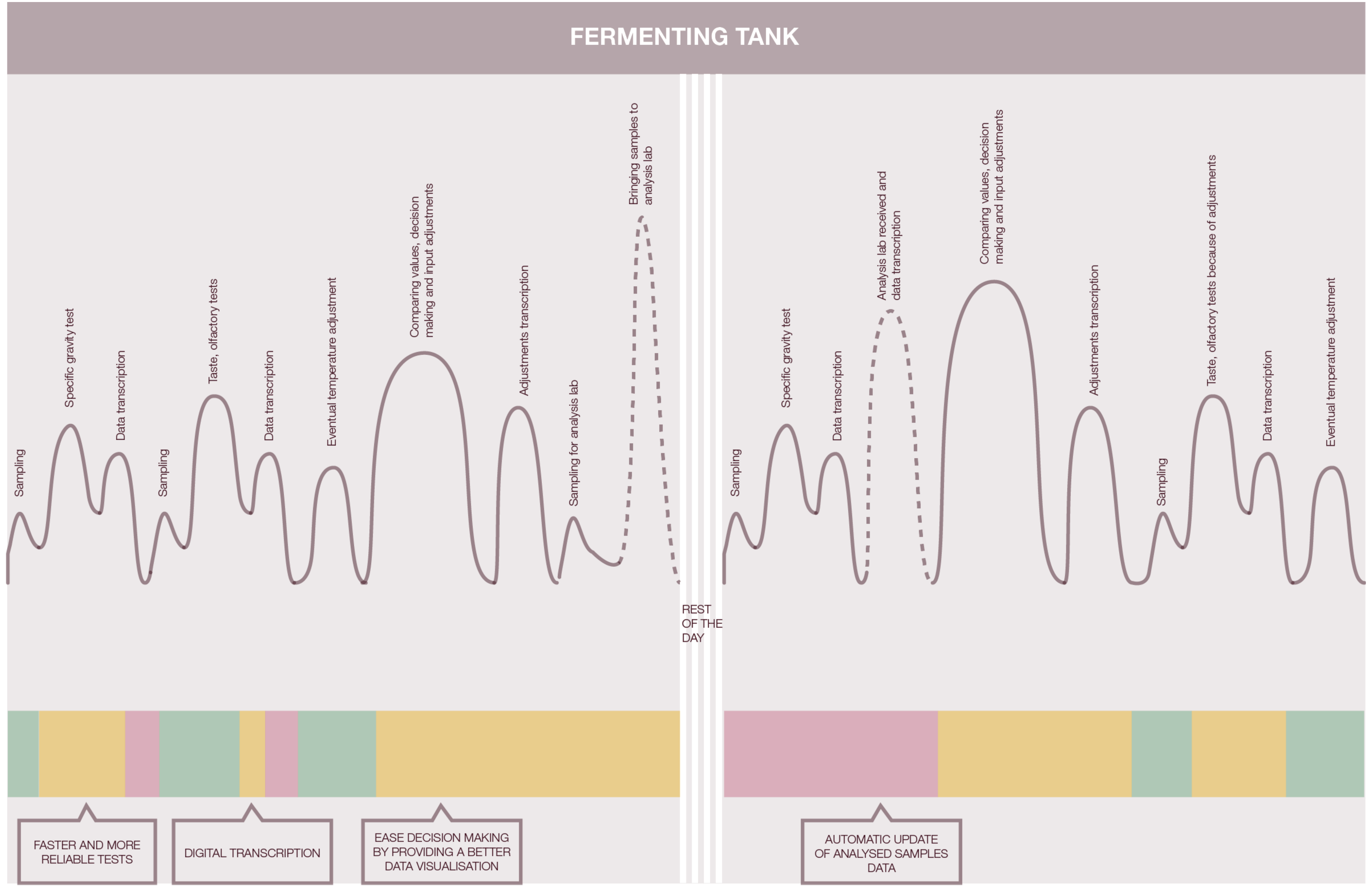

Figure 4.8 Single Fermenting Tank Tests.

4.4
CURRENT - DESIRED INTERACTION

To sum up, the current interaction that the user experiences with the fermentation process can be described as discontinuous, slow and repetitive. Indeed, the user has to solve tasks both in the vineyard and inside the cellar, splitting his efforts during the day. The interaction is slow, since the winemaker relies on an external laboratory for technical analysis and double checks. This causes extended periods of waiting for results. Moreover, manual tests are conducted twice a day and are repeated for each fermentation tank.
On the other hand, the desired interaction can be described as handy, fluid and targeted. Frequent tests taken by a fermentation system could relieve the user from the huge number of manual tests, making the process more sustainable. Remote monitoring and data visualisation are aimed to increase the oenologist control over the process, at the same time reconnecting the user's attention. Finally, providing an overview of all values, analysis and treatments is expected to increase concentration and ease decision-making.

INTERACTION VISION

An interaction vision has been chosen to summarize the design concept: "**driving following directions of your smart fellow traveller**".
As well as the Persona, the desired interaction qualities and the interaction vision have been taken as a point of reference during all phases of project definition.

Figure 4.9 Interaction vision.

4.5
FerMentor CONNECTED SYSTEM

The goal of the FerMentor is to ease the management of simultaneous fermentation processes, enabling a better decision-making process through the visualisation of sets of data gathered from the cellar.
By achieving these goals, the oenologist could increase wine quality, improve work conditions and sustainability.

SMART FERMENTATION MONITORING SYSTEM FEATURES

Insights from the analysis of the Persona and the user's journey mapping with its design opportunities led to the definition of some features that a smart fermenting system should possess.

Gathering values digitally: temperature, pH and specific gravity may be measured by the system that can gather data from each tank at specific times or intervals. The selection of these three values was done because their combination can provide an overview of the evolution of the fermentation process. Other parameters such as wine acidity require chemical reactions and are still intended to be analysed by specialised laboratories;

Real-time data visualisation: data gathered from the system may be immediately ready to be consulted. In addition, there may be a direct communication with the laboratory, that can send results through the system itself;

Remote monitoring: the same data visualisation can be available remotely, when the user is somewhere else besides the cellar (e.g. vineyard);

Notifications and alerts: the system should send notifications or alerts to the user when problems are detected. User's timely intervention could reduce wastes and wine defects.

Data history available: at the end of the fermentation process, all data gathered may be stored and compared in a report, downloadable from the user. This function could increase the oenologist's awareness and expertise.

This smart monitoring fermentation system should at the same time respect the user's values of traditions and his know-how. Only the most time-consuming and labour-intensive tests are replaced by the system. User's tastes and olfactory analysis are still under his control, as well as the final decision of eventually adjusting wine composition.

Furthermore, FerMentor should be integrated in the existing network of relationship of the territory, without interfering with it. Thanks to improved connections, bonds may become stronger and more beneficial for each actor.
Specifically, the bond between the oenologist and the technicians of the laboratory for analysis is enhanced. A direct connection with the system allows a more efficient communication.
The following scheme illustrates how the system has been designed and its connections inside the winery. Devices must be installed in each tank in order to gather data about Ph, temperature and specific gravity. Each tank device is connected to an app that can show values and set of data. Finally, users interact both with the digital app and the connected system to visualise information and make decisions.

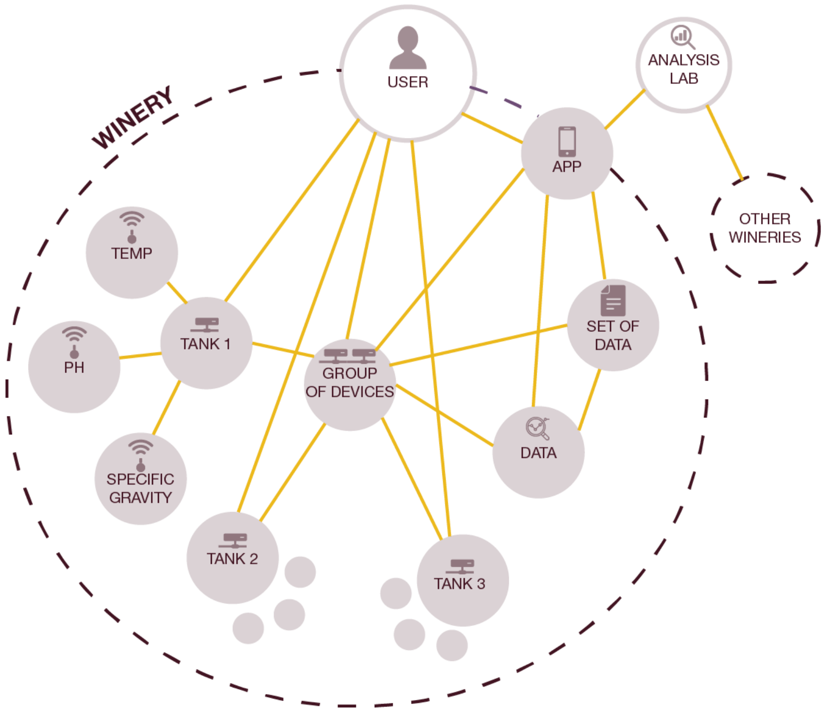

Figure 4.10 Model of FerMentor key concepts and links.

EXPLORING INTERFACES & INTERACTIONS

Once the connected system functionalities were defined, an analysis of user interaction was conducted with the aim of avoiding overturning the user's workflow and habits.

Categorisations of interaction and interface typologies were researched and are listed below (Elizabeth Goodman, 2015, pp. 275 - 326).

Interactions

Tangible and Tactile Interaction

This section includes either interfaces that work with manipulation and the addition of physical products or interfaces that deal with haptic and tactile feedbacks. An example of the first category of tangible user interface is the Reactable music instrument, a table which make sounds depending on the position and movement of tokens over its surface. On the other hand, an example of tactile output may be the AR electrical muscle stimulation (EMS) that makes interaction with virtual bodies tangible throw haptic force feedbacks (Pedro Lopes, 2018).

Benefits: Analogic experience, it does not feel like interacting with digital or virtual object or even with a computer.

Drawbacks: Other components need to be added to the system that may have a limited lifespan or may be lost.

Figure 4.11 Reactable electronic musical instrument. (Image: Daniel Williams)

Context sensitive interaction

It involves context-aware computing.
A device in this category may be aware of

Figure 4.12 Eddystone compatible location beacon. (Image: 01Net)

different kinds of context such as environmental context or user activity context. For instance, the weather forecasting device created by David Rose shows different levels of information visualisation to the user, depending on his/her proximity to the product itself. Another example is the Bluetooth Beacon technology, mainly used for proximity advertising, because of its ability to send instant notifications to smartphones that are located inside the connectivity range.

Benefits: Progressive information disclosure. High level of complexity may be handled with little interaction intuitively.

Drawbacks: User's options are limited. The interaction occurs without much or any input from the user.

Gestural interaction

Computer vision may also be used to recognise gestures and associate them to commands. The Leap Motion Controller is a tool that can be embedded to a PC or other personal devices. It recognises previously taught gestural commands and performs the required task.

Benefits: the interaction is easy, it replaces manual inputs and can be fast to respond to commands.

Drawbacks: False positive recognition may happen and interactions are not precise.

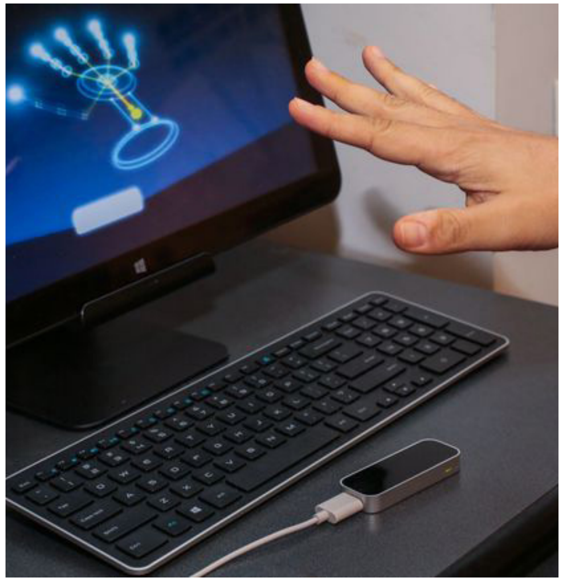

Figure 4.13 Leap motion controller. (Image: CNet)

Figure 4.14 Ikea app with Apple ARKit.
(Image: Corriere della Sera)

“Seeing” devices interaction

This last interaction section deals with devices that are able to see what is around them or respond to a specific activity. Computer vision in an enabler of this interaction. An example of this interaction may be the Ikea catalogue, which allows the user to augment the traditional experience by visualizing more information about some products using VR with smartphones.

Benefits: Replacement of manual inputs rapidly.

Drawbacks: it requires computer vision features or the presence of additional software (like QR readers) that can increase complexity.

Interfaces

Physical interface and controls

This is the most common interface. Almost every device is equipped with push buttons, switches, sliders or rotatory knobs. They are needed in order to choose between two states (on/off), between multiple settings and so on. When designing physical interfaces, haptic and ergonomics need to be researched in order to realise the desired affordance.

Benefits: They provide direct and fast controls.

Drawbacks: Connected systems require functions to be controlled from multiple places and remotely. Physical

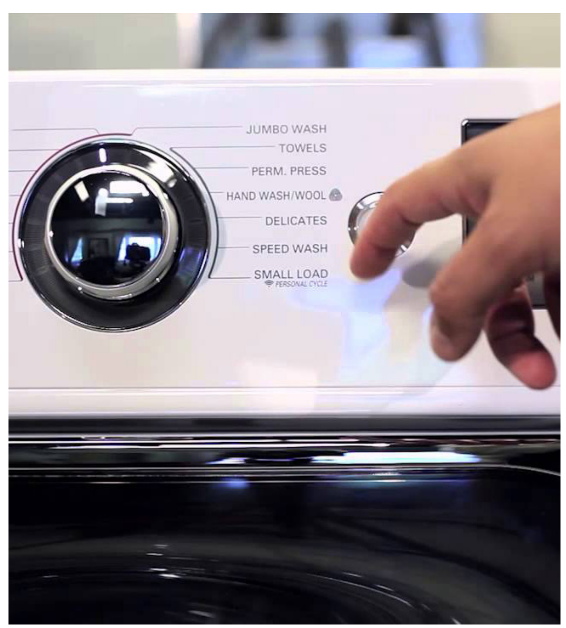

Figure 4.15 LG washing machine control buttons.
(Image: LG)

controls only work locally.

Figure 4.16 Notification light that changes colour.
(Image: Android PIT)

Screen interface

The level of information content of displays is higher than that of light interfaces.
They may be LCD (liquid crystal display), they may use a character set layout or they can even be high definition screens. The choice of the quality level depends on the kind of information that is intended to be visualised.

Benefits: Devices can provide detailed information. Dynamic screens offer flexible interaction.

Drawbacks: the user experience becomes more complex and its duration increases.

Light Interface

This section includes light interfaces, usually in the form of LEDs. Lights are used to communicate information about the status of a device or a system. Sometimes colour codes are used to show additional and more complex information.

Benefits: glanceable and nonintrusive information output.

Drawbacks: only simple information can be conveyed.

Figure 4.17 Fitbit bracelet using a display.
(Image: The Verge)

Audio interface

Sound interface particularly useful as output method. Alarms and signals are usually in the form of beeping.

Figure 4.18 Beep notification.
(Image: Impetus Fitness)

Different sounds, different frequencies and duration can refer to contrasting situations. Due to the high emotional value sound carries, it is easy to identify and pay attention to this interface.

Benefits: useful for urgent and time-critical alerts, when attention must be captured immediately.

Drawbacks: sound output may become annoying for some environments and disturb other people who are not supposed to interact with the device.

Voice interface

This last section deals with voice either as an input or as an output. A wide range of information may be provided with a computer speech instead that with a sound. Navigation systems, for instance, give indications through a computer voice.
On the other hand, devices may interact with users through speech recognition.

Benefits: useful when minimal physical interface is required as well as complex data input.

Drawbacks: voice interfaces may cause problems of unsuccessful input since speech recognition can be unreliable.

Figure 4.19 Amazon Alexa voice service.
(Image: The Verge)

MULTIMODAL INTERACTION & INTERFACE

The previous detailed categorisation of possible interactions and interfaces has been crucial for the selection of the desired combination of FerMentor.
Two guide principles have been choses: the "flexibility-usability tradeoff", one of Butler's universal principles of design (William Lidwell, 2010, pp. 102 - 104) and the made up "analogical-digital tradeoff". The first one states that balance is needed among many functions and features of a device and the ease to be used. The second principle establishes the aim to balance the digital content of the system with the analogical perception of it. Specifically, four system interaction features have been selected for FerMentor. The first one is the impression of interacting with an analogic system. Then, a coordination among physical controls for each tank and the remoted connected app is required. In addition, notifications and alerts are essential to the system functioning: they may spring to action without stressing the user. Finally, FerMentor should react to user's proximity to reveal information.

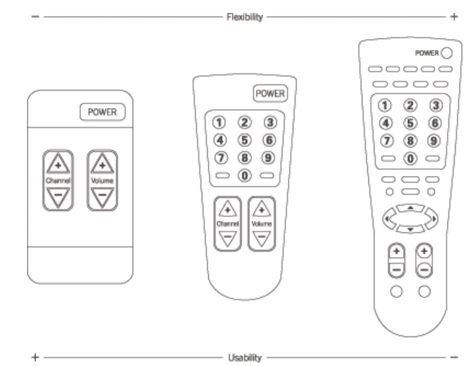

Figure 4.20 Flexibility Usability trade off.
(Image: O'Reilly)

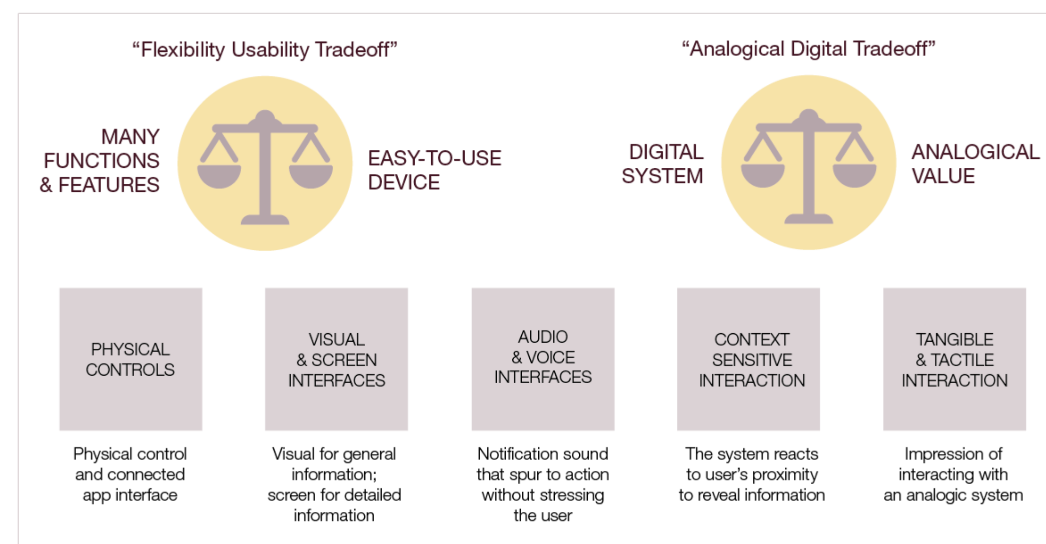

Figure 4.21 Multimodal interactions and interface key concepts.

4.6
SYSTEM COMPONENTS: UX AND UI

UX and UI of FerMentor system may be divided into two main areas: remote monitoring with notifications and alerts and in loco interaction with the tank. A mobile app and a wearable play a leading role in the first area, while a control knob is essential in the second one.

MONITORING PROBE

The monitoring probe is composed of three sensors (Ph, temperature and specific gravity) and a bodywork that contains them all. Since the probe has to be put inside the liquid, it must be water-resistant, at least with level IPX7 of protection (immersion up to 1 m depth).
In order to enter the wine fermentation tank, the probe should behave as well as a valve. Indeed, tanks are closed environments and the only opening present is the vent valve which assures the correct internal pressure. The development of this bodywork containing the valve was not carried on, since it is does not regards the focus of this dissertation. It may be considered as a future development of FerMentor design.

WEARABLE: BRACELET

The design of a mobile app allows the winemaker to visualise fermentation data whenever he wishes. Notifications are received regarding updates and data availability.
In addition, a smart bracelet connected to the system has been designed with the aim of alerting the user when problems are detected inside the cellar.

The wearable has been chosen in order to provide immediate response with a preferred channel. Indeed, during the performance of tasks such as harvesting, smartphones may be left in a pocket and signals may

not be perceived as important. Moreover, a bracelet is a non-intrusive component that can be carried constantly by the oenologist.
Alerts are provided in the form of vibrations that are immediately detected by the user. Light and sounds were not considered for this purpose, because they could go undetected in bright or noisy environments.
Also, during some tests, it has been proven that haptic output captures attention more than light and sound ones.

The aesthetic of the bracelet refers to the shape that wine creates when the glass is tilted for tasting.

Furthermore, the material chosen is silicon, since water resistance propriety is required.

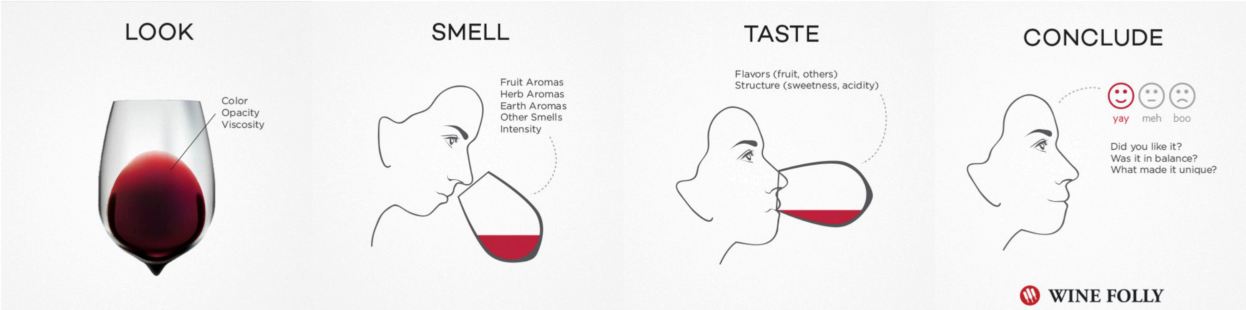

Figure 4.22 How to taste wine. Identification of the bracelet shape. (Image: Wired)

Figure 4.23 Wine colour test, tilting the glass while tasting. (Image: Wired)

CONTROL KNOB

Current interactions during the fermentation process were reviewed with the aim of designing a user interaction coherent with the oenologist's routine inside the cellar. During the definition of the journey mapping, it has been said that sampling always precedes each test. Then, the main interaction with the wine fermentation tank is the opening of the faucet, by turning a knob of a handle.
For this reason, a turning knob has been designed to turn on and off the device for each tank. This interaction occurs when the fermentation process starts and when it ends. A graphic component has been added to the button, in order to produce a visual feedback in an analogic way. Indeed, when the tank is filled and the knob is turned, the silhouette of wine waves is composed, to point out that the fermentation process is going on.

When the user reaches the tank to complete testing, a second interaction with the knob arises. In that moment the oenologist has to check the mobile app that illustrates all fermentation parameters and make decisions. Since each winery has several tanks for fermentation (twenty-thirty), an easy and immediate way for the identification of each tank was needed. For this reason, proximity push visualisation has been chosen with the scope of triggering the opening of the concerned page.
A small chance of failure was considered, due to interferences or disconnections. So, a secondary procedure has been designed as well. A physical contact between the bracelet and the knob could restore the desired feature. In order to boost the affordance, a recess with the same shape of the bracelet has been added at the centre of the knob.

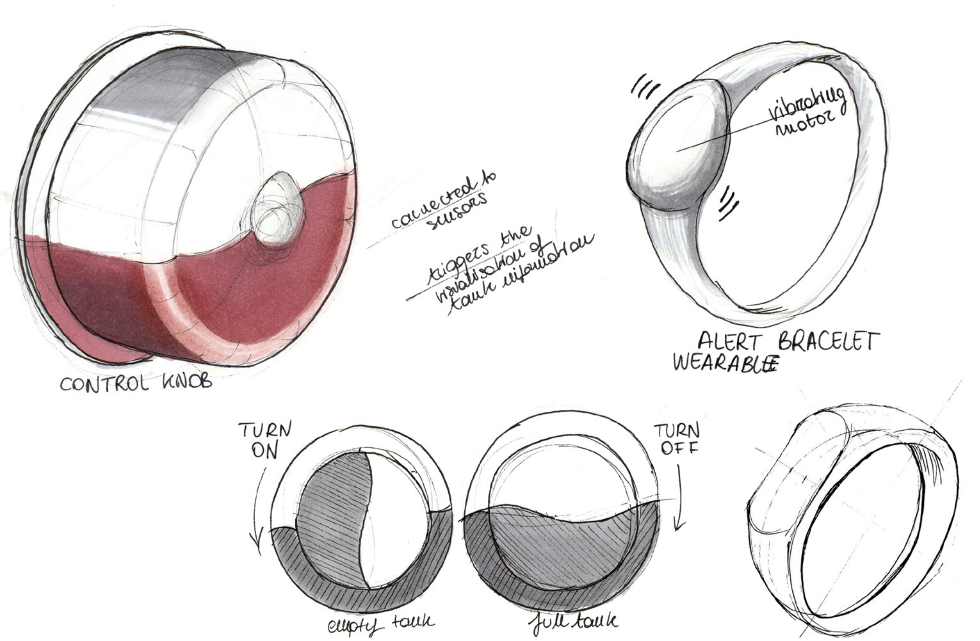

Figure 4.24 Sketches of the control knob and of the bracelet.

MOBILE APP

Figure 4.25 FerMentor app icon.

FerMentor mobile app contains several functions that aim to make the user feel in control of the entire monitoring system.
Its design is based on the principle of Progressive Disclosure, which means that information is revealed in coherence with a pyramidal approach. Insights are the first information visualised, followed by their explanations and at the end by supporting data. The more the user interacts with the app, the more knowledge he gains.

Graphics are clear and elegant and the colour palette has been inspired by grapes and colour during the wine production process.
A mock-up of FerMentor app has been designed in order to clearly illustrate all its features and then to test the UI.

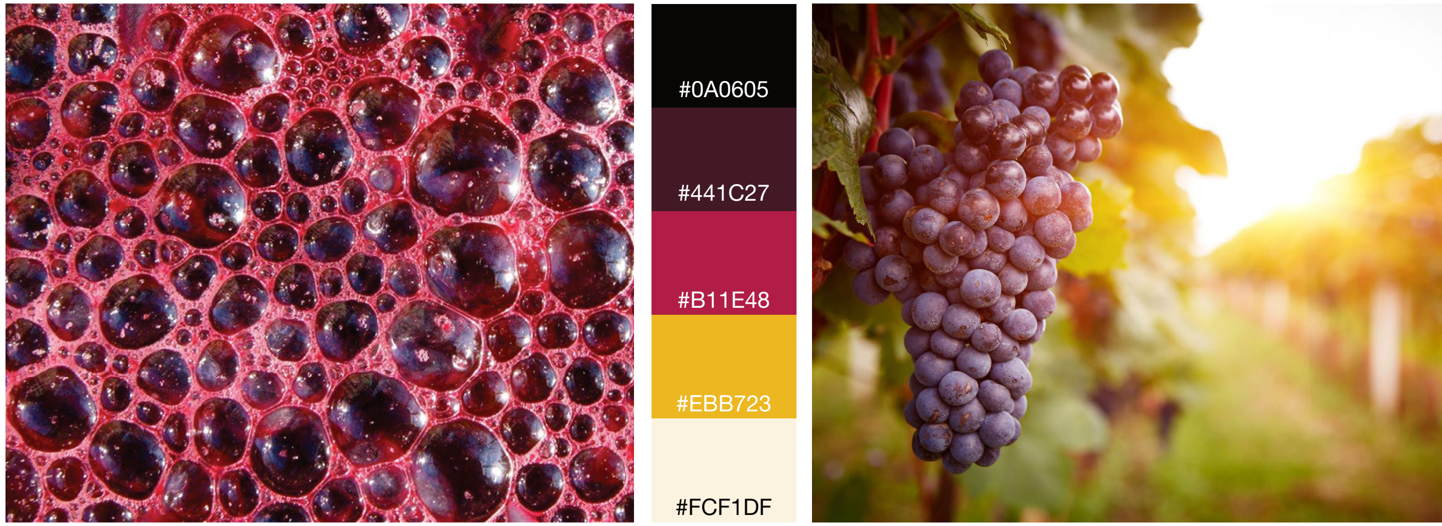

Figure 4.26 Colour Pelette and inspiration images.
(Image A: Jardins Eféméros; Image B: Fanrto)

Setup

An initial setup has been considered because each oenologist produces different wine typologies and owns a diverse number of tanks. Also, more than one tank may be devoted to the fermentation of the same wine.

The app setup provides the possibility of mapping all tanks, so that when a problem occurs, the user is able to pre-visualise where to go. Two methodologies have been considered for the design of cellar planimetry and consequent tanks mapping. The first mapping procedure deals with computer vision and the second one with an artificial intelligence. Presently, the first technology is called SLAM (Simultaneous Localization and Mapping) and it is commonly applied in the

Figure 4.27 Microsoft Hololens SLAM process. (Image: 36Kr)

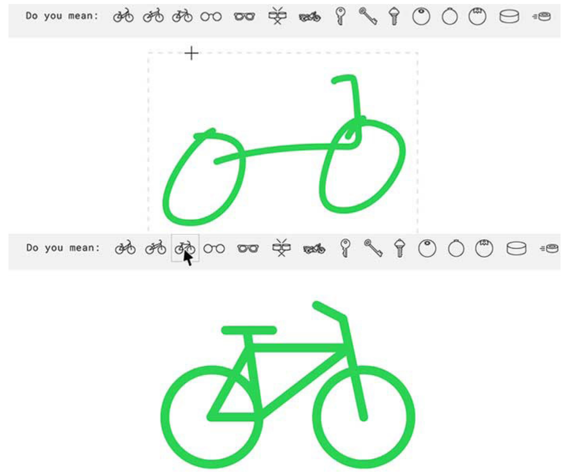

Figure 4.28 Google Auto Draw example. (Image: Dunyanews)

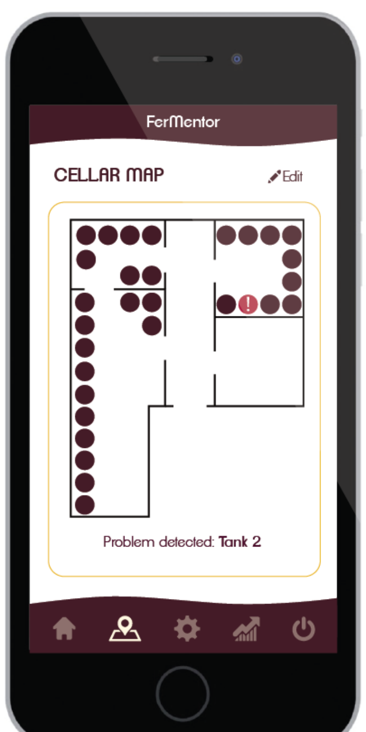

Figure 4.29 Visualisation of the cellar map after setup. The highlighted tank is the one that needs attention.

Figure 4.30 Dashboard with wine typologies after setup.

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robotics field.
For this reason, the second option has been selected. Specifically, it refers to the Google AutoDraw that recognises doodles and transforms them into more realistic drawings. Then, the app could allow the user to sketch the planimetry of his cellar and, as a result, it could offer a realistic representation where to position all tanks.
Finally, setup deals with pairing each component of the system together. The connection with the laboratory for analysis has to be created in this initial phase as well.

Customisable rules

The user can personalise functions regarding data gathering timing, threshold values of sensors and notifications and alerts. He can decide when to receive notifications or alerts, for which reason and if to disable them during the night. The system flexibility is extremely important for adapting FerMentor to small wineries.

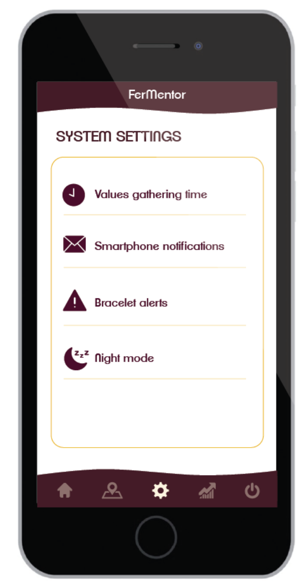

Figure 4.31 System settings options.

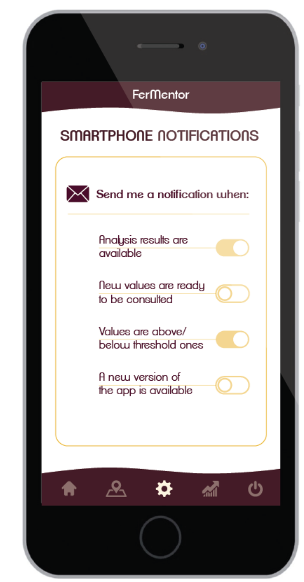

Figure 4.32 Pesonalisation of smartphone notifications.

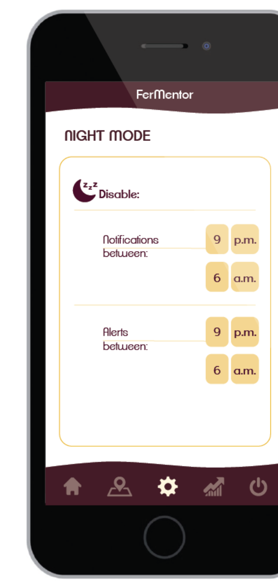

Figure 4.33 Setting time for the night mode.

Visualisation of unified values

A portion of the app allows the winemaker to visualise real time gathered data from each tank. For each parameter, it is possible to decide its optimal range and monitor the development during the fermentation process. In addition, each tank section contains a button that refers to the laboratory of analyses. There, all tests results are received, li-

sted and ready to be consulted.
A direct connection with the laboratory may reduce stress and worry while awaiting results, at the same time easing the decision making for eventual treatments because of the complete overview.

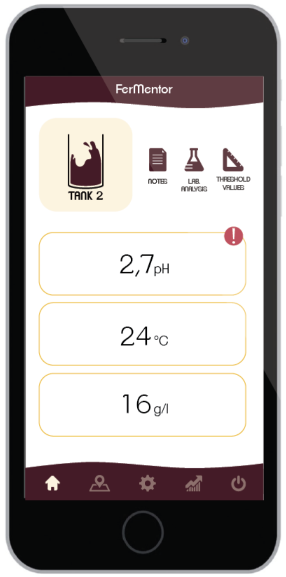

Figure 4.34 Overview of data gathered for each tank.

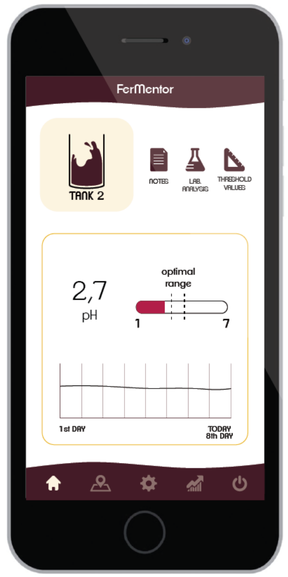

Figure 4.35 Progressive disclosure of information about each tank.

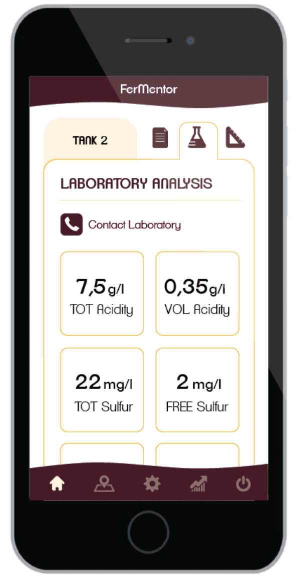

Figure 4.36 List of values analysed from the laboratory.

Notes

The user can add annotations about tasting, olfactory analyses, additions and processes taken over each tank.
All information is stored and classified with date and hour, under the previous big categories.
This function was added with the aim of replacing the time-consuming transcription of information for each tank by hand on paper sheets.

Final reports

At the end of the fermentation processes, a report of history data becomes available for download.
It provides an overview of annotations, values gathered, analyses results, additions and wine treatments.
The aim is to increase user's knowledge and improving future managements, by comparing difficult situations with past experiences when similarities are detected.

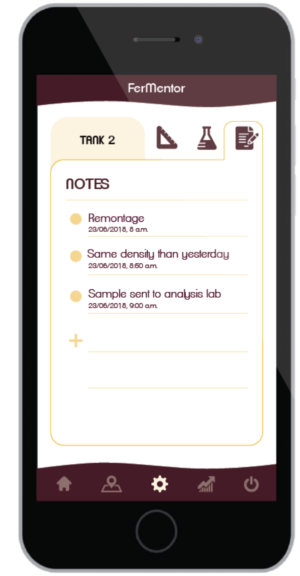

Figure 4.37 Annotations function available for each tank.

Figure 4.38 Report ready for download.

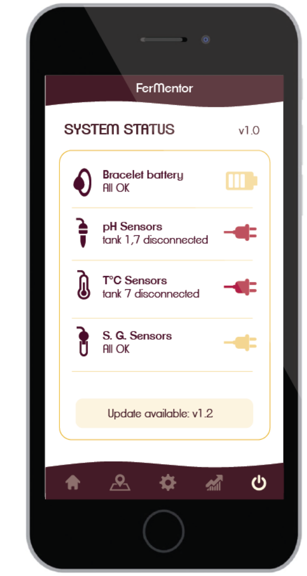

Figure 4.39 System status.

System status awareness

FerMentor app gives the possibility to visualise the status of the system. Specifically, it is possible to understand the battery level of the bracelet whereas Ph, temperature and specific gravity sensors are connected and functioning.

SYSTEM ARCHITECTURE

In order to assure the functionality of FerMentor, an internet connection has to be installed both in the cellar and in the vineyard. Indeed, each part of the system must communicate and exchange data with the others.

The system is composed by several nodes, a gateway and the secondary controller: the wearable.

Nodes

There is a node for each tank. They include three sensors and a Bluetooth module for the in loco connection with the app and the wearable.

Gateway

It provides the Internet networking and security of the system.
It may be a source of control that can keep

the system running even when Internet is unavailable.

API

Fine-grained API allows for control of specific devices or retrieving specific pieces of data.
Moreover, they enable communication with third parties like the analysis laboratory that has to communicate analyses results to the connected system.

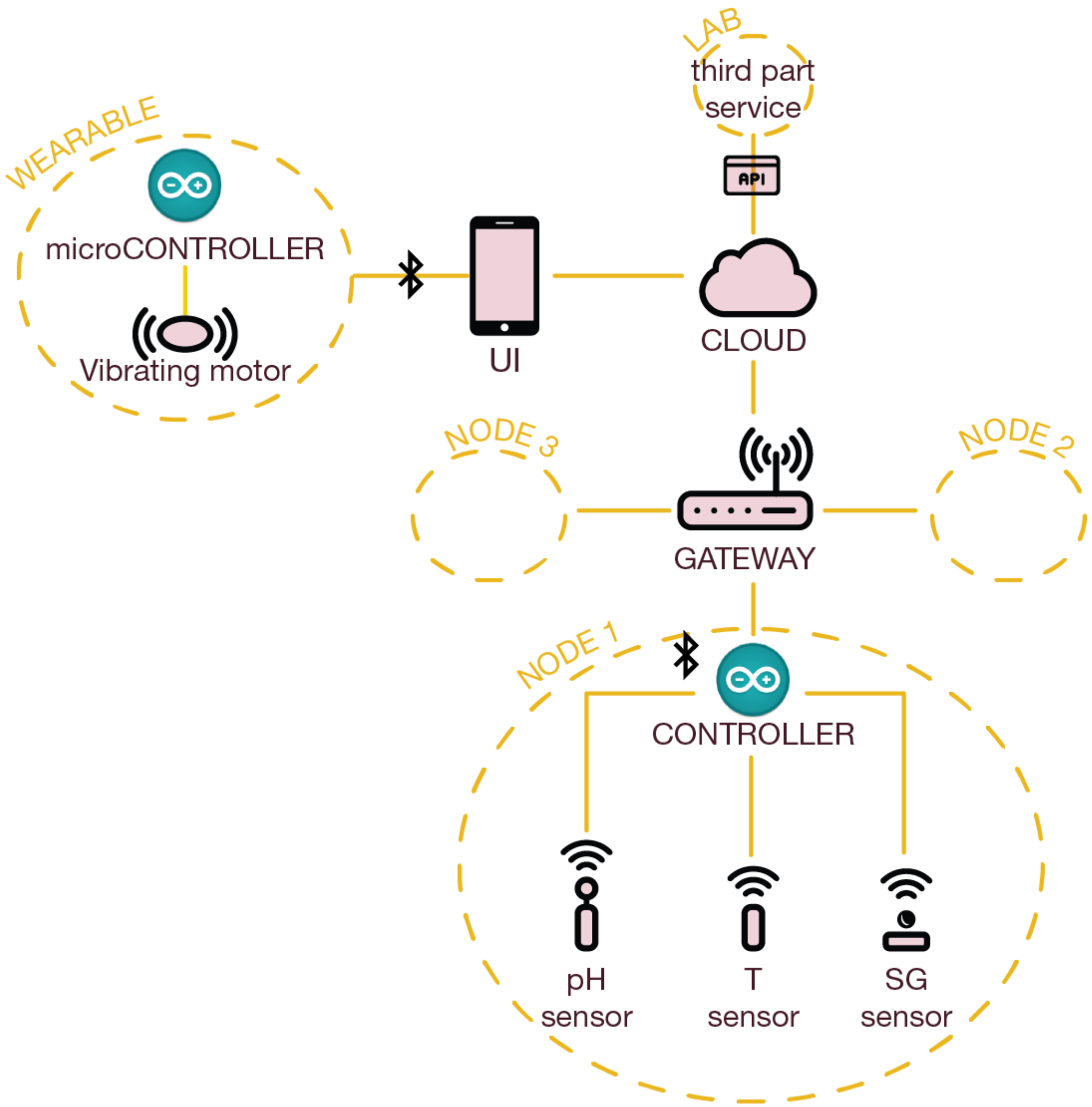

Figure 4.40 FerMentor connected system: architecture scheme.

PROTOTYPATION

The electronic controller used for the prototype is an Arduino Yun.

The ability to connect to the internet and communicate with cloud was essential, especially concerning data and the communication with the second smaller controller for alerts. This second controller is responsible for the vibration of a vibrating motor for alerts.
First of all, it was necessary to program Arduino in order to extract values from a liquid sample.

The digital hydrometer has not been built since it is not just a sensor but a combination of separate parts. Among all possibilities of measuring the specific gravity of the must, the best method discovered works thanks to an accelerometer. It may be inserted inside a test tube, which floats on the must, measuring the angle variations as the density of the fluid changes.
Sine the value extracted could be imprecise, the prototype that has been built focuses only on gathering temperature (DS18B10) and Ph (SEN0161).
Specifically, calibration was required for the Ph probe, using a basic and an acidic solution.

Subsequently, a program was created, whose task is to receive the data and to interact with the second controller: Arduino MKR 1000. Its task is to make a motor vibrate in case the collected values are below or abo-

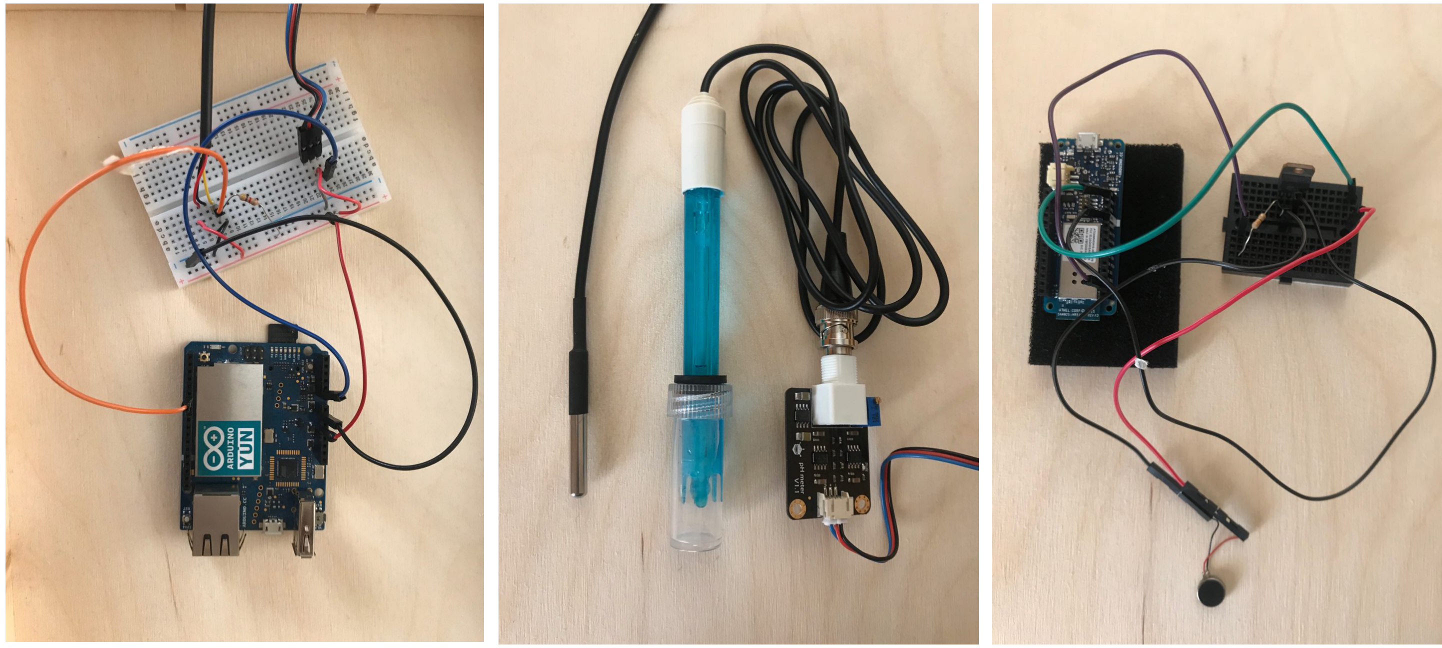

Figure 4.41 A-First controller: Arduino Yun
B-Temperature probe and Ph probe
C-Second controller: Arduino MKR 1000 + vibrating motor.

ve the set threshold level. The motor simulates the wearable bracelet vibration that alerts the user if problems are detected.

Finally, data collected by Arduino is sent to Google Firebase, which enables users to keep track of the values and communicate them to a web page. For this purpose, a portion of the app has been created: it shows the overview of a tank with data gathered.

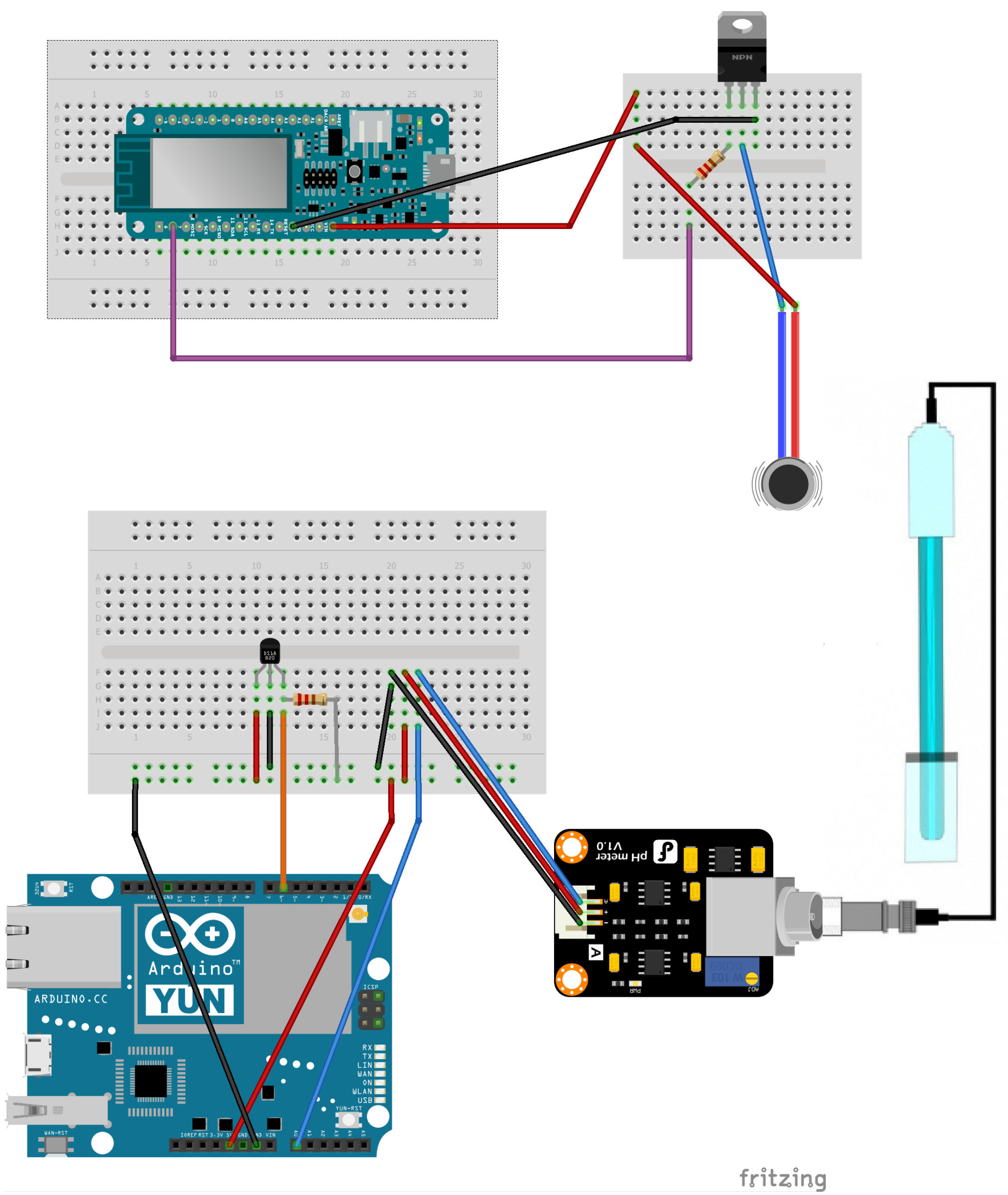

Figure 4.42 Circuit diagram.

ESTIMATED PRODUCTION COSTS: MAKERS vs. INDUSTRIAL PRODUCTION

A reflection on potential costs of the FerMentor connected system is essential to show its practicality and applicability in small wineries.
Two cost analyses are possible: while the first one concerns the do-it-yourself option, the second regards the hypothesis of an industrial production.

The makers' movement is increasingly growing in popularity and more and more people have been trying to realise smart projects as interactive electronic objects by themselves. Indeed, technological advancement promotes the dissemination of low cost processors and sensors, whose availability in the past was unthinkable. Moreover, makers can be considered small businessmen who target niche markets, solving precise personal needs. Jason Kottke refers to this new group as "small batch" (Anderson, 2012, pp. 95 - 97).
This dissertation proved that it is possible to build a functional monitoring system based on physical computing, for instance using Arduino, an open source electronic platform. Following this lead, some winemakers could decide to build the system by themselves, or asking for help to makers' communities. In this case, the estimated cost for monitoring a tank is about 100 €, considering sensors and controller.
However, in order to foster this self-handling, it would be essential to share the project features with a community. Indeed, if FerMentor were open source, everyone could contribute to its technical development, depending on each user's needs.

The second cost analysis may be done, with regards to the industrial production. In this case, it is not possible to consider small production batches anymore, since industries work with high numbers (over 1000 units). This industrial production could be useful when more than one winery cooperates, as has been seen with cooperatives.
The estimated cost for large-scale production is about 50 €.

4.7
TESTING THE FerMentor CONNECTED SYSTEM

After the prototype and the app have been designed and built, it has been possible to test them in order to confirm the assumptions made so far, UX and UI of FerMentor.
In doing so, it has been chosen to have this system tested with its potential user: the oenologist of a small agricultural holding. Indeed, all research about users and their customer journey has been carried on considering the winemaker at the centre of the project. Also, the cooperation with oenologists from small wineries has led to the understanding of their needs and to the identification of design opportunities. For all these reasons, it has been deemed as essential to interface once more with the real final user of the connected system.

FerMentor has been designed with the intention to relieve oenologist's stress, increase user's control over the process, augment his knowledge and decrease potential findings during vinification. All the previous assumptions were questioned during the testing.

PROTOTYPE TESTING

The prototype and the app mock-up have been tested twice with two oenologists from two wineries. The first testing was conducted at the Azienda Agricola Poggio, with the owner and oenologist Matteo Poggio. The second testing was conducted inside the Bi.Lab., with the oenologist Luca Faccenda and some members of this chemical laboratory, close to Alba.

The testing started with a tutorial on how the prototype with sensors works. The two Ph and temperature probes where inserted in a glass of water and the system was turned on. Then, the portion of the app that communicates with the cloud was shown to let the tester visualise gathered data. In order to complete the experience of the user during these experimenting, threshold values

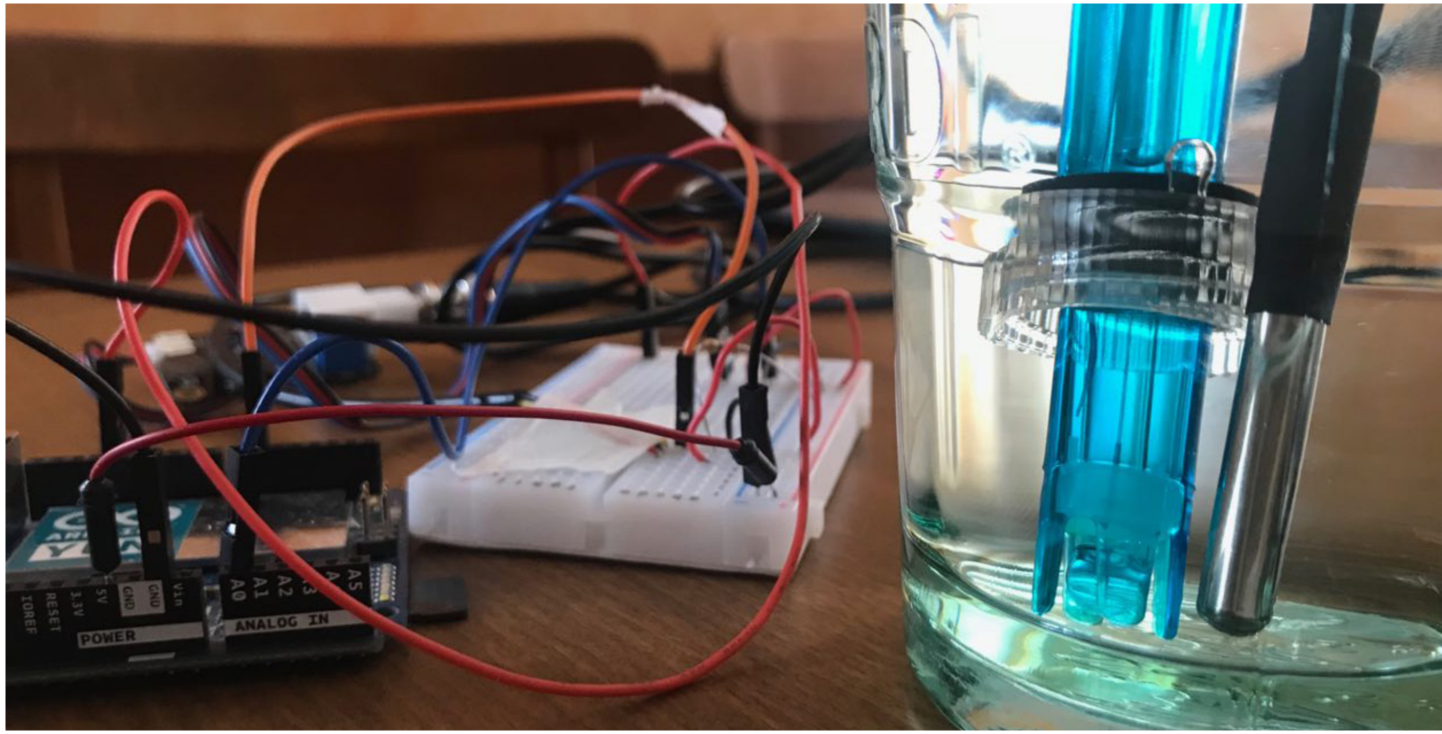

Figure 4.43 Testing the prototype while gathering data from a glass of water.

of the Ph probe were set as though a problem was occurring inside the solution. As a consequence, it has been possible to evaluate user's reaction to the alert feedback. The testing of vibration was conducted by making the users touch the vibrating motor with the aim of simulating the haptic alarm of FerMentor bracelet.

The second part of the testing focused on

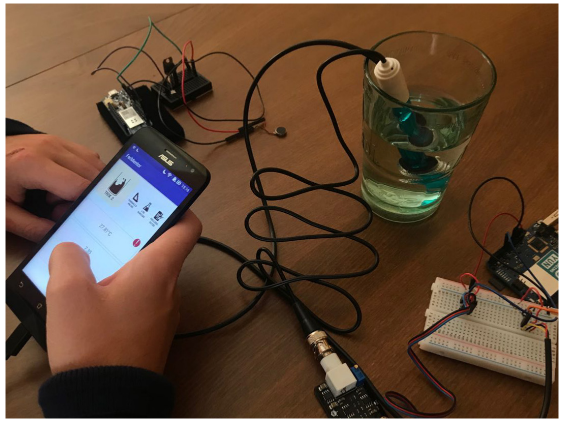

Figure 4.44 Real time visualisation of data gathered from Ph and temperature sensors.

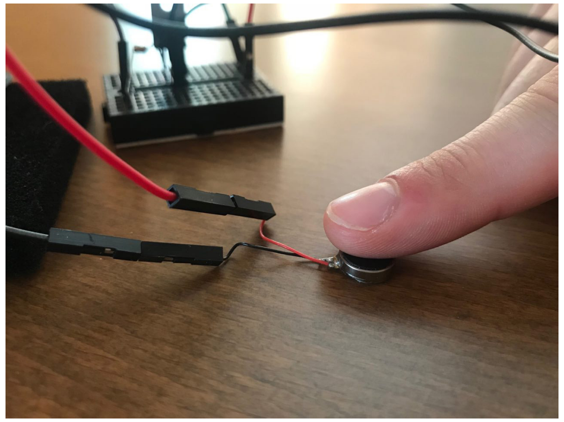

Figure 4.45 Testing the vibrating motor alert.

the mock-up of the mobile app. In this case, initial indications were given to the testers, in order to let them interact with the mock-up independently.

At the end of the testing, a questionnaire was filled out. Initial questions were related to the general functioning of FerMentor, the expected use experience, its critical points and strength. Some questions were meant to test the app and its usability, while others focused on the wearable. Finally, some suggestions about future developments or possible implementing where asked.

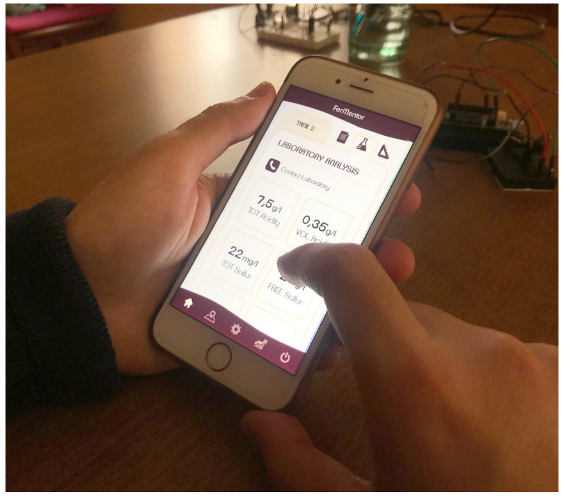

Figure 4.46 Testing of the mobile app mock-up.

INSIGHTS AFTER TESTING

During the testing and the completion of the questionnaires few insights have been received concerning either the entire system or its components. Main findings are descripted below.

FerMentor connected system general review

First of all, the desired interaction qualities (handy, fluid and targeted) were confirmed, meaning that assumptions about the user experience were right.

The general functionality of the system was appreciated since advantages over the management of the cellar were recognised. The possibility to frequently monitor fermentation status was particularly appreciated because it could increase the oenologist's control, by providing an overview of fermentation evolution. FerMentor was compared to a tutor which can address the winemaker attention towards the right decision.

Connection with the laboratory for analyses review

Also, the immediate connection with the laboratory for analyses was considered beneficial because it could reduce the number of steps in the relationship among winery and laboratory.
As a consequence, this powered link could speed up oenologist's problem solving in troubled situations and help the technicians selecting the most suitable tests.

Annotations function and data history report review

During the mock-up testing, the "note" function was also appreciated because it may reduce user's efforts in taking notes by hand regarding additions, process steps and tests results.

Moreover, the possibility of storing this information digitally could ensure their durability and allow comparison when some fermentation processes present similarities.
The report availability brings some advantages as well in this respect. Indeed, they could offer a complete backup of past practices, useful for increasing the oenologist's decision making and for tracing the entire production process.

Notifications and alertseview

Notifications on the smartphone and alerts on the bracelet were considered valuable because they could capture users' attention especially when they are busy solving other tasks such as harvesting. These functions are able to augment oenologist's interventions readiness.

EXPECTED ADVANTAGES DERIVING FROM THE APPLICATION OF FerMentor

Thanks to the above-mentioned insights, it is possible to represent a new fermentation flow, which refers to the previous illustrated journey mapping.
In general, the workflow is more balanced, stressful moments are fewer, final satisfaction is higher as well as output quality because FerMentor allows a better management of the production process.

The following images (Figure 4.47 and Figure 4.48) illustrate a comparison between the current journey mapping in small wineries and the expected journey mapping after the application of FerMentor connected system.

The first image illustrates the workflow for each tank. In this graphic it is possible to notice that the apexes of each curve are lower because stress decreases. Indeed, the possibility of visualising and controlling values and the fermentation evolution from the mobile app allows faster decision making and faster intervention.
Moreover, oenologist's actions for each tank are reduced, because some tests are already being taken by FerMentor.
Also, manual notes transcriptions are no longer necessary, meaning that a lot of time can be saved.
Finally, less distractions arise since analyses results from the laboratory are received directly on the app.

The second image shows a comparison between two typical days in the intermediate phase of the fermentation period. Even in this case, it is possible to notice that the stress amount is decreasing. In fact, the user is expected to be more at ease since he can monitor the fermentation state remotely and he is notified when problems are occurring.

At the beginning and at the end of the day, the workflow changes because the oenologist's attention is focused on those tanks in which the connected system has detected a problem first. The intervention on these tanks is faster and less adjustments are needed, because they are foreseen to be more precise.

As a consequence of these improvements concerning the user's journey, the production process is planned to become more fluid and wine quality is expected to increase, since inconveniences may be readily dealt with.

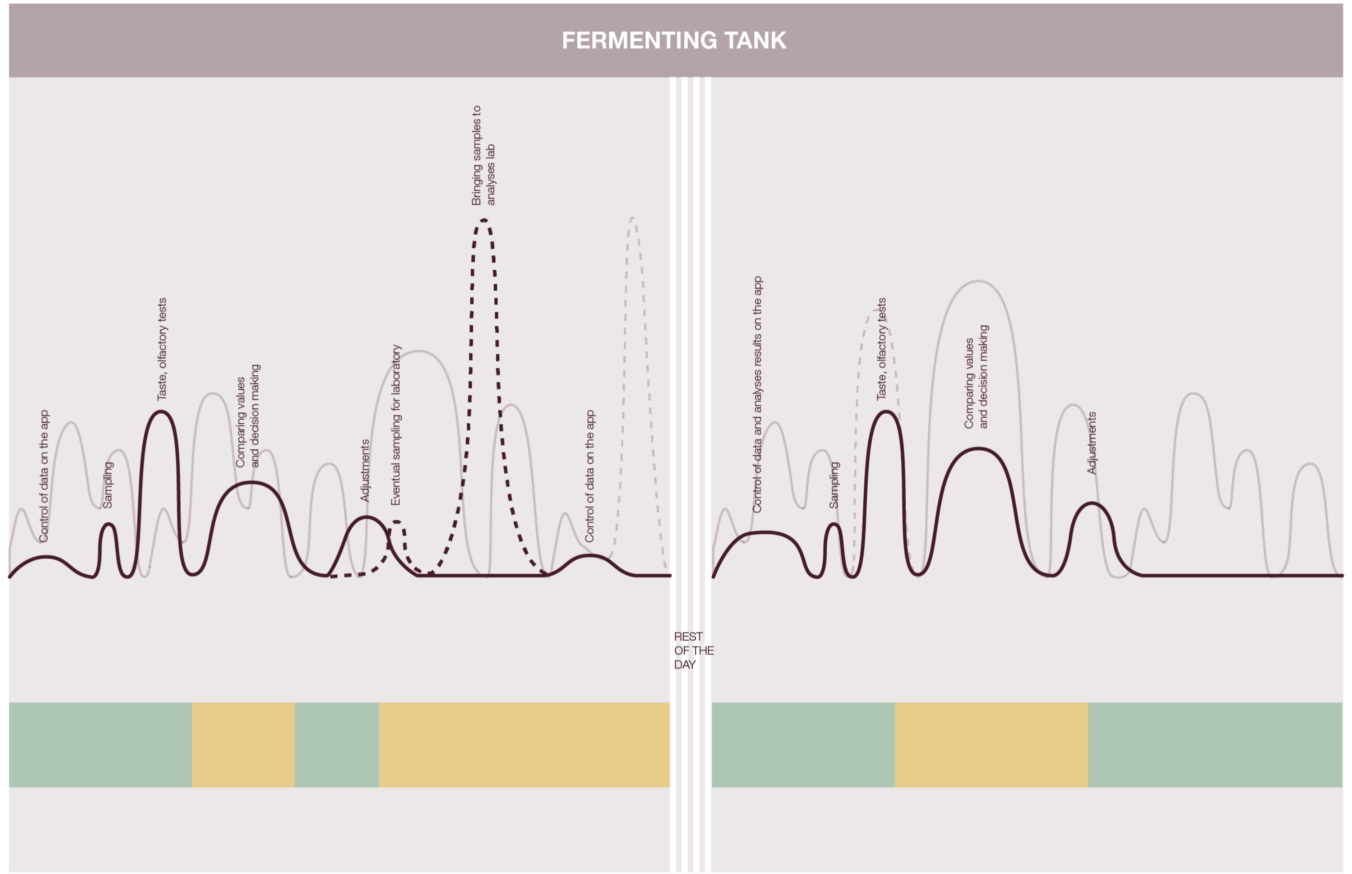

Figure 4.47 Expected journey mapping of the interaction with a fermenting tank using FerMentor, compared to the current journey mapping in small wineries.

Chapter 4. WINE FERMENTATION MONITORING TOOL: FerMentor

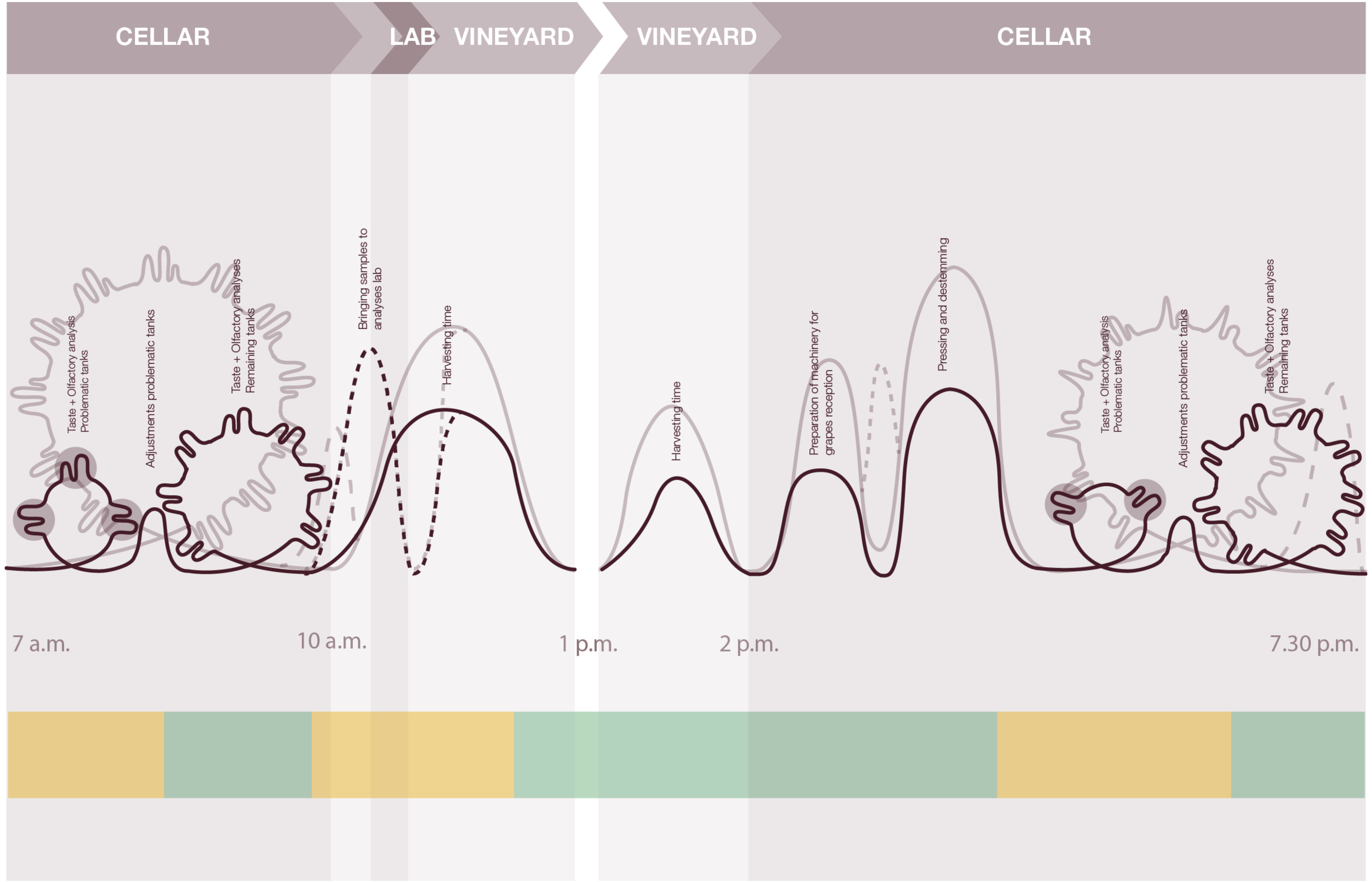

Figure 4.48 Expected journey mapping of a typical day in the middle of a fermentation period with FerMentor in use, compared to the current journey mapping in small wineries.

APP IMPROVEMENTS

In general, the app graphic was considered intuitive and the usability was good. Some suggestions were given regarding specific professional classifications such as wines hierarchy in the home dashboard, in which an additional layer was required. All these suggestions were taken into account during the app update after testing.

First of all, wine buttons have been reorganised: the first visualisation concerns grape typologies, while the second one clusters wine typologies, starting with the general category. As well as wine buttons, icons for the tank visualisation were positioned according to their importance.

Also the “note” function was redesigned: subcategories were created in order to ease the transcription of information. This app upgrade allows the winemaker to better organise his annotations depending on their nature (tasting, additions and processes).

Furthermore, the report was divided into three layers: report for each tank, report for each wine typology and final seasonal report. This data organisation is useful to bet-

Figure 4.49 Redesign of wine classification: from grapes tipologies to wines typologies.

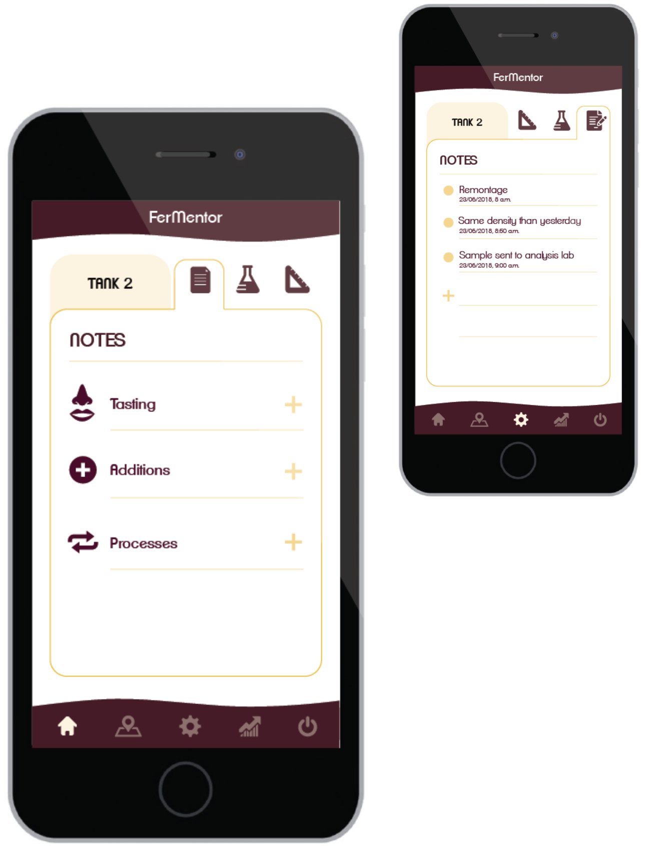

Figure 4.50 Redesign of the “note” function: new subcategories

ter help consultation and comparison.

Finally, more flexibility has been provided regarding notifications and alerts, for instance an intuitive and easy way to disable bracelet alerts not only at night, similar to a “do not disturb” feature.

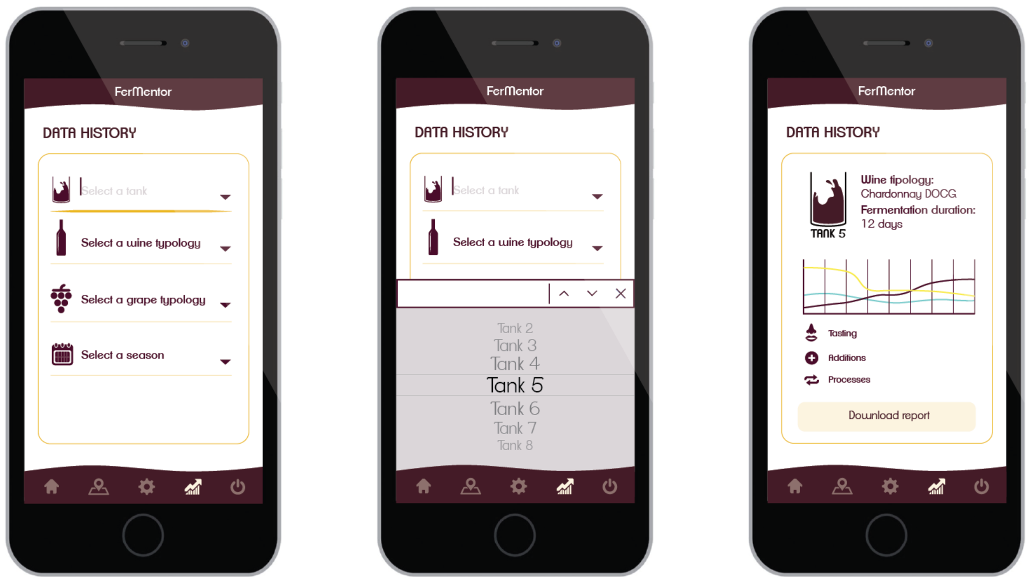

Figure 4.51 New organisation of the “report” function, divided into single tank, wine typology, grape typology and seasonal report.

FUTURE DEVELOPMENTS OF FerMentor CONNECTED SYSTEM

To sum up, User Experience and User Interface of FerMentor were designed carefully in order to create a specific tool for small wineries. Its functions and features were outlined and a system architecture was illustrated. However, further studies have to be done regarding coding, connectivity in the vineyard and circuits of both the monitoring system and the bracelet.

Sensors must be researched in order to find the right solution for wine as regards precision and durability. It could be useful to add some sensors for monitoring other steps of wine production such as the malolactic fermentation for red wines. Flexibility for each tank could be considered, with the aim of personalising the probe depending each step of wine production.

Another future development of FerMentor is the design of knob shape, bracelet shape and probe bodywork. Instructions have been given about the balance between form

and function and a further study about ergonomics could be useful for defining the final shape of these objects.
Specifically, the design of the probe bodywork requires a detailed design since it must contain and protect sensors against the must. In addition, probe positioning inside the tank must be studied to avoid disturbance related to must state, assuring the correct data reading.

The connection with a laboratory for analyses warrants further studies as well. Indeed, during the setup of FerMentor, a pairing should be necessary. Moreover, data communication system should be adjusted, depending on how analyses results are made available from laboratories.

The app itself may be updated with some arrangements: the note function could be expanded to the entire wine making process, in order to provide more control over production. Finally, a web version of the app could be coded to provide more flexibility for the user.

CONCLUSIONS

The aim of this dissertation has been to explore the development of a design approach for innovating small farms. The goal was to prepare their transition towards agriculture 4.0 by offering technical and experiential improvements, while respecting and encouraging traditional values and methodologies. The adoption of FerMentor is expected to pave the way for moving closer to new technologies in the wine-growing sector.

The analysis of what is meant for agriculture 4.0 and its facets has been essential for the understanding of the future of agricultural holdings and farmers.
Among all agricultural branches, the viticulture case study was considered the best context where to experiment this approach because of its strong roots in the culture of the Piedmont territory. Indeed, small wineries are numerous and play an important role in high-quality wine production on the territory. The analysis has focused on the scope of emphasising, supporting and enhancing their expertise while at the same time respecting workflow and relationships between workers.
FerMentor was designed after an in-depth study of this context, the user and the wine production process. The continuous interaction with case study wineries and oenologists has been fundamental for the identification of small farms' needs and therefore of the connected system features. Persona and journey maps as well were highly useful for understanding the workflow, touch points and design opportunities.

At the end of the design process that has been carried out during this dissertation, the overall evaluation is positive. The desired interaction has been confirmed and the designed UX and UI meet users' needs. In general, FerMentor is expected to be merged seamlessly into small wineries, even considering its costs. Moreover, winemakers' judgment is favourable since their role is not overridden by the connected system but actually supported, especially when it comes to decision making and problem solving.
Further developments have to be done in order to prepare FerMentor for the application in the real-world context. Even in this improvement phase, the approach described in this dissertation should be followed in order to suit and respect users' needs in small wineries. This sustainable approach is actually found to be beneficial to provide tailored technological solutions to small farms.
In conclusion, the Bi.Lab. laboratory where FerMentor prototype has been tested showed an interest in developing the connected system and in testing it in the real context, during the fermentation period in September.
With the support of PIC4SeR interdepartmental centre of robotics, it is believed that this collaboration could optimise the project as regards the definition of the appropriate sensors, the design of the probe and its insertion inside tanks and the way of receiving analysis results that must be visualised inside the app.

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“Machines that fit the human environment,
instead of forcing humans to enter theirs,
will make using a computer as refreshing as
taking a walk in the woods.”

M. Weiser