FINAL REPORT

TEAM SUGAR

Contents

1. Executive Summary

This report outlines the exploratory design process of the 2024 SUGAR project, a collaboration between business, design, and engineering students from Aalto University in Finland and Linköping University in Sweden. The project was conducted under the auspices of the EU's Horizon 2020 Research and Innovation Programme, part of the ATTRACT initiative, which introduced two pioneering technologies: Pipe 4.0, a gas composition analysis tool, and UnicornDX, a bionanosensor for detecting small chemical compounds.

The goal was to explore how these technologies could enhance quality monitoring in the wine and beer industries. The initial research phase involved comprehensive background studies and field visits in Austria, Portugal, Finland, and Sweden. This phase aimed to understand the key factors affecting wine quality and assess the feasibility of integrating Pipe 4.0 and UnicornDX into these processes.

Although the project ultimately found that direct use of Pipe 4.0 and UnicornDX was not feasible, these technologies served as critical inspiration. The team developed and refined multiple prototypes to test the broader concepts and principles these technologies represented. Early-stage prototypes explored innovative concepts like a sensory glove for winemakers and a wine aging measurement device. These experiments provided valuable insights and helped narrow the focus to more practical solutions.

The project's final stages concentrated on developing a tangible solution tailored to the fermentation monitoring needs of large wineries. The proposed solution, FermiSense, integrates an advanced infrared (IR) spectrometer system with a user-friendly app for continuous monitoring and real-time data analysis. This system aims to streamline the fermentation process, reduce manual workload, and enhance communication between winemakers and lab personnel.

Ultimately, FermiSense leverages the principles inspired by Pipe 4.0 and supplementary IR technologies to offer precise, real-time monitoring of critical fermentation parameters, such as nitrogen, sulfur dioxide, carbon dioxide, and oxygen levels. The project envisions significant benefits for large wineries, including improved process efficiency, reduced labour, and enhanced wine quality through more consistent monitoring.

1.1. Legal Disclaimer

As a disclaimer, this is part of the ATTRACT program that has received funding from the European Union's Horizon 2020 Research and Innovation Programme (GA 101004462).

Further, the European Commission's support does not constitute an endorsement of the contents, which only reflect the views of the authors, namely the Master students from Linköping and Aalto University. The Commission is not responsible for any use of the information therein.

2. Project Context

The SUGAR project is an exploratory design course funded by the EU's Horizon 2020 Research and Innovation Programme (GA 101004462) through the ATTRACT initiative. The course aims to turn emerging technological research into real-world products and services. This effort seeks to drive Europe's economic growth and enhance citizens' quality of life by innovating, creating new companies, and expanding employment opportunities.

This year, the focus is on improving quality monitoring in the wine. The emphasis on improving quality monitoring addresses the challenge of product consistency, affected by variables like raw material variability, climate change, new regulations, and shifting consumer trends. In the wine industry, which includes varieties such as red, white, sparkling, and fortified, the main emphasis is on the quality of how it's made. Quality in wine is a multifaceted concept, viewed through subjective perceptions of taste and cultural preferences, as well as objective criteria such as chemical composition and balance. However, this report faces some limitations, given the broad diversity of wine and the intricate interplay between subjective enjoyment and objective measurable quality standards, making a comprehensive assessment of quality challenging.

To tackle these issues relating to wine quality monitoring, ATTRACT has provided our diverse team with two pioneering technologies: Pipe 4.0, which specializes in gas composition analysis, and UnicornDX, adept at detecting small chemical compounds in the 10-100 nanometer range.

The team consists of three students from Linköping University in Sweden and four from Aalto University in Finland.

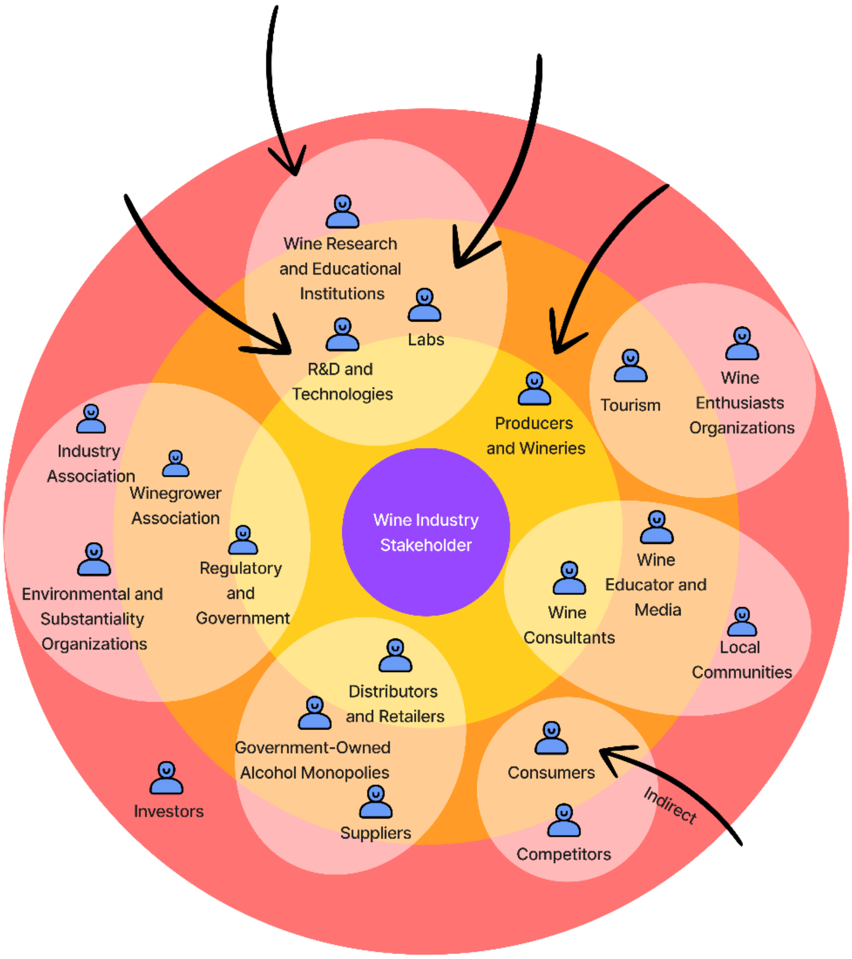
The project unfolded in three stages:

1) The initial stage focused on comprehensive research and analysis, involving desk research and field visits to explore winemaking and beer production in Europe, and countries like Austria, Portugal, Finland, and Sweden. The aim here was to gain a deep understanding of the key factors affecting quality. Additionally, this phase entailed an assessment of possible technological solutions, with a particular emphasis on incorporating Pipe 4.0 and Unicorn DX technologies into these production processes. This stage involved comprehensive evaluations and conversations with winemakers, wine quality institutes, and the developers of these two technologies.

2) The second stage involved developing and refining multiple prototypes, leading to a final proof-of-concept prototype. These prototypes were designed to test and demonstrate how well the Pipe 4.0 Raman instrument and the Unicorn DX biosensor can be adapted to and function within the specific contexts of winemaking and beer brewing.

3) The project concluded with the creation of a tangible solution (e.g. user-friendly interface or tool). This final product aimed to incorporate the technologies to simplify the tracking of essential quality metrics, serving to the practical needs of winemakers and brewers. However, as the report will later elaborate, the final tangible solution is proposed utilizing different imaging technologies due to several limitations to the application of the ATTRACT-provided technologies in the context of wine and beer making. These limitations and the thought process behind the final concept are explained within this report.

2.1. Stakeholders in the Wine Industry

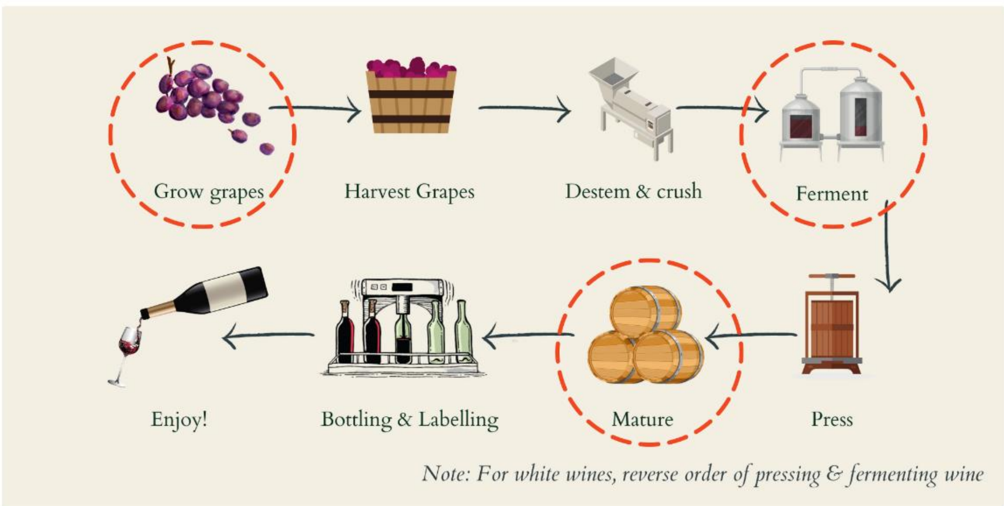


Overall view of stakeholders within the wine industry, with emphasis on the key stakeholders (for Wine Quality Monitoring)

The wine sector is composed of a diverse array of stakeholders. Through a combination of desktop research and field investigations, our team identified a range of stakeholders and divided them into several categories based on their roles and functions, also highlighted with a star the key stakeholders most relevant to our project. These categories are somewhat interconnected and can overlap, but they help to organize the stakeholders by their involvement in the wine industry. In the following table, the most interesting stakeholders within our process are further highlighted with a star:

Category	Stakeholders
Research and Development	1) Wine Research and Educational Institutions ⭐ 2) Labs ⭐ 3) R&D and Technologies ⭐
Support and Influence	4) Environmental and Sustainability Organizations 5) Industry Winegrower Association 6) Regulatory and Government
Investment	7) Wine Investors
Production	8) Wine Producers and Wineries ⭐
Supply Chain	9) Wine Suppliers 10) Distributors and Retailers 11) Add Government-Owned Alcohol Monopolies (Alko, or Systembolaget) (Typical in the Nordic Countries)
Market and Consumers	12) Consumers ⭐ 13) Competitors
Promotion and Tourism	17) Tourism 18) Wine Enthusiasts Organizations

2.2. Identified Pain Points in Wine Making and Winery Sizes



General journey map for winemaking with pain points

This journey map outlines the fundamental stages of the winemaking process, with the highlighted sections identifying the steps that we found particularly challenging to monitor and forecast. Our project team decided to concentrate on the fermentation and aging/maturing phases, as these areas currently represent gaps in terms of technological progress and investment. Growing the grapes was also considered but was discarded as the two technologies would be better equipped for measuring liquids (e.g., must before and during fermentation, and finished wine).

From our desktop and field research, we concluded that the most value could be created by focusing on stakeholders from the Production category, namely the 8) Wine Producers and Wineries. Thus, we have created two winemaker personas and a journey map with the needs: one for small wineries and another for larger wineries. Different personas and journey maps were created as the scale of the wine production has a significant impact on the monitoring needs of the winery.

The foundation for the personas was laid during a field visit to Vienna in November, where we visited a wine school institute and two small wineries. These personas were further refined through subsequent visits to breweries and wineries in Sweden and Finland, alongside ongoing desktop research. The final persona development was completed during a field trip to Porto, Portugal where we visited two small wineries and one large, international wine producer. A final iteration of the personas was done later on, as the final concept was defined and we validated our final concept with further large winery owners, as well as wine quality monitoring lab personnel.

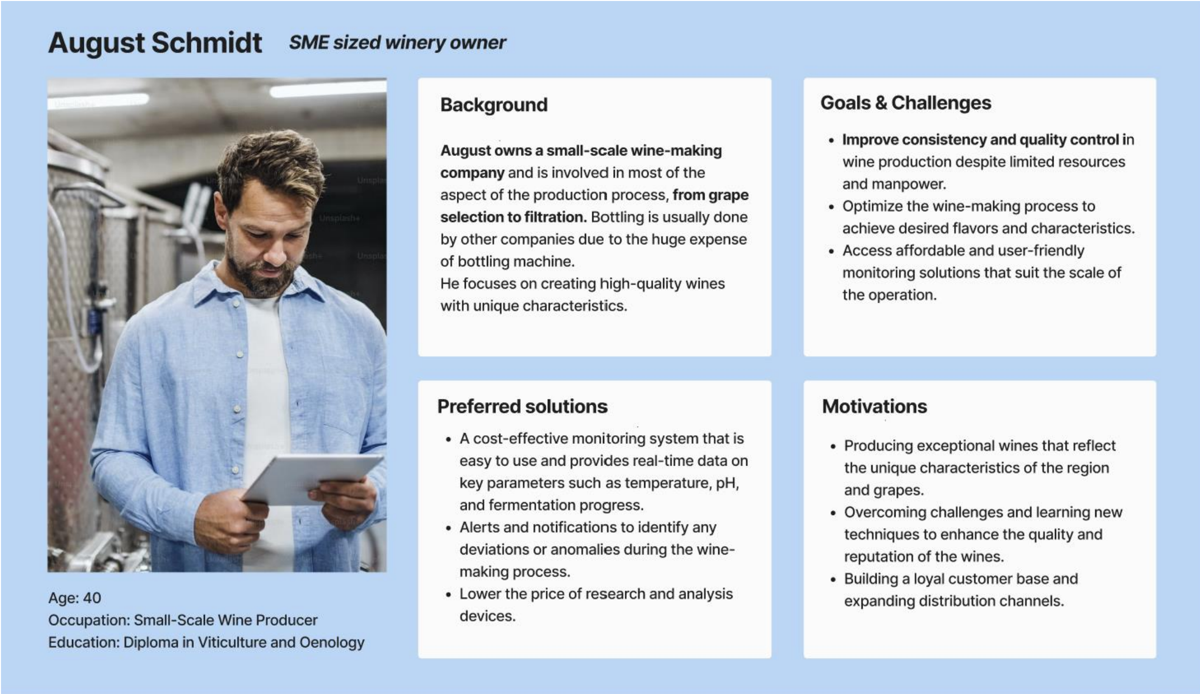
Based on these visits, we categorized and divided the wineries we visited in terms of size:

Winery Type	**Size (hectares)**
Extra Large	Over 900
Large Winery	100 - 900
Medium Winery	20 - 99
Small Winery	Below 20

2.3. Personas (Different Sized Wineries)

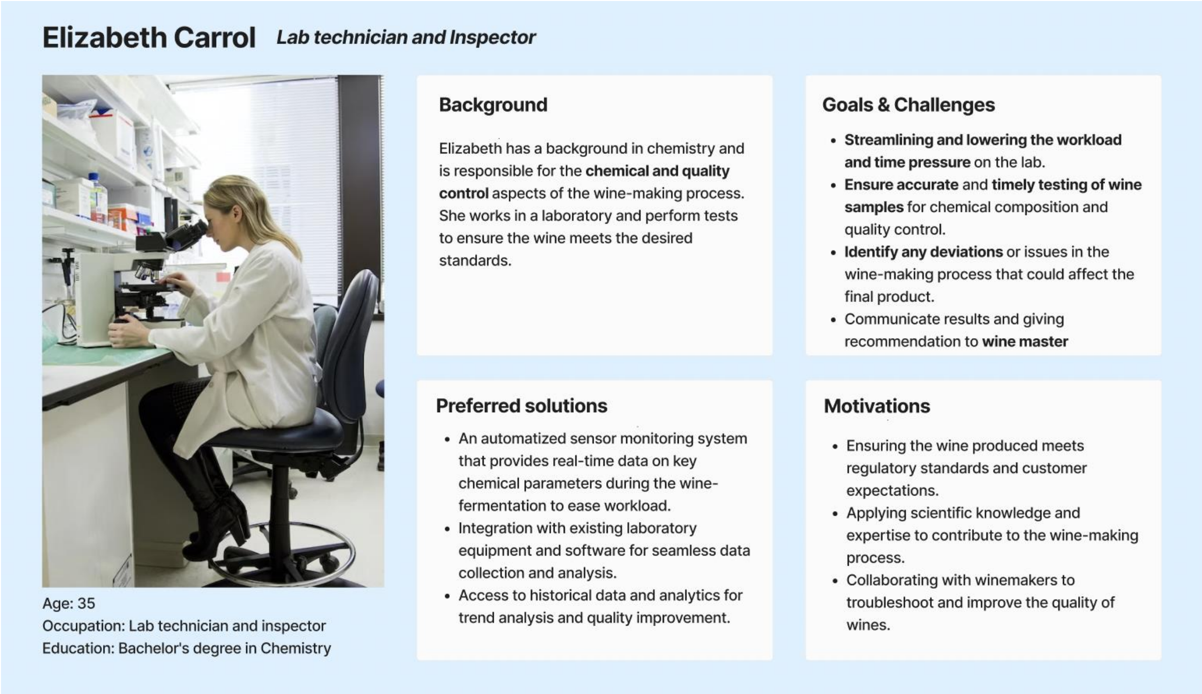
Persona for a large winery (size)

Based on our interviews research indicates that larger wineries prioritize maintaining a consistent wine profile and quality to align with consumer expectations. A broader variation in the wine's profile is generally more acceptable for wines produced in smaller quantities. However, for wines produced on a larger scale, consumers expect a consistent taste and appearance. Consequently, wineries that produce millions of bottles of a single wine variety need to implement more stringent control measures and enhance efficiency to ensure consistency across their production. Such technologies and systems are very expensive to implement. Many of these systems require one technology (sensor) for each measurement taken like density, sugar, O2, etc.



Persona for a Small-medium sized winery

For a smaller, tradition-driven winery, the emphasis lies on the personal touch and craftsmanship that goes into each bottle of wine. This winemaker does not have an interest in learning the difficult chemistry behind winemaking and instead trusts his sure instinct for the desired taste, aroma, and texture of their wine. They typically utilize laboratory services once or twice from the grape pressing stage to bottling for comprehensive testing and quality assessments. Routine tests for sugar, pH, and sulphur levels are often conducted in-house using simple and cost-effective methods. The primary goal for these winemakers is to produce a distinctive, high-quality wine that reflects their unique wine profile, all while keeping expenses low.



Persona for lab technician or wine quality inspector

This persona is a lab technician and a wine quality inspector with a keen focus on the winemaking industry. The person has an integral role in ensuring that the chemical and quality control aspects of the wine-making process are up to standard. Her goals include streamlining laboratory workflows to lower the workload and reduce time pressure, expediting quality checks, and pinpointing any discrepancies in the wine-making process that could compromise the final product. To achieve these objectives, this persona prefers utilizing automated devices and sensors for real-time monitoring of chemical parameters, both during fermentation and post-bottling. She values the integration of such systems with existing lab equipment for seamless data collection and analysis.

3. Prototypes and Experiments

In the following section, an overview of the prototypes and experiments conducted in the process is described. While typically prototypes are left to the latest stages of a design process, following the SUGAR methodology, prototyping is used from early stages to either visualize or test an idea. This way, ideas, and concepts can more easily be communicated and visualized to users, as well as this also provides an opportunity for co-creating directly with users. In this section, we will describe our process of diverging and converging through prototyping and user-testing, which will provide a crucial perspective to our decision-making process towards our final design direction, as user feedback has been imperative to guide our decisions.

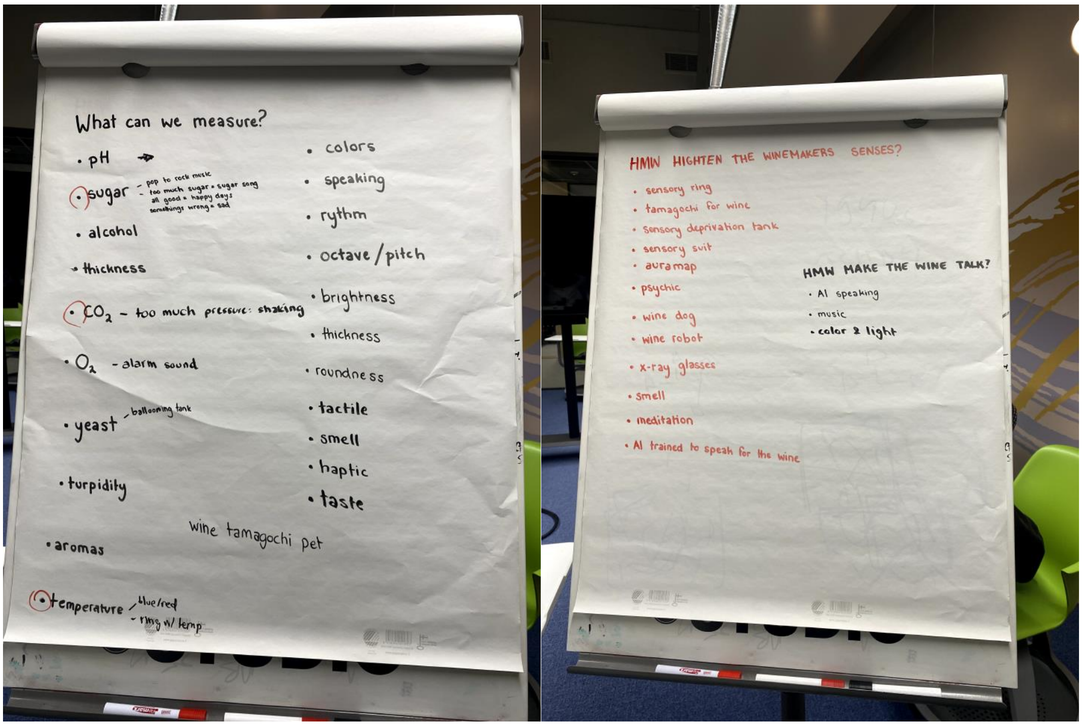
3.1. Early-Stage Prototypes

Initial prototypes were created still during the divergence phase of the process. The purpose of these prototypes was to explore new avenues and perhaps even shift paradigms. These prototypes fall under the categories of "early experiments" and "dark horse prototypes". "Dark horse prototypes" are a method to broaden our view of the problem space by experimenting and prototyping ideas that might initially feel too expensive, radical, or impossible. Essentially, these experiments are created with the sense that they will likely fail.

In the "dark horse" phase, we focused on the most potential pain points identified during our user research and problem space exploration phase. We created two "dark horse" prototypes: one framed around the problems of the winemakers not understanding the fermentation process to a high level of accuracy, and the second framed around trying to make sense of how wine ages.

3.1.1. Fermentation – How Might We Help Winemakers Feel the Wine

In our initial user research, we noticed that winemakers rely heavily on their senses, like taste, smell, and even hearing, to follow the fermentation process. This is disrupted if the winemaker becomes sick, as they will no longer be able to taste or smell with as high a level of accuracy. While the idea of heightening the winemakers' senses sounds quite radical, we found it an exciting frame for prototyping at such an early stage, as it was an unexpected approach.



Initial ideation around making wine making a more sensory experience.

To heighten the sensory experience in fermentation, we wanted to translate important measures in fermentation, such as pH, sugar, and alcohol levels, into sensory experiences. We ideated on sensory experiences that felt intuitive for the different measures, such as different colours, smells, brightness, and so forth. Additionally, we thought about how to create the sensory experience – would it be more feasible through a sensory room or perhaps a wearable device? Based on initial brainstorming, we landed on creating a glove that the winemaker could wear in the winery, and which provided different sensory cues based on what was going on with the wine. To simplify the test setting and development, we landed on creating a glove with three sensory cues: vibration for sugar level, colour emitted from light for pH level, and a buzzer for temperature.

Initial conceptualization and the final product in a user testing situation.

Since we were unable to access winemakers for such an early-stage experiment, we decided to test the prototype with any outside user to gain some feedback on how the sensory experience felt. In the user test, we simulated fermentation by creating a "wine solution" with different coloured "solutions" to fix any issues in the wine related to pH, temperature, or sugar level. Overall, the test was fun but proved that the idea would likely not be feasible in reality. The users enjoyed the process and distinctive cues made it easy to understand what was going wrong. However, memorizing the different cues and their "solutions" could become complex if there were more parameters. In addition, the users had some concerns related to the accessibility of such a broad range of cues, as changing colours might not be detected by a visually impaired winemaker, or a buzzer sound not heard by a hard-of-hearing winemaker.

A closer look at the final prototype

3.1.2. Aging - *How Might We Measure Aging Through a Wine Box?*

In pursuit of our goal to accurately measure the aging process of wine, we embarked on creating another dark horse prototype within a wine box. Despite the prevalent use of bottles in the wine industry, our research pointed towards wine boxes as a more environmentally friendly alternative. Interestingly, this notion was later confirmed during our visit to Portugal at Porto Protocol, where we witnessed a growing interest in wine box adoption. Our decision to prototype with wine boxes was motivated by their ability to maintain wine in dark conditions, crucial for preserving beverage quality. Additionally, the potential to have transparent plastic in wine boxes facilitates straightforward measurement, a vital requirement for our sensor's effectiveness. For our prototype, we chose to simulate a wine box structure using a juice box. We created "doors" by cutting openings on the surface, providing easy access for our sensor. Prototyped in blue foam, our sensor was designed to be inserted through these openings into a transparent plastic bag within the box. Once the sensor is positioned inside the box, the "doors" are securely closed, ensuring the beverage's environment remains undisturbed.

3.2. Converging Prototypes

In February, we began a process of converging with our prototypes and experiments. Instead of trying to be radical and create paradigm-shifting concepts we synthesized what we learned from them, focused our attention back on the pain points, and tried to create and bring to users' concepts that we felt could help them. In this process, we focused on the same two potential frames that we had identified: fermentation and aging.

3.2.1. Aging – Measuring Wine Aging Through the Bottle

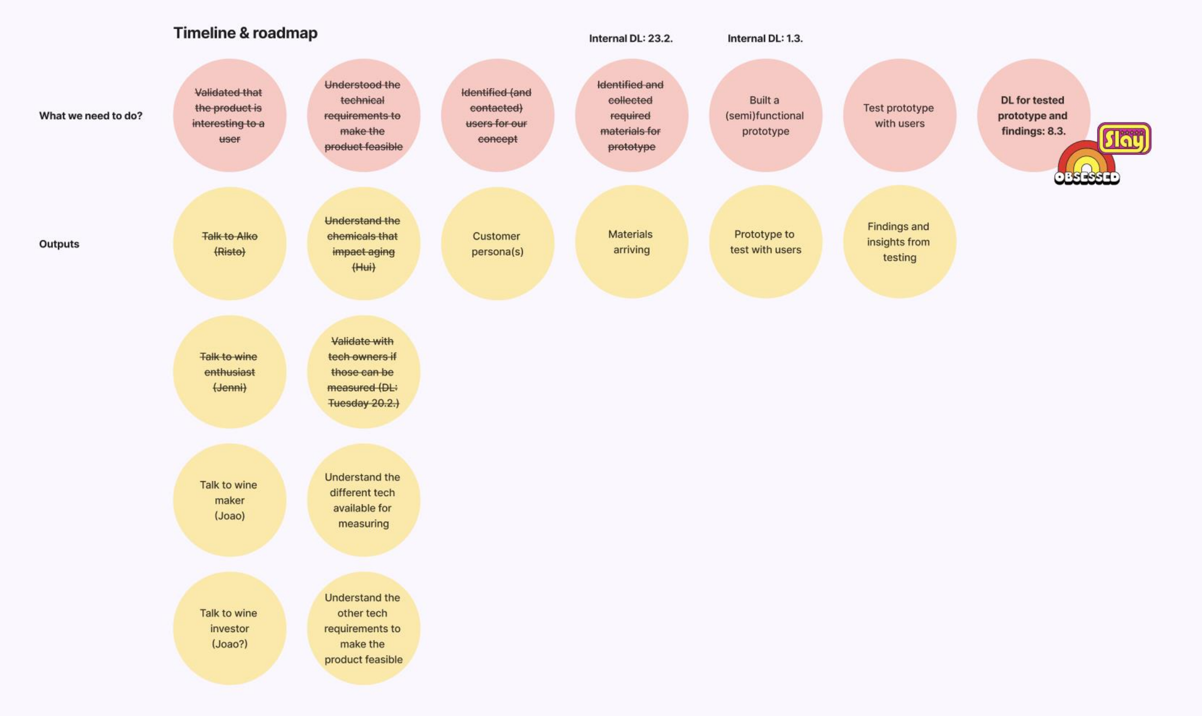
We started our "FunKy" prototype for aging with a problem frame of how we could create a bottle to represent all the wine. We focused our efforts on new stakeholder groups: investors and buyers. To understand the process, we started to identify things that we needed to learn about the aging process to create a real prototype. Initially, we wanted to learn:

- What does the bottle measure?
- What does the form look like? What about the technology?
- What kind of data is communicated to the user? How is it communicated?

We realized that for the aging process, there would likely be more interest in the idea from other stakeholders in the industry outside of winemakers. We identified potential interest from the retail sector, especially in Finland and Sweden, where the sale of high-alcohol volume products is under a government-owned monopoly. We also hypothesized that the idea could be of interest to wine investors, who might be particularly curious about predicting aging potential and following the aging process, as these can provide relevant information about their investments.

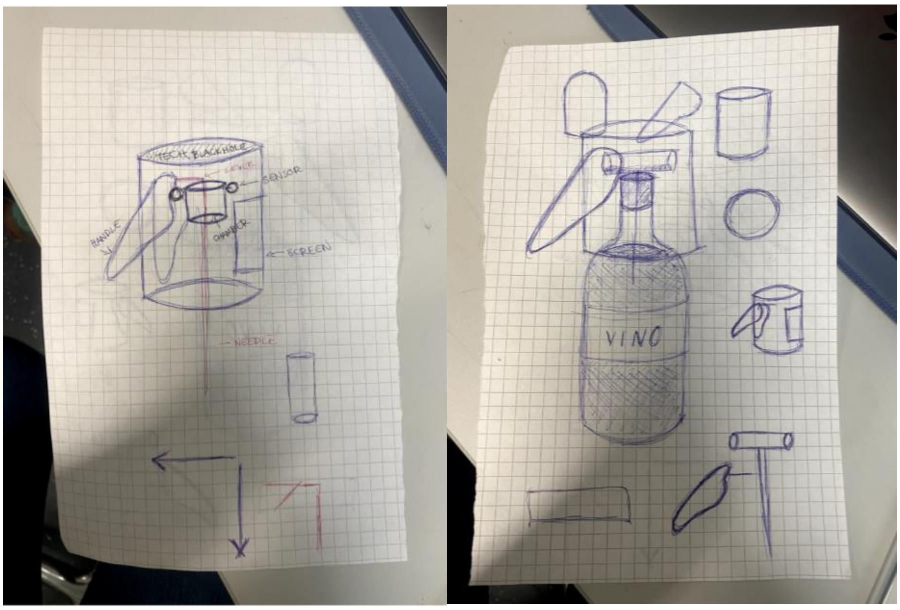
The initial prototype for concept validation

Once we had conducted some research about the important chemicals in the wine aging process, we created a quick prototype of a potential form for the wine aging device – a case that could measure the wine through the bottle. We included a small "screen", which provided information about the aging of the wine, such as ethanol and acetaldehyde content, as well as the amount of sulphur dioxide. We also translated this into what it means in practice, that the wine is still good to drink based on those parameters.



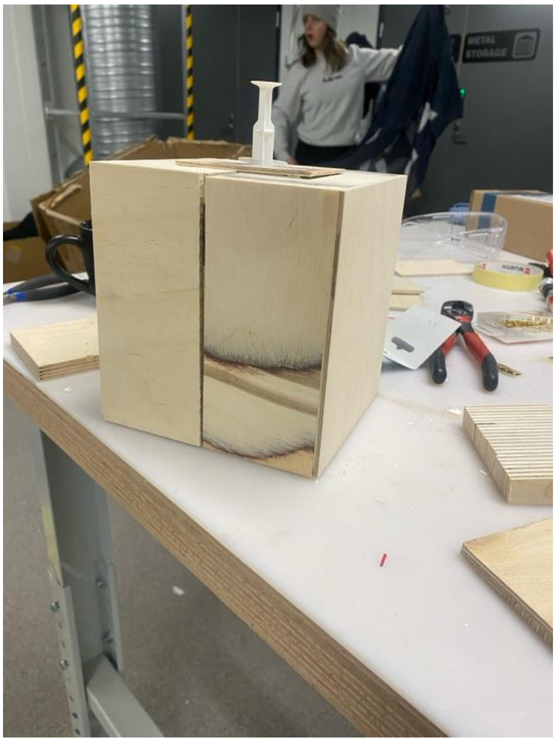
Roadmap for validating and building a more functional prototype.

Before we moved on to a more functional prototype, we wanted to initially test the concept with users, as this prototype and concept focused on an entirely new user for us. We took the "FunKy" prototype to two branches of Alko, the Finnish government-owned alcohol retailer. One was specialized in wines, while the other was a more regular Alko store. At both stores, the workers commented that the device could be very useful as a quality control measure. They acknowledged that wine does go bad and cork taint, for example, is a typical issue. Both gave such positive feedback that we felt it would be a good concept to continue with to create a more functional prototype.



Initial concept sketches of a functional prototype

Once we had validated the idea, we started to focus more on how to make an idea like measuring wine through the bottle technically feasible. We identified different chemical compounds (Appendix A) that could be interesting for detecting contaminations and aging potential in wines after bottling. We also started to consider the detection with different available technologies. In the functional prototype, we wanted to be able to detect something, and due to the dark colour of wine bottles, it can be hard to detect through the glass. Therefore, for the prototype, we decided that we would create a version where we collected a sample with a needle into a small tube, where the sample was then taken. This idea took inspiration from a pre-existing product called Coravin, which allows wine drinkers to enjoy a glass of wine without having to de-cork a bottle. In our prototype, we measured the turbidity of the wine in real-time through the sampling tube, as well as provided additional measures that we simulated onto a screen of the prototype.



During the building and the finished product

However, we worked in parallel to understand if the prototype would be possible without having to take out a sample. We learned through different conversations that Raman spectroscopy could be utilized for measuring liquid compounds, as well as that there are Raman spectrometers that can detect hazy materials that are not fully clear. We also learned that Raman spectroscopy for liquids has been used in wine detection with success and that it is one of the effective tools for imaging wine (Teixeira dos Santos et al., 2018). Therefore, as we hypothesized that perforating the cork would likely be a pitfall of our initial prototype, we could propose this alternative method of imaging the wine to users when testing in Portugal.

3.2.2. *Fermentation – Wine analysis in a platform for winemakers*

We chose to focus on simplifying and streamlining the fermentation process for winemakers. During fermentation, sugar is converted into alcohol, it is also when the wine gains its character. Therefore, winemakers need to taste daily and keep track of parameters such as temperature, pH, and sugar levels to ensure that fermentation is progressing as it should. During the development of our prototype, the focus was to ensure that we didn't make assumptions but rather based our choices on the insights and lessons we gained in Austria and our study visits in Finland and Sweden, as well as research conducted online.

Why did we choose to develop an app for the fermentation process?

- We met a Swedish winemaker Niclas, who expressed a desire to receive as much information as possible from his tests digitally through an app, including notes.

- An Austrian winemaker mentioned that he would have appreciated knowing when wines should be tested throughout the day. He emphasized the need for a better overview of what is happening in each tank to plan his day effectively.

- Since the process relies so much on the winemaker, we also saw value in this being able to help experienced winemakers maintain control remotely and communicate with other team members.

During a workshop, we began to build stories around where the value lay for our solution. Here, we discovered that the value arose if the winemaker fell ill, if there was a generational change, and if the winemaker wanted to scale up by purchasing more tanks but felt unable to control so many tanks. We created stories around these scenarios, ultimately leading to a story where all three problems were interconnected. The idea emerged that an app or platform that educates on what is happening in the fermentation tanks would help the winemaker maintain control remotely and help other team members to better understand what is happening.

Yeasty

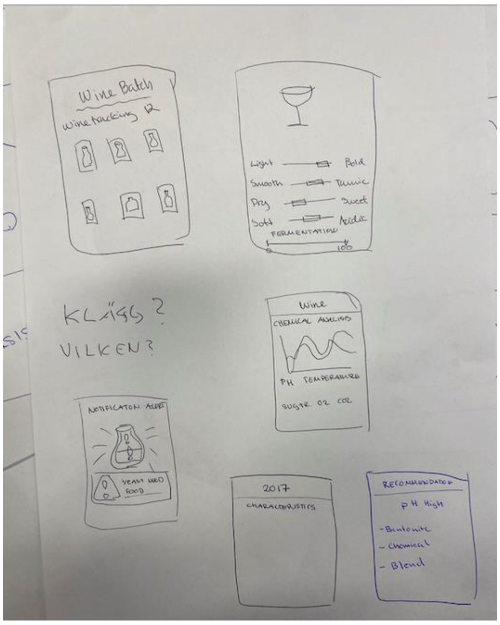
We started developing “Yeasty”. This prototype aimed to create an interactive way for the winemaker to communicate with the wine. The idea was to create a character, a mascot with a personality, like a Tamagotchi, that would represent the wine or the yeast and express needs during the fermentation process. The idea stemmed from the recognition that winemaking is such an artistic and important, or emotional, process and that this is something we do not want to eliminate by adding technology. The purpose of the prototype was to create a sense that the connection to the wine increases rather than decreases, by giving the wine a personality.

What is important to measure?

- **Temperature:** Monitor fermentation temperature for optimal yeast activity and overall fermentation rate.
- **pH Level:** Measure pH to ensure proper yeast function and maintain overall wine quality.
- **Brix/Sugar Content:** Track sugar content or Brix level for insight into fermentation progress and alcohol prediction.
- **Specific Gravity:** Monitor specific gravity to gauge fermentation progress based on liquid density changes.
- **Dissolved Oxygen (DO):** Control and monitor dissolved oxygen levels to prevent oxidation and preserve wine flavor.
- **Pressure:** Measure pressure to understand Coronation levels, especially in sparkling wines, and detect issues like leaks.
- **Turbidity/Clarity:** Measure turbidity or clarity to monitor sedimentation and ensure wine clarity.

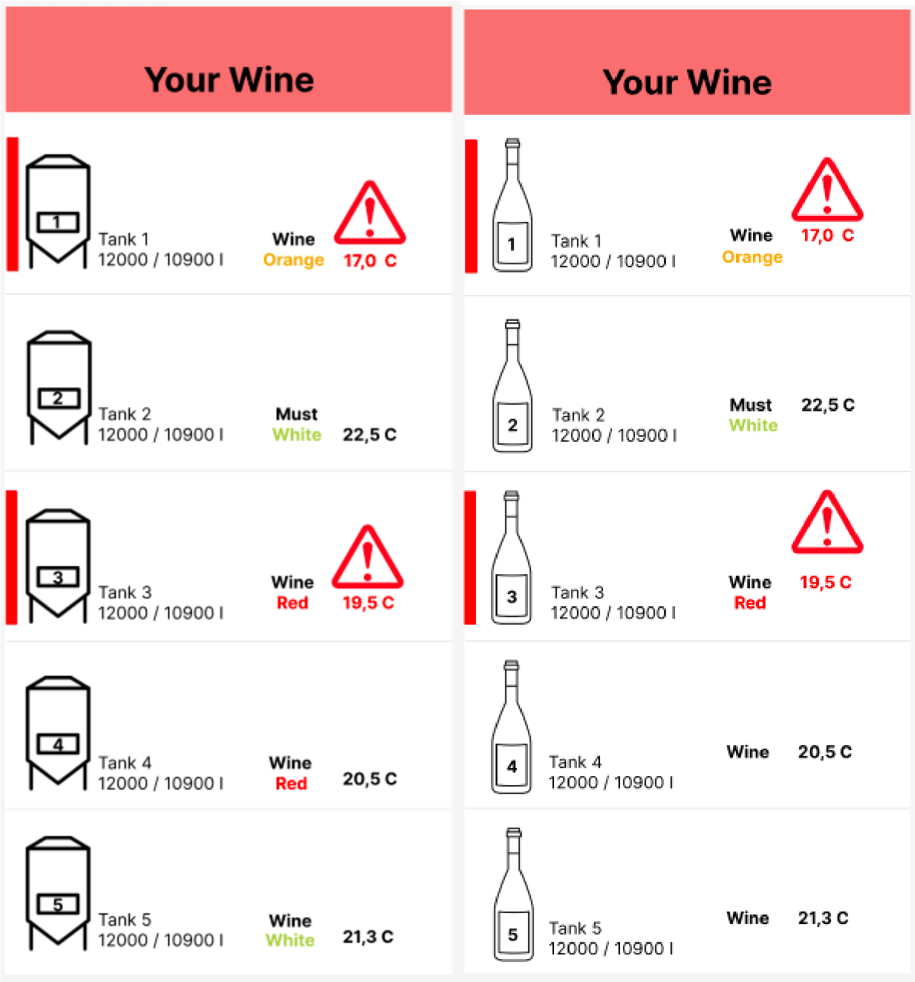
Simultaneously, we were considering simpler visualizations of how the wine develops during fermentation, keeping in mind that the winemaker when testing their wine with simpler instruments, might find the "Yeasty" character "disturbing" of the results and figures they are looking for. We met with a winemaker in Linköping who was already using apps to view the results of their measurements. He mentioned that he would appreciate having the results displayed in a clear and simple way on his phone or screen on the tank.

We began by sketching on paper to visualize our ideas without technical limitations.



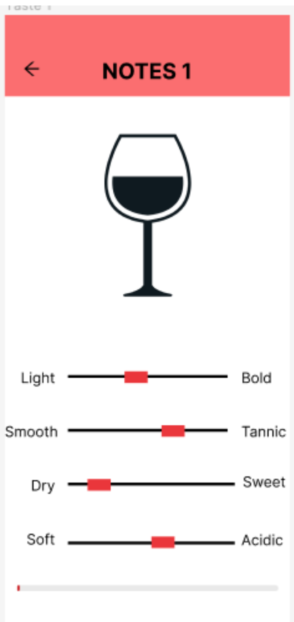
We ended up prototyping an app that displays the winemaker's various tanks on a screen along with concise information about each tank, including temperature, and alerts in case any values are off. The idea is to help the winemaker have an overview of all tanks without needing to physically test and take notes. We have learned that tasting the wine is crucial for the winemaker, so the idea is not to replace tasting but to assist with other tests and aspects important for keeping fermentation under control.

Later, we acquainted ourselves with Figma and tried to create an understandable, educational app that should feel facilitating rather than complicated. We started with different wine bottles to represent each wine, but we ended up changing to wine tanks since it is the tanks that are being analysed and not the end product.



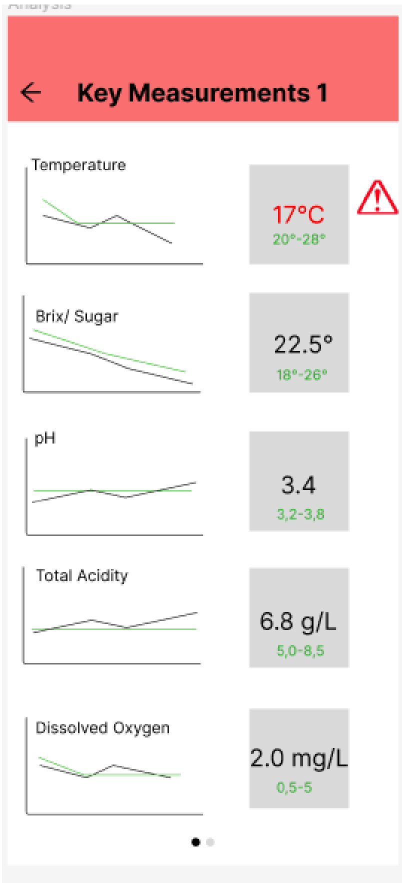
By clicking on the tank, the winemaker can choose whether to delve deeper into tasting notes, the tank's current values (analysis), or the historical data of the wine from previous years.

In the tasting notes section, the winemaker can personally input how the wine tastes when sampled. The purpose of these notes is for the winemaker himself to understand and reflect on how the wine evolves with each tasting. One of the objectives of tasting the wine, as highlighted by a Swedish winemaker is to understand how the wine develops over time.



In the analysis section, the winemaker can observe how the values evolve on the left side and view the numerical value, for example, pH, on the right side. The selection of values is based on both what we've heard from winemakers regarding important parameters and research on the internet concerning which values are crucial for winemakers to monitor during fermentation. Parameters such as pH, sugar, and temperature are values that even small winemakers test using simpler instruments. Therefore, we chose to visualize the readings similar to the displays on these instruments, with black numbers on a grey background to evoke familiarity since that's how they appear on the instruments they currently use.

The decision to include curves showing the development is based on the fact that fermentation is a developmental phase, and winemakers have expressed interest in understanding how the values change. The example values for each measurement on the prototype were determined by researching how respective values typically evolve during fermentation. The green line represents the "desired value." The idea is for the winemaker to input, based on historical data, how they wish each value to develop during fermentation.



We chose these measurements as they are examined daily using simpler instruments. The idea was to integrate these instruments into the tank. A description of how these instruments could be included in the tank can be found in Appendix B.

4. Identified "Right" Problem to Solve

In March, we embarked on a field trip to Portugal with our fermentation tank and aging concepts, seeking feedback from key stakeholders. Our visits spanned from small wineries, such as Prior Lucas and Casa Algar, to the extra-large wine company Sogrape. These encounters provided insights into unique wine-making processes, innovations, challenges, user demands, future visions of the industry, and so forth. We open these insights here below:

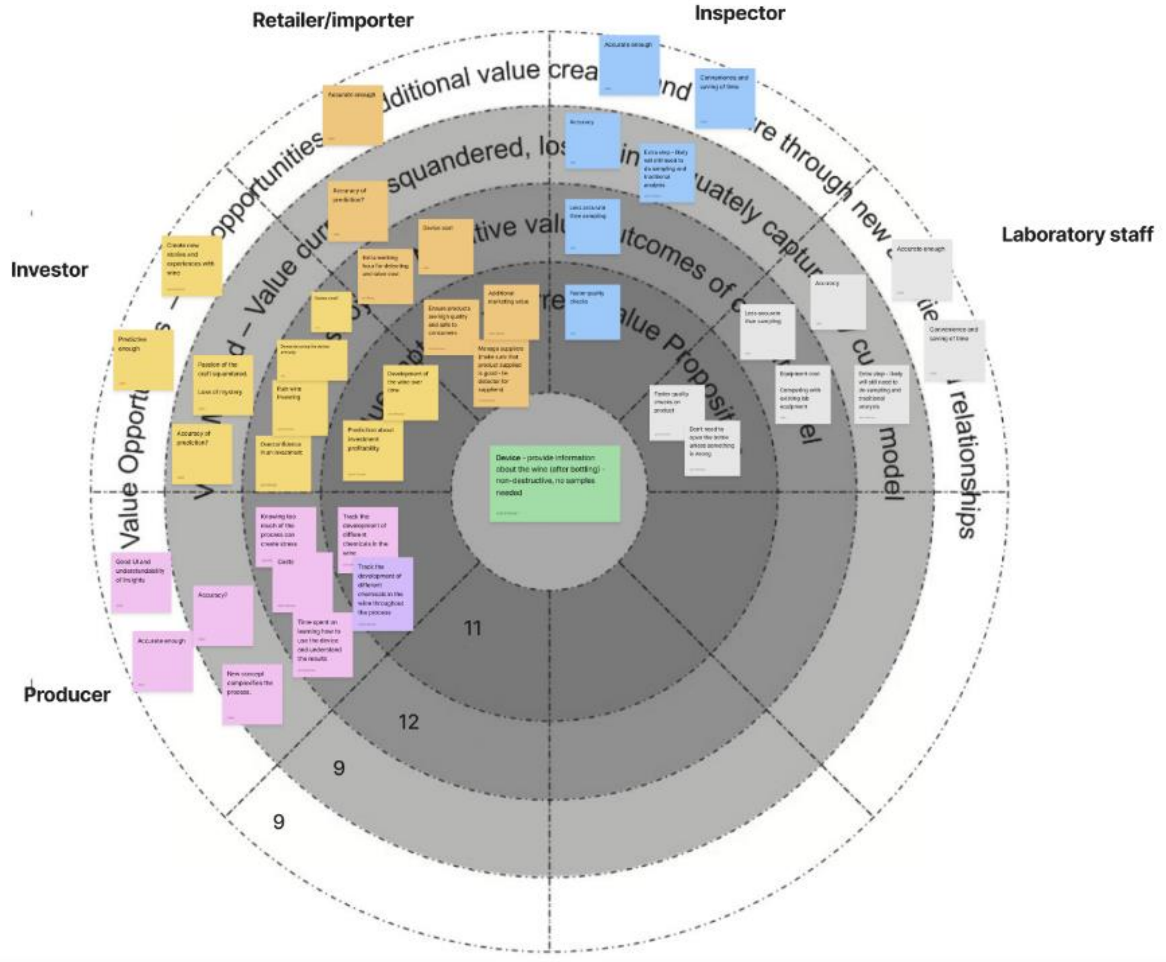
Small wineries expressed a keen interest in the fermentation process, particularly in data recording, monitoring compound changes, and incorporating an alarm function. Conversely, Extra-large wineries (such as Sogrape) have already worked a lot in the improvement of different stages in winemaking and their current challenge lies in detecting sulphur dioxide levels and mitigating the high costs of sensors. Notably, the aging idea did not raise wineries' interests greatly, attributed to Portugal's preference for consuming fresh wine within a year of production over aged wine. Furthermore, winemakers were not the ideal target group for such a product, which could have potentially been more interesting for investors, importers, and buyers.

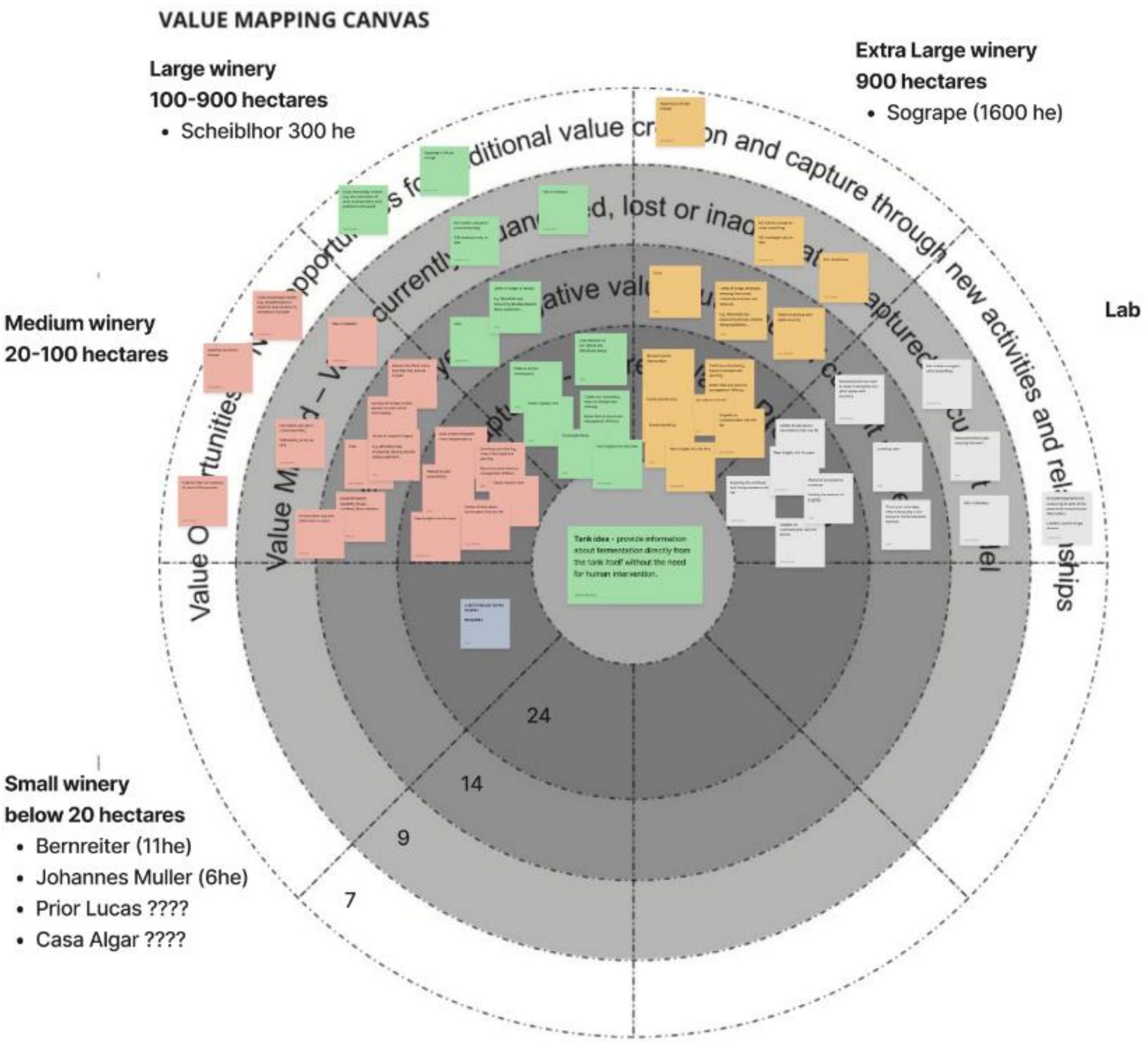
Following our visits and interactions, we deliberated on our project's direction, considering the insights gained. We start by listing out potential users and their demands and brainstorming about how we can meet their demands. There are six potential user groups (also, explained earlier in the stakeholder section of this report): wine investors, retailers, inspectors, wine importers, wine producers, and lab persons.

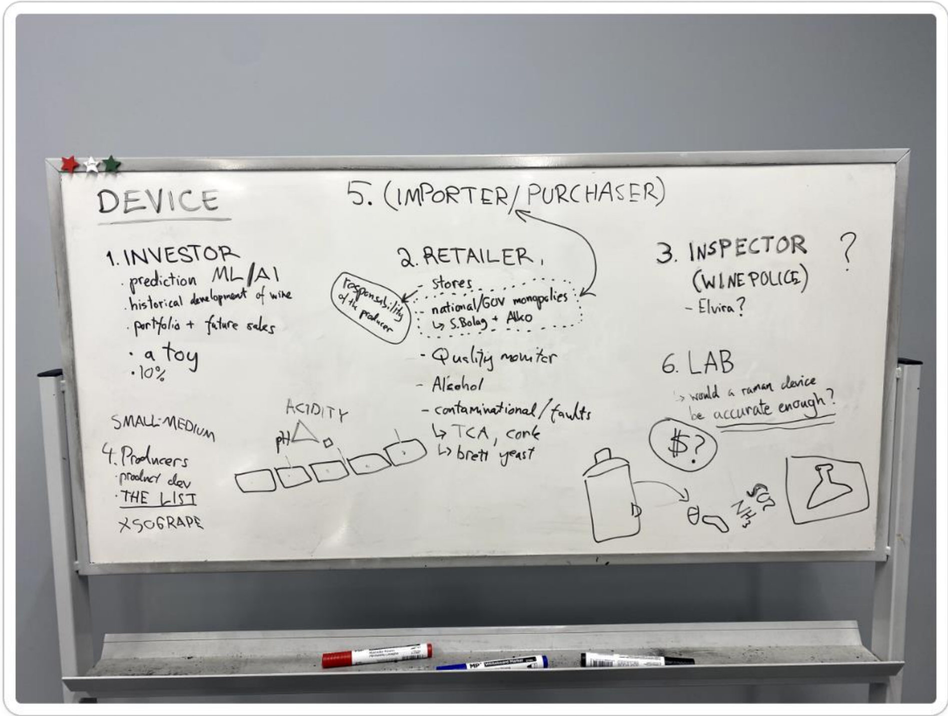
- **Wine investors:** Financial stakeholders who allocate capital to various segments of the wine industry, seeking to grow their investments through the success of vineyards, wineries, wine, and market performance.
- **Retailers:** serve as the direct link between the wine producers and consumers, offering a selection of wines through brick-and-mortar shops or online platforms.
- **Wine inspectors:** responsible for ensuring the quality and authenticity of wine, often working within regulatory frameworks to maintain industry standards.
- **Wine importers:** specialize in bringing wines from various regions into new markets, handling the logistics, legalities, and marketing of international wine sales.
- **Wine producers:** at the heart of the industry, cultivating grapes and crafting them into the diverse range of wines available globally.

- **Lab personnel:** conduct scientific analysis and experiments to improve wine quality, safety, and innovation in production methods.

By analysing their needs, we brainstormed three possible ideas: a fermentation tank sensor with an app, an aging box, and a portable wine analyser.




VALUE MAPPING CANVAS
Large winery
100-900 hectares
• Scheiblhor 300 he
Extra Large winery
900 hectares
• Sogrape (1600 he)
Medium winery
20-100 hectares
Lab
Small winery
below 20 hectares
• Bernreiter (11he)
• Johannes Muller (6he)
• Prior Lucas ????
• Casa Algar ????
Tank idea - provide information about fermentation directly from the tank itself without the need for human intervention.
24
14
9
7


DEVICE
5. (IMPORTER/PURCHASER)
1. INVESTOR
· prediction ML/AI
· historical development of wine
· portfolio + future sales
· a toy
· 10%
2. RETAILER
- stores
- national/GOV monopolies
↳ S.Bolag + Alko
responsibility of the producer
- Quality monitor
- Alcohol
- contaminational/faults
↳ TCA, cork
↳ brett yeast
3. INSPECTOR ?
(WINE POLICE)
- Elvira?
6. LAB
↳ would a ramen device be accurate enough?
$?
SMALL-MEDIUM
4. Producers
· product dev
· THE LIST
X SOGRAPE
ACIDITY
pH

In the next step, utilizing a value mapping canvas, we explored the opportunities and values each idea presents to stakeholders. We were a bit stuck in deciding on which idea to go forward, due to the perceived benefits of each concept. We also tried to calculate the cost of different ideas, but it was quite time-consuming and not easy to calculate the estimated cost since the devices used are quite niche and price comparisons are difficult to make.

We shifted our focus to identifying the right problem and targeting users through user need ideation. We assessed the most crucial demands of each stakeholder, categorizing them into different wine-making processes. This exercise led us to refine our scope based on several criteria:

1. **Focusing on key stakeholders**
   We decided not to consider inspectors, since it is a stakeholder group that we did not know a lot about, as it focuses on monitoring the quality of wines based on legislation or certificate criteria.

2. **Concentrating on the part that the cooperative technologies could help**
   We decided not to focus on the pre-fermentation process because it is mainly about the protection and detection of grapes, incompatible with the technologies, and this area has not been researched enough by us to contribute at this time.

3. **Focusing on the process with higher potential**
   After bottling has a great value in terms of detecting the aging process of wine. However, in Portugal, 90% of wines are consumed within a year and aging happens slowly so the following process is not interesting to winemakers and lab persons. Moreover, the aging forecast seems desirable, but we don’t know if we are really convinced with the technology being there.

4. **Addressing problems within our capability**
   Value in the post-fermentation process is more about the chemical analysis of the wine itself. We had done a lot of research, but we found that the chemical analysis of compounds was beyond our capabilities, and other interesting avenues fit our team’s skills and strengths better.

wine process Users	~~pre-fermentation~~	fermentation	post-fermentation: wine	~~after bottling~~
winemaker	1. ~~**Harvesting moment/Getting right characteristics of the grape:** Balance Holy trinity of grapes (sugar, acidity, pH) to know when to harvest~~ 2. ~~**Preventing catastrophes with the vineyards:** reacting faster if things are going wrong~~ 3. ~~**Getting lab information accurately and timely:** from more than one phase of the wine making process~~	1. **Manage resources more efficient:** Knowing/Estimating when fermentation ends 2. **Consistency in wine:** Recording the compounds data and analyze to keep flavor profiles and make quality wines, follow laws and regulations. 3. **Preventing catastrophes in fermentation:** reacting faster if things are going wrong	1. **Preventing catastrophes:** reacting faster if things are going wrong (contaminants) 2. **Understanding what you have made:** (legislation, bureaucratic, certificates)	1. ~~**Maximize profit:** shelf-life, flavour profile, marketing~~
lab	1. ~~**Reduce workload:** faster and more efficient testing, (outsource to winemaker), communication to winemakers~~	1. **Reduce workload:** faster and more efficient testing, (outsource to winemaker), communication to winemakers	1. **Understanding what you have made:** standardizing flavor profile, understand the shelf-life, flag any problems 2. **Reduce workload:** faster and more efficient testing.	1. ~~**Reduce workload:** faster and more efficient testing, (outsource to winemaker), communication to winemakers~~
retailer/ importer	NA	NA	NA	1. ~~**Maximize profit:** shelf-life, flavour profile, marketing, knowing what you buy~~
~~inspector~~	~~NA~~	~~NA~~	~~NA~~	~~NA~~
investor	NA	NA	NA	1. ~~**Maximize profit:** shelf-life, flavour profile, marketing, knowing what you buy~~

Consequently, while doing this exercise, we decided to pivot back and focus to enhancing the fermentation process through Pipe 4.0 gas Raman technology. Discussions with stakeholders revealed that monitoring chemicals in the fermentation process, especially the level of sulphur dioxide and nitrogen can provide valuable, new information to the winemaker about the process. Additionally, the device could help the laboratories of larger wine bottlers decrease their workload by testing more efficiently and reducing the workload of communication with wineries, as the envisioned device could monitor continuously and report problems directly to the winemaker.

Key user of the device

We decided to focus on large growing wineries (approx. 100-900 hectares of vineyards) because large wineries are more potentially growth-driven and equipped with high-tech devices, or in search of such technologies. Although our group did not visit any wineries within this range, we met and spoke winemakers outside this range, and received confirmation that might be the correct size to focus on. In contrast, Extra-large wine producers such as Sogrape already have a very robust R&D and Innovation department. Therefore, the users for this device would mainly be the winemakers and lab persons. Note, the winemaker and lab person can also be the exact same person.

Kristofer Gruber *Big wine making company wine maker*

Age: 50
Occupation: Big Wine Company wine maker
Education: Oenology

Background

Kristofer is a winemaker at a large wine-making company that produces wines in 100+ hectares of land.

He aims to maintain **consistent quality and wine profile** year after year and meet the expectations of loyal customers.

Goals & Challenges

- **Ensure consistent wine profile, quality** and taste across different vintages of wines.
- To enhance wine quality and consistency, focus on optimizing production and minimizing variations, while also reducing contamination risks during fermentation.
- Identify and implement technological advancements to improve efficiency and product quality.
- Understand results and communication with Lab.

Preferred solutions

- Advanced monitoring and data analysis systems that enable real-time tracking of critical parameters throughout the wine-making process.
- Integration with existing systems and databases for seamless data management and analysis.
- Predictive analytics and machine learning algorithms to identify patterns and predict potential quality issues, enabling proactive interventions.
- Simplify communication process with lab.

Motivations

- **Maintaining the reputation of the brand** as a producer of high-quality wines.
- Meeting customer expectations and building long-term customer loyalty.
- Increase operational efficiency to save money.

Elizabeth Carrol *Lab technician and Inspector*

Age: 35
Occupation: Lab technician and inspector
Education: Bachelor's degree in Chemistry

Background

Elizabeth has a background in chemistry and is responsible for the **chemical and quality control** aspects of the wine-making process. She works in a laboratory and perform tests to ensure the wine meets the desired standards.

Goals & Challenges

- **Streamlining and lowering the workload and time pressure** on the lab.
- **Ensure accurate** and **timely testing of wine samples** for chemical composition and quality control.
- **Identify any deviations** or issues in the wine-making process that could affect the final product.
- Communicate results and giving recommendation to **wine master**

Preferred solutions

- An automatized sensor monitoring system that provides real-time data on key chemical parameters during the wine-fermentation to ease workload.
- Integration with existing laboratory equipment and software for seamless data collection and analysis.
- Access to historical data and analytics for trend analysis and quality improvement.

Motivations

- Ensuring the wine produced meets regulatory standards and customer expectations.
- Applying scientific knowledge and expertise to contribute to the wine-making process.
- Collaborating with winemakers to troubleshoot and improve the quality of wines.

The values that we wanted to provide for users

1. Continuous detection of gas content with real-time alerts for any issues in the fermentation tank, preventing substandard wine production.

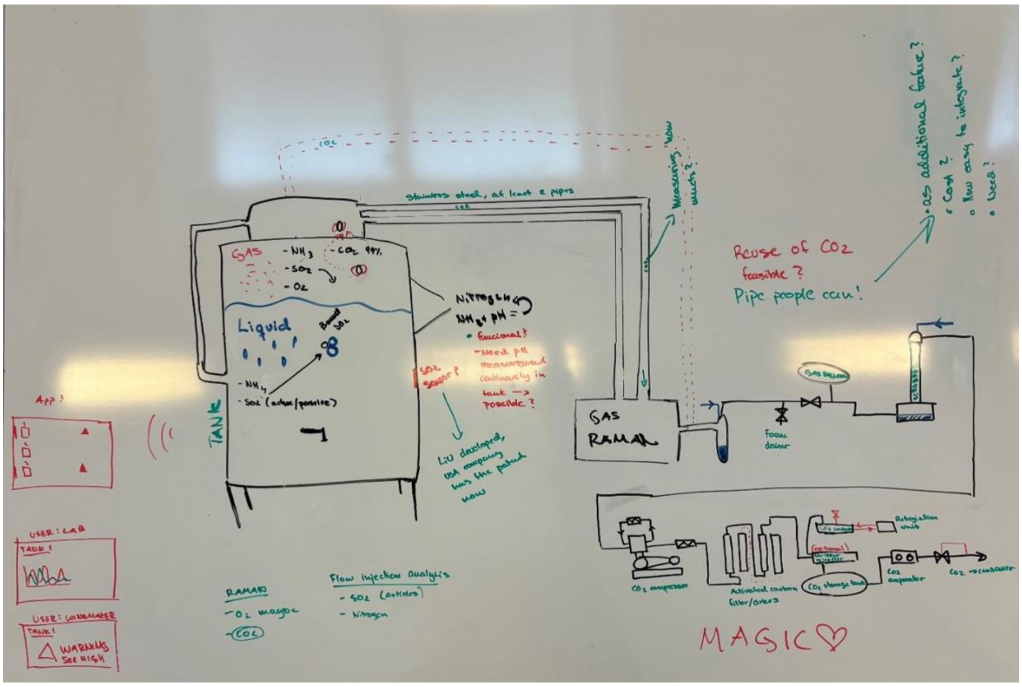
2. Calculate the content of sulphur dioxide. (Unfortunately, we discovered Pipe 4.0 cannot do this. Thus, must focus on other technology)

3. Reduce workload for lab persons by faster and more efficient testing and smoother communication with winemakers through continuous monitoring and reporting of small issues.

5. Final Concept

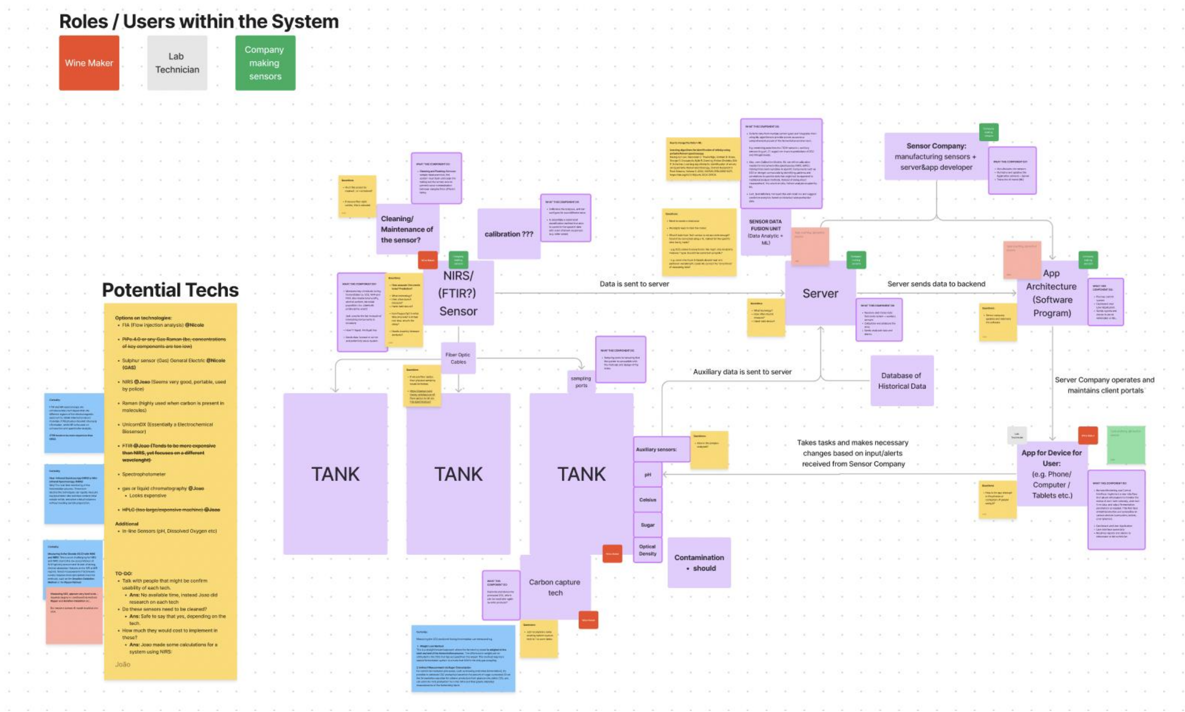
5.1 Development Process

In our project's development, we achieved significant progress by creating two prototypes: the Box Prototype for analysing the aging process and the Winemaker App for fermentation management. The Box Prototype utilizes a needle for non-invasive sampling, providing immediate turbidity readings and substance analysis within wine bottles. Meanwhile, the Winemaker App is a digital suite offering essential tools for data analysis, process scheduling, and communication enhancements, enabling more efficient remote management and operation. However, based on our group’s deliberation, as elaborated upon in section 4, we collectively decided that we would focus our efforts on the final solution of developing a fermentation monitoring device specifically for large and extra-large wineries.



Idea of how the prototype might look in the end

We organized our team into international pairs that worked in parallel to approach our final concept from different perspectives. We identified that there would be significant work to be done to understand the concept from different parts of the system that we outlined: one part was to understand the technology needed to make the constant monitoring of fermentation tangible, second was to understand how to transform the data provided by the technology into a form that is understandable to the user with algorithms, and the third part was to define how exactly the information should be communicated to users through an app or user interface. Based on this, we outlined a more detailed system map.

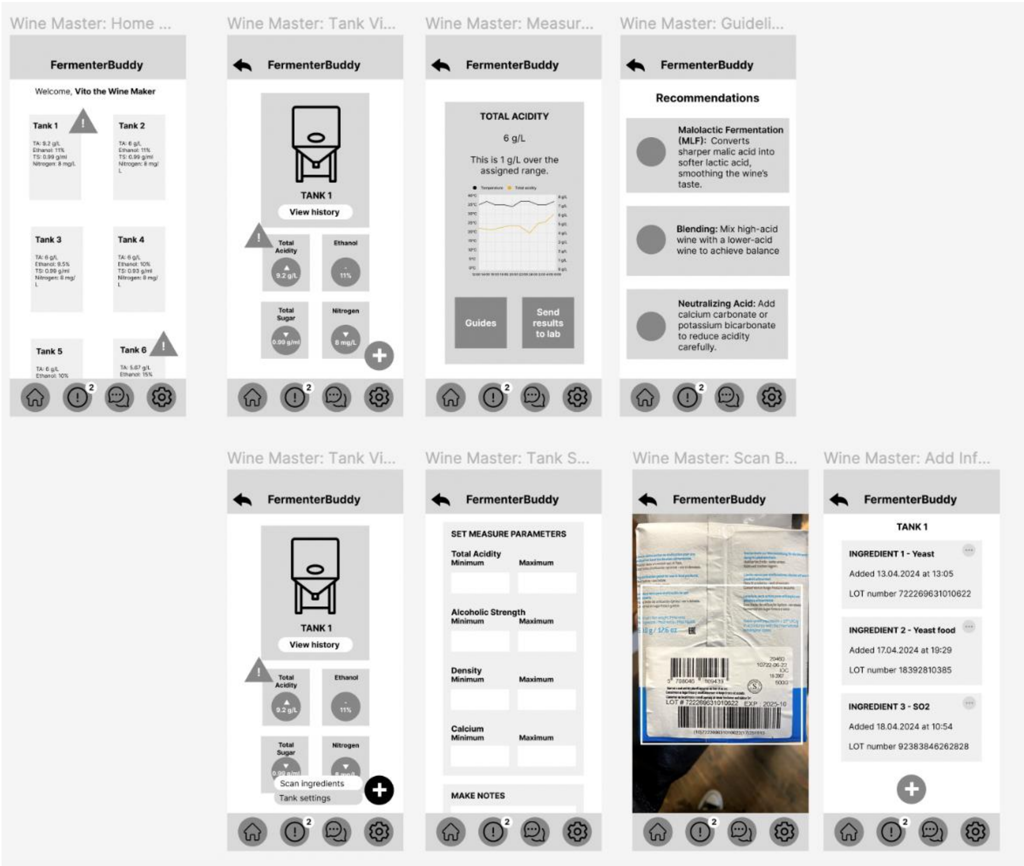


Detailed system map that guided our development work

The initial step was to understand what kind of technology would be used to make the solution feasible. At this phase, there was a shift towards incorporating Raman, NIR, FTIR, or similar technology. This change came after finding nanosensors, despite their precision, were costly and challenging for our winemaker test group to use effectively. However, there's potential for nanosensors in the wine industry, especially for labs needing to detect yeast saccharomyces. Nevertheless, we prioritize real-time continuous measurement over developing lab equipment.

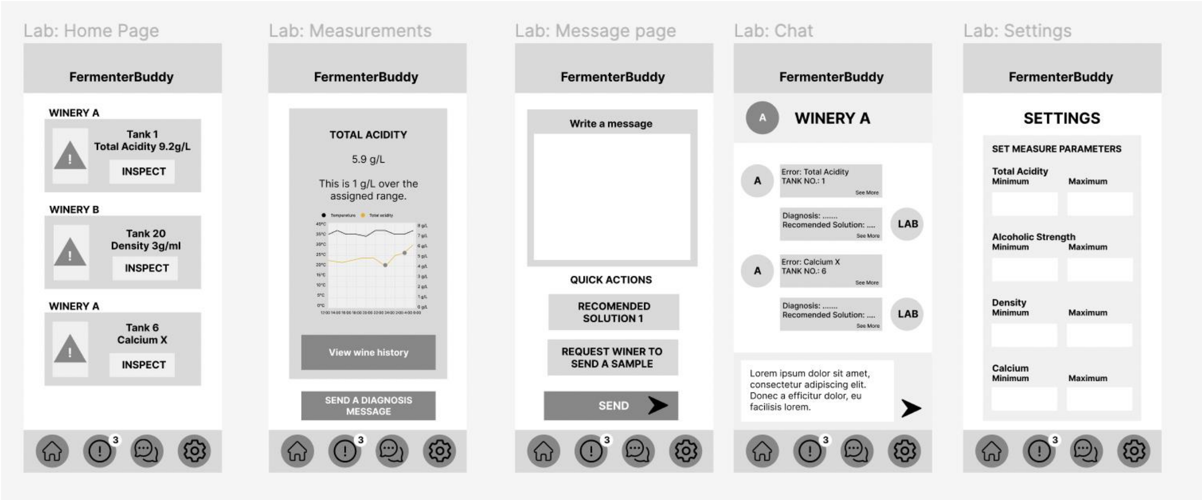
Gas Raman technology could enable non-intrusive detection of chemical compounds through spectral analysis, promising precise, real-time data for quality control without compromising wine samples. However, it primarily measures gas, leading us to explore 'liquid-Raman' technology for measuring liquid substances, which may better serve the fermentation process of wine. We focused on monitoring nitrogen, SO_2, CO_2, and O_2 levels during fermentation, vital for accurately measuring these challenging substances. Nitrogen is vital for yeast nutrition and affects fermentation speed, while SO_2 preserves wine freshness and prevents oxidation. Monitoring CO_2 and O_2 during wine fermentation is crucial for tracking fermentation progress, controlling the rate, and avoiding oxidation, thus ensuring the desired quality and stability of the wine. Furthermore, we saw an opportunity for Gas Raman sensors to align with sustainability goals, as inspired by our meeting with the Porto Protocol. By using Gas Raman technology to track CO_2 in the atmosphere, which is a reusable by-product of winemaking, we can help make the wine industry more sustainable. However, this is not our main objective.

In parallel to understanding the technical feasibility, we began working on understanding what kind of communication and interface would be most useful for winemakers. To make an interface that fit the needs of our users, we started by building a quick wireframe that we showed to stakeholders, both winemakers and lab personnel. Through this, we were able to ensure that we included features that fit the users' needs, as well as communicated the data from the fermentation tanks in a way that was efficient and intuitive.



Initial wireframe developed for winemakers

Discussions with users were especially useful at this point, as both winemakers and lab-side personnel were able to give ideas for development, as well as validate hunches about key features. For example, we learned from winemakers that being able to scan and include what ingredients (such as yeast) have been added to the wine is imperative, as this information is important to collect and can be helpful when diagnosing what is wrong with the wine. Further, they were able to validate that it is important that the user can set the parameters for different measures themselves, as these are not fixed and vary based on the type of wine that you are trying to make.



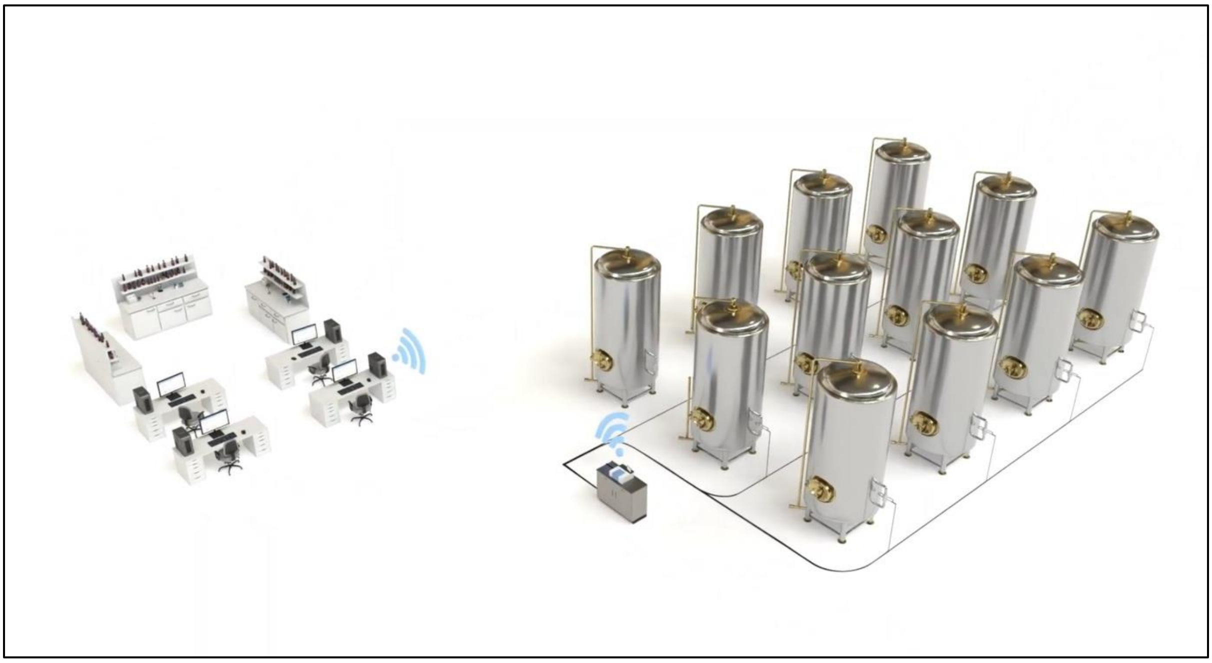
Initial wireframe developed for lab personnel

Furthermore, we learned from the interviewed lab personnel that it would be valuable if they could access all the information and historical data of the batch when making a diagnosis. This is important, as it can make the diagnosis process faster and easier because it decreases the additional testing requirements for the lab. A chat communication function was also added, as it was quickly found that much of the collaboration between the winemaker and the lab is done by just talking. With these insights in mind, we continued the development process of the app and system around it.

5.2 Final Solution | FermiSense

Based on the previous discussion and user feedback on the wireframe, we propose FermiSense, a wine monitoring system designed to anticipate fermentation issues, reduce manual labour, and improve communication flow for winemakers and lab personnel.

FermiSense consists of two main components. The first is the physical sensor system, which connects multiple tanks to a near-infrared sensor through fibre optic cables. The second component is an app that connects winemakers and lab personnel directly to the monitoring system, thereby reducing their workload and facilitating communication.

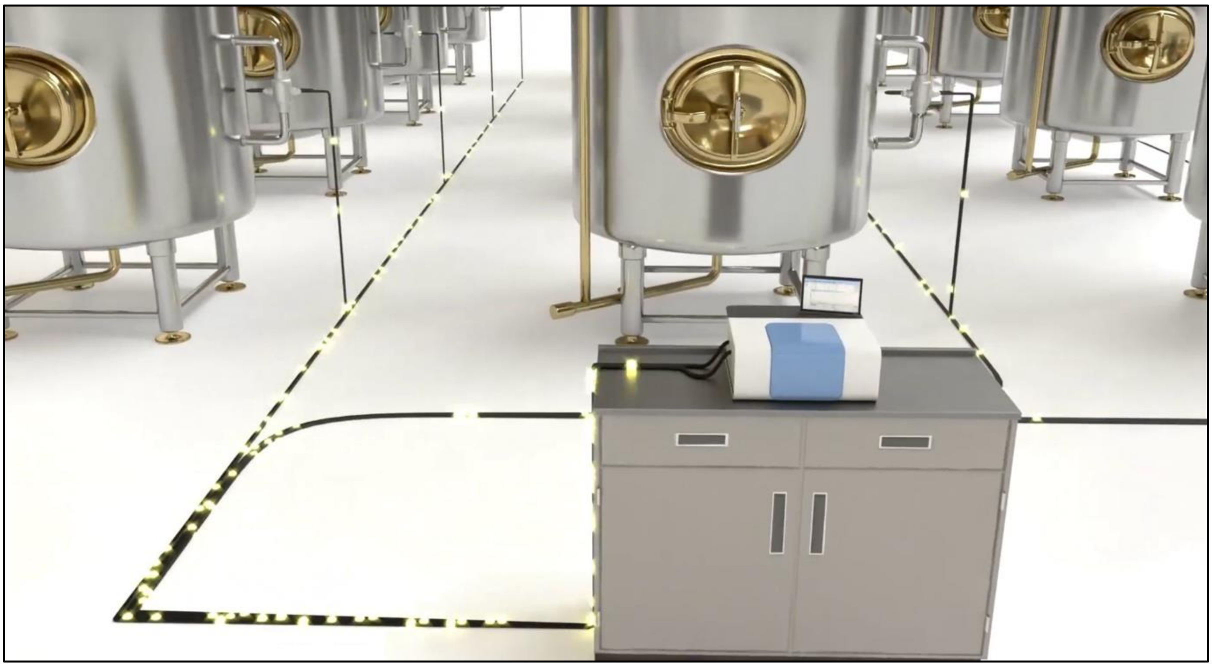


5.2.1 Physical sensor system

The physical side of our concept, FermiSense, consists of 3 main components: 1) infrared process flow cell, 2) fibre optic cables, and 3) centralized infrared spectrometer (IRS).

1) The infrared process flow cell (PFC) is a physical sensor designed for in-situ monitoring of chemical streams using NIR spectroscopy signals. In our system, a PFC is installed directly to each fermentation tank using a by-pass loop, allowing a slow, yet constant stream of the fermenting liquid to be analysed and scanned using IR light. Measurements can be programmed to be taken in real-time or at desired intervals (e.g. 2-10 times a day). Using a PFC enables the identification of the wine's chemical compounds and their concentrations.

2) Fiber optic cables (e.g., silica multimode fibres) function as the medium which transmits the IR scan analysis from the PFC to a centralized IR spectrometer device. We chose fibre optics for carrying the analysis signal from the tank's PFC to the IRS to reduce contamination and eliminate the need to transport physical liquid samples from the production facility to the lab. Although the use of fibre optics adds an extra and new layer to winemaking, the addition is novel and has the potential to simplify the process and mitigate some of the risks related to sample contamination and transportation.

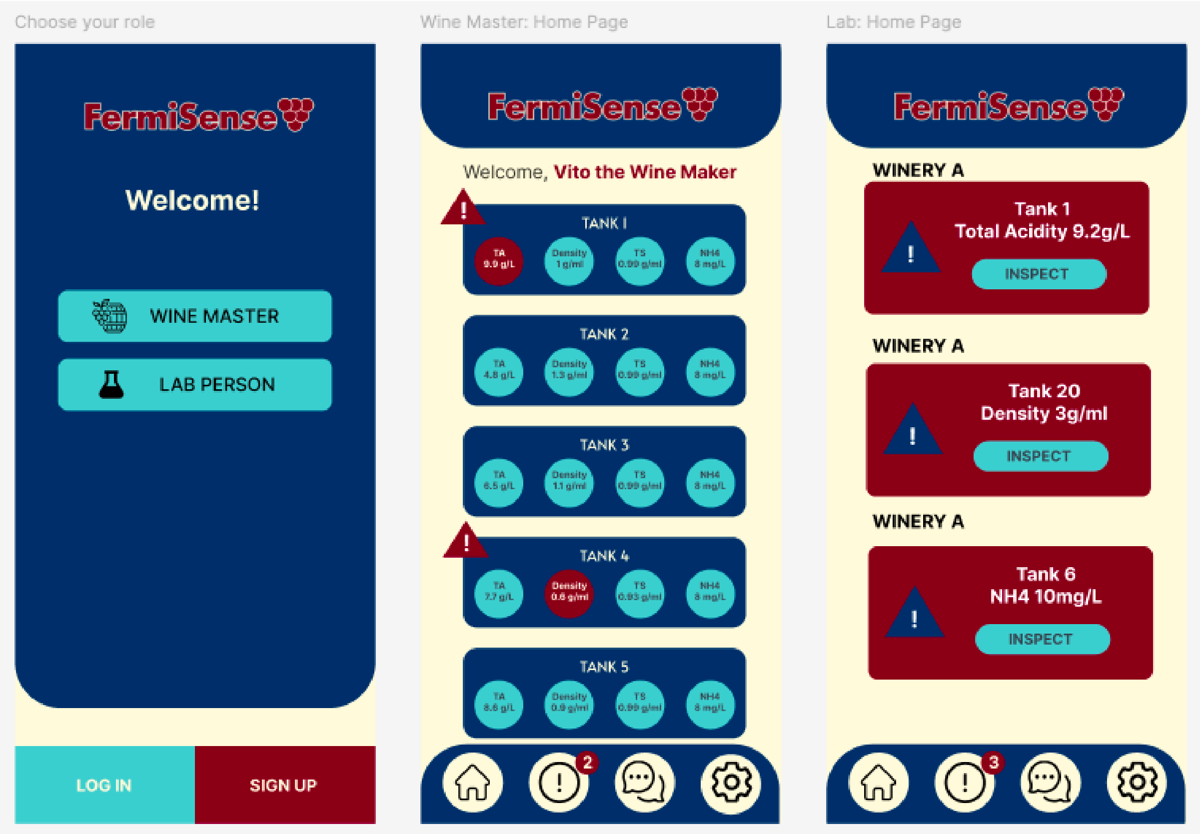


3) The centralized IR spectrometer is where the actual analysis occurs. We opted for a system that employs a single centralized IRS device to take measurements from multiple tanks with a single device, rather than having a separate sensor for each tank. This decision was inspired by interviews and visits conducted at the Sogrape Wine Production facilities in Porto, Portugal. It is important to note that our team's operational skills of such devices are limited, thus we did not want to specify or define which commercially available IR spectrometer to install in the setup. However, our design was inspired by existing vibrational technologies such as MIRS (Mid-Infrared Spectroscopy), NIRS (Near-Infrared Spectroscopy), Raman Spectroscopy, and FTIR (Fourier-Transform Infrared Spectroscopy). We understand that each of these technologies have their opportunities and challenges, and further research and experimentation is needed to determine the best option in terms of economical and operational feasibility. These vibrational technologies do however have the potential to analyse many of the important chemicals and biomarkers currently tested in fermenting wine; such as ethanol, nitrogen, yeast strain classification, potassium and calcium, total acidity and other volatile compounds (Egidio, Sinelli, Giovanelli, Moles, & Casiraghi, 2010; Wang, Ye, & Zhang, 2016). As an example, for what Near Infrared Spectroscopy (NIRS) can measure please see the comprehensive list here (Jackson, *Wine analysis* 2023).

Once the IRS analysis is completed, the chemical analysis results can be transmitted directly to either the lab or the winemaker. This takes us to the next step in our user experience; the FermiSense app.

5.2.2 FermiSense APP

With the sensor system doing the measurements, we built the APP for winemakers and lab personnel to connect with the system consistently. Since there are two key users: wine makers and lab personnel, we made two separate versions for different uses.



5.2.2.1 Winemaker

For winemakers, their pain points centred on spending too much time tasting, doing daily sensory testing, recording, and analysing measurements by hand, relying on lab personnel and wine consultants, and the biggest one, not being able to notice problems on time.

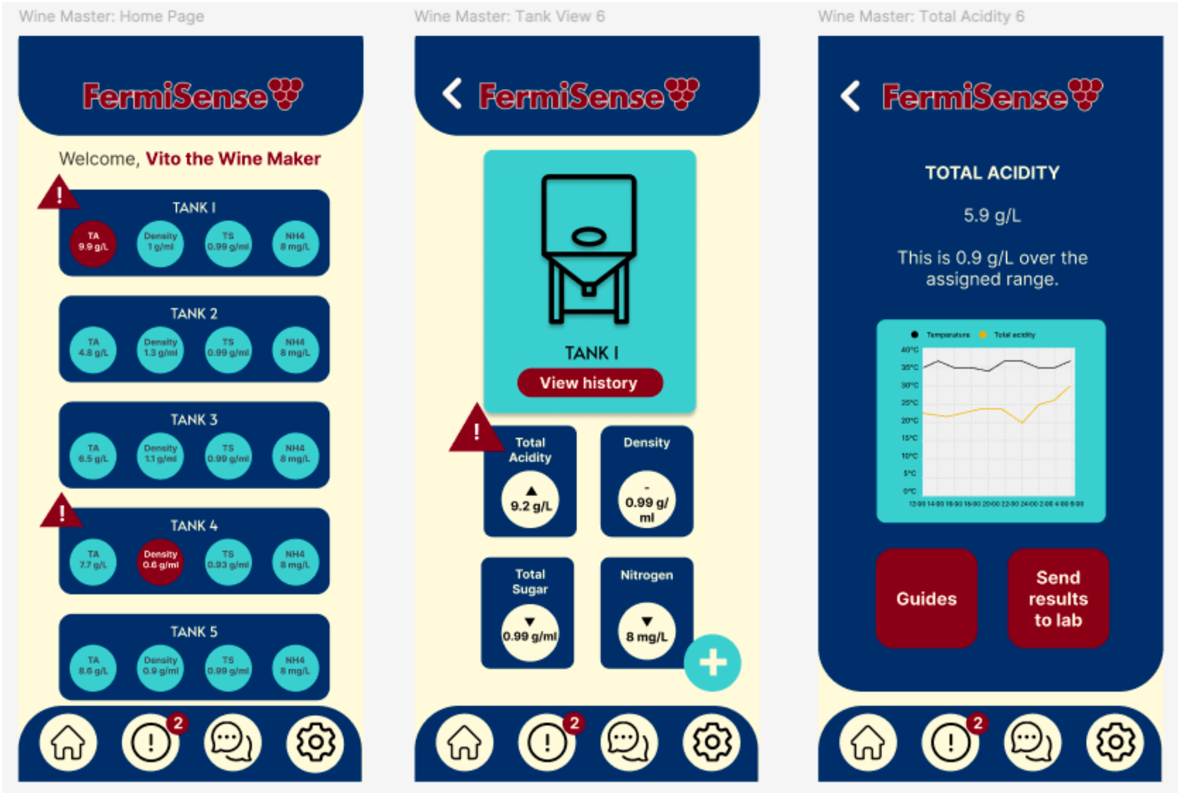
Correspondingly, our APP is capable of several functions that solve their problems:

- Tank Information
- On time Alerts
- Measurements details
- Intelligent Problem diagnosis
- Chat box

Before monitoring, users need to set up the tanks that are connected to the infrared sensor, and input information and desired parameters for the wine, such as wine type, grapes, yeast information, and measurement parameters. When recording some information like yeast, users only need to scan the barcode of the product and recording will be done automatically. Any additional ingredients can also be scanned and added to the wine's historical data whenever needed.

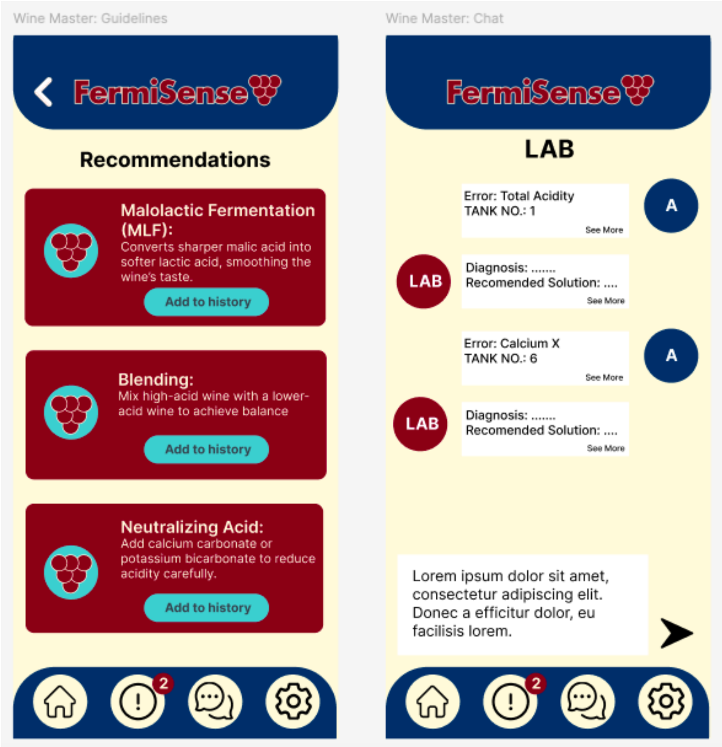
Winemakers are asked to input information and desired parameters for the wine

After setting up, when anything goes wrong, wine makers will get an immediate notification and the alert icon will be shown on the top left of the tank on the home page. Next, after clicking on the alerted tank, users will be able to the details of each measurement with graphs and description.



Tank interface

To increase independence, the APP is capable of an intelligent system that could analyse the problem with the database and AI tools. Therefore, winemakers can fix the problems on their own according to the recommendations provided by the App. Every action point could be recorded on the APP with a few clicks, which also provides vital information for both the winemaker and the lab personnel, who will have access to all the data whenever diagnosing issues. However, sometimes problems might be tricky, and easy communication between winemakers and lab persons could be the key to saving the wine. The chat box allows winemakers to send the whole tank history to the lab side, including yeast, yeast food, measurements, and action points.



Recommendations and chat interface with lab

5.2.2.2 Lab personnel

For the lab personnel, when receiving the message from wine makers, they immediately have the access to the whole tank history. This allows them to analyse the data and diagnose the problem quickly and easily and reduces the time wasting on sending sample on both sides. Surely lab persons can request a sample if the problems are too complicated, or else they could recommend their solutions to winemakers. Besides functions that ease the flow of communication, lab personnel also could change the tank setting for better monitoring.

Interface for the lab personnel, which includes similar functions to the winemaker

6. Future directions

As this project concludes, several potential advancements and pathways for future exploration have been identified. Here, we outline the possible future directions for the various technologies developed.

6.1. Future Directions for FermiSense Technology

The future of FermiSense technology includes several potential advancements. Enhancing AI capabilities can enable more accurate and predictive fermentation analysis, allowing winemakers to identify and address issues before they escalate.

Expanding the system's scalability can accommodate both larger operations and more extensive networks of tanks, making it suitable for wineries of all sizes. This includes developing cost-effective solutions tailored for smaller wineries, making advanced monitoring and control systems more accessible to them.

Integrating IoT devices can provide comprehensive monitoring and control, streamlining the winemaking process and improving overall efficiency. Advanced data analytics can offer deeper insights into fermentation trends and patterns, aiding in better decision-making and process optimization. Additionally, focusing on sustainability features can help wineries monitor and reduce their environmental impact by tracking metrics such as CO2 emissions.

6.2. Future Directions for Handheld NIR Device for Wine Analysis

One interesting direction we considered was the development of a handheld device for winemakers to physically analyse wine using Near-Infrared (NIR) technology. This idea emerged from discovering existing market solutions that utilize NIR to analyse wine through the bottle (Harris et al., 2022). Our concept was to create a handheld device that could scan wine through a transparent section of the fermentation tank. This device would allow winemakers to receive immediate information about various parameters, such as sugar content, alcohol levels, phenolic compounds, and other critical particles involved in the fermentation process. By simply pointing the device at the wine through a transparent window, the NIR technology would provide real-time data displayed directly on the device. According to research, NIR spectroscopy is already being used effectively for non-invasive analysis of these parameters in various contexts (Sheth, 2021; Kicherer et al., 2023).

Additionally, this handheld device would be useful during the aging process. Winemakers or wine sellers could scan the wine through the bottle to gain insights into its composition and aging potential. This dual-use capability during both fermentation and aging phases could greatly benefit winemakers by offering continuous monitoring and real-time data. It would also assist wine sellers in understanding and marketing the aging potential of their products.

However, we did not choose this path due to the significant research and development required to ensure its feasibility and effectiveness. Instead, we opted for a continuous monitoring system and an associated app, as we believed this approach offered additional advantages, such as providing real-time updates, historical data tracking, remote accessibility, and automated alerts, all of which enhance the winemaking process and overall efficiency. Nonetheless, the handheld NIR device remains an interesting direction for future exploration and development, offering significant potential benefits for the wine industry.

6.3. Future Directions for Pipe 4.0 GasRaman Technology: Carbon Dioxide Measurement

At the beginning of the project, we were introduced to the Pipe 4.0 GasRaman technology, which offers the capability to analyse wine without direct contact. Initially, we faced challenges in utilizing this technology for gas analysis as opposed to liquid analysis, which is typically more relevant in winemaking. However, during our visit to the Porto Protocol, we identified a promising application for GasRaman technology. As wineries strive to become more environmentally friendly, there is a growing need to measure and capture carbon dioxide emissions during the winemaking process. We learned that the Pipe 4.0 GasRaman system could continuously measure CO2 levels in the winery environment, helping wineries ensure they remain within environmentally friendly parameters. This represents an exciting future direction for the technology. Despite the current limited market, as few wineries prioritize CO2 emission monitoring and capturing today, we believe this solution has significant potential. As environmental regulations become stricter and more wineries adopt sustainable practices, the demand for such technology is likely to increase in the future.

6.4. Future Directions for Unicorn DX Nanosensor in Fermentation Analysis

One of the initial technologies assigned to our project was the Unicorn DX Nanosensor, which we identified as having significant potential for analysing yeast during the fermentation process. This technology requires the extraction of liquid samples, which led us to consider its integration within fermentation tanks. The idea was to implement a system within the tank that could periodically extract small amounts of liquid during fermentation. The extracted liquid would then be analysed by the nanosensor to provide precise readings of various parameters, such as yeast concentration and the presence of specific metabolites. However, we decided not to pursue this approach due to its high costs and the limitation that it only allows for intermittent sampling rather than continuous monitoring. Nonetheless, if the technology could be deployed on a larger scale to achieve cost efficiencies, there is potential for its future application.

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APPENDICES

APPENDIX A

Measures of wine aging

- Ethanol content: 5.5% - 16% (ABV, essentially how much alcohol is in the wine)
- Acetaldehyde and other aldehydes content: table wines have below 75 mg/L, and over 125 mg/L start to have a strong sherry flavour (also note that ethanol turns into aldehydes when oxidized, so as the content of aldehydes grows the content of ethanol decreases)
- SO2: naturally 10-20 mg/L (white wines have more than red wines, SO2 helps preserve wine from oxidation)
- The yeast consumes amino acids (most amino acids [e.g. arginine] during fermentation, proline [30-85% of all amino acids in the wine] is the most common after fermentation [not consumed by yeast], next are alanine, glutamic acid + glutamine, arginine & y-aminobutyric acid - red wines have more [300-1300 mg/L])
- Amines (histamine, tyramine, phenethylamine)
- Thiols: hydrogen sulphide H2S, 3SH, 2SHA, 4MSP, phenyl methanethiol PMT (citrus and tropical flavours in Sauvignon Blanc, but also e.g. Riesling and Pinots, more common in whites but also present in reds, amount lowers with oxidation but SO2 can help preserve, PMT produced from oak in barrel aging)
- Flavan-3-ols and flavonoids
- Polyphenols (e.g. gallic acid)
- Phenolics
- Quinone and hydrogen peroxide
- Acidity
- Sugars
- Oxygen
- CO2

APPENDIX B

Continuous Measurement Methods for Wine Tank Parameters

pH Measurement:

Continuous pH Measurement:

Equipment Required: pH probe, data logger.

Procedure:

- Install a pH probe in the fermentation tank.
- Set up the probe to continuously measure pH values at predetermined intervals.
- Connect the probe to a data logger to record pH readings over time.
- Ensure regular calibration of the pH probe to maintain accuracy.

Current Method: Winemakers typically measure pH using handheld pH meters or pH test strips. These manual measurements are taken intermittently throughout the fermentation process.

Brix/Sugar Measurement:

Continuous Brix/Sugar Measurement:

Equipment Required: Inline refractometer, data acquisition system.

Procedure:

- Install an inline refractometer in the pipeline or tank.
- Set up the refractometer to continuously measure sugar levels in the wine flow.
- Connect the refractometer to a data acquisition system to record sugar concentrations over time.
- Regularly clean and calibrate the refractometer to ensure accurate measurements.

Current Method: Winemakers traditionally measure sugar levels using manual methods such as hydrometers or refractometers, which require periodic sampling and testing.

Dissolved Oxygen Measurement:

Continuous Dissolved Oxygen Measurement:

Equipment Required: Dissolved oxygen probe, monitoring system.

Procedure:

- Install a dissolved oxygen probe in the fermentation tank.
- Configure the probe to measure dissolved oxygen levels in the wine continuously.
- Connect the probe to a monitoring system that records oxygen concentrations over time.
- Perform regular maintenance and calibration of the dissolved oxygen probe for reliable measurements.

Current Method: Dissolved oxygen levels are typically measured intermittently using handheld meters or test kits. These manual measurements may not provide continuous data throughout the fermentation process.

Total Acidity Measurement:

Continuous Total Acidity Measurement:

Equipment Required: Acid analyser, real-time monitoring system.

Procedure:

- Install an acid analyser capable of continuous measurement in the tank.
- Connect the analyser to a real-time monitoring system to track total acidity levels.
- Implement automatic sampling and analysis routines for seamless measurement.
- Conduct routine maintenance and calibration of the acidity analyser to ensure accuracy.

Current Method: Total acidity is typically measured using titration methods in the laboratory. Samples are collected periodically, and acidity levels are determined through manual analysis.