Linnéuniversitetet

Household Food Waste
Exploring a New Way of Food Inventory Management in Households Using Modern Technologies to Reduce Food Waste

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To Zait, Adisha, Kreshnik and Stefanie. Thank you for your never ending support.

Abstract

Food waste is becoming an increasing threat to the environment and the economy. Estimates indicate that annually, a third of the food produced around the world ends up being wasted. Only one-fourth of that food is enough to take nearly a billion people out of starvation. Food waste is especially higher in more developed countries, including most of the states in the European Union and the USA. Sector-wise, food is being lost from field to fork, with households topping the charts. Overbuying, not knowing what already is in the fridge, unaware of the food until it eventually expires, are among the most common reasons that contribute to the food waste. The potential prevention of such a massive waste could significantly reduce the amount of greenhouse gas emissions around the world and help the economy of the households including all the parties involved in food production, distributing and retailing.

On the other hand, technology has progressed in very rapid steps. The advancement of Artificial Intelligence (AI), Machine Learning (ML), Internet Of Things (IoT), and voice-enabled devices has revolutionized many industries and has made us more efficient as human beings. Unfortunately, these advancements haven't yet had any significant impact in assisting families with their food choices and in preventing them from overbuying and throwing food away. Most of the proposed solutions addressing this issue, do not get integrated into everyday life. That is because they require a lot of manual input, rely entirely on mobile phones, do not show immediate results to keep users motivated, and on top of all, for the sole fact that modern lives are quite complex, and although an important issue, food waste is not an everyday cause of concern of an average person.

This thesis takes into account all of the shortcomings of the previous works and aims to create a more sustainable solution by exploring new ways of food inventory management in the households by automating the process so that users don't have to manually enter the data themselves. The proposed solution consists of a device that should be easily mounted into any fridge and acts as an interface between users and their food inventory. The device contains a bar-code scanner for the item input and a back-end that is capable of recognizing the item and can in return show user-friendly and valuable information such as the approximate price of the item, the approximate due date etc. and notifies users when an item is about to expire so that they can take appropriate actions.

7 out of 9 participants in the final conceptual design study said they would use this solution in their homes. The rest of the results from the designed test cases indicate a clear excitement and interest in participants and a willingness to see the prototype in the finished state, all the comments and insights together with the future work and how the feedback will be used into the next iteration are part of the final discussion of this thesis.

Keywords: *Food waste, sustainability, technology, IoT, mobile, web, smart fridge*

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Contents

List of Abbreviations

AI Artificial Intelligence

ML Machine Learning

IoT Internet Of Things

U.S. United States

E.U. European Union

UN United Nations

EIT European Institute of Innovation and Technology

UNEP The United Nations Environment Programme

SNFA Swedish National Food Agency

SEPA Swedish Environmental Protection Agency

SBA Swedish Board of Agriculture

LNU Linnaeus Universit

LGPL Lesser General Public License

GPL General Public License

DIY Do It Yourself

FUSIONS Food Use for Social Innovation by Optimising Waste Prevention Strategies

USEPA United States Environmental Protection Agency

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1 Motivation

Food waste is one of the most important environmental issues the world will have to address in the coming years. Estimates show that a third of all the food produced on the entire planet ends up wasted.[1][2]

The current state of the globalized food system is unsustainable on many levels.[3] With the existing efficiency and metrics, food production has to increase by 70 percent for 9 billion people to be fed by 2050.[2] [4] Around 88 million tonnes of food waste is generated in the **EU!** (**EU!**) alone. Put in an economic perspective, annually 143 billion euros is lost on food that never gets consumed. However, the damage that food waste causes is not only economical. Industrial agriculture, intense and monoculture farming practices and their reliance on fossil fuels have severe environmental consequences, including air pollution, contribution to climate change, loss of biodiversity, and low animal welfare. [3] The water wastage generated is equivalent to the entire annual flow of the Volga-Europe's largest river. The energy that goes into the production, harvesting, transporting, and packaging of all the wasted food, generates more than 3.3 billion metric tons of carbon dioxide. If food waste were a country, it would be the world's third-largest emitter of greenhouse gases, behind the US and China. [5]

In order to address the waste issues, the **EU!** has set up Food Use for Social Innovation by Optimising Waste Prevention Strategies (FUSIONS) in order to work towards a 50 percent reduction of food waste generated in the **EU!** and a 20 percent reduction in food chain resource inputs by 2020.[6] European Institute of Innovation and Technology (EIT),[7] aims to stimulate entrepreneurship, innovation, and research in the food sector to create a more sustainable and future-proof food sector. Their program 'Zero Waste Agenda' is one of four innovation programs and aims to develop solutions for food security, improve the efficiency of the food value chain and reduce food waste.[8]

The United Nations Environment Programme (UNEP) has set future goals for raising awareness on the value of food people eat, as well as the environmental impacts of their choices with the perspective to redirect consumption patterns to less resource-intensive food.[2] Here in Sweden, the Swedish National Food Agency (SNFA), in collaboration with the Swedish Environmental Swedish Environmental Protection Agency (SEPA) and the Swedish Board of Agriculture (SBA), have developed an action plan that consists of 42 proposed measures and specified needs as regards investigation, research, and innovation to combat the waste in all the food chain within the country.[9]

In the last decade, technology has progressed with astonishing steps and has redefined many aspects of our lives. Only in recent years, the increased amount of data generated by everyday users has given power to different AI and ML services to transform and change entire industries. The data and insights generated from such services have made us more efficient and continue to aid us in making better choices when it comes to clothes, friends, partners, health decisions, etc, The proliferation of IoT sensors has brought unprecedented opportunities to enable a variety of new services [10] unfortunately, such technologies haven't yet been applied to the issue of food waste.

There are some smart fridges presented by companies such as LG[11] and Samsung,[12] that try to help families manage their food inventory. Their large displays are good for playing music, checking the weather, and surfing the internet, but not yet that useful for translating the products it stores, into valuable data for the family. One good feature that they offer is integrated cameras. They allow the user to check the contents of the fridge from their smartphone. Nevertheless, that doesn't easily translate into their shopping list and it neither provides them more metadata about the food they possess such as; any food soon to expire, the amount of milk left in the milk box, etc. Besides, the available capabilities pose a risk of privacy leakage through the camera and also come at a high cost. [13] Therefore, keeping inventory by the aid of a smart fridge is still hampered by time-consuming scanning of items or receipts as well as manual registration. This situation creates skepticism towards the maturity of the smart fridge concept within the tech press.[14]

1.1 Problem and Needs

Studies show that wasting food is not a mindless activity conducted by people with "bad" attitudes, but a process involving a complex network of social interaction, routines, and practices, material infrastructure, emotions, and knowledge.[14] Hebrok and Boks[14] suggest that a successful design intervention will contribute to "nudge" people to reduce their food waste, perhaps without having to change their attitude be educated or raise their effort greatly.[14] Reitberg et.al. argue that instead of forcing users towards a behavior, system designers should focus on helping them make their changes. [15] "Nudging" individuals towards a certain behavior should be done in a way that makes the desired behavior more silent e.g. making a healthier food option the "default" meal for school children. [16]

During their literature review, Farr-Wharton et al. [17] concluded that future interventions should target the household fridge to reduce household food waste because it is a tool that impacts both food purchasing and storage. In addition, they argue that emerging studies in HCI have targeted behavior change, to increase awareness on issues such as climate change, however the effectiveness of such motivational techniques such as reward systems, emotional motivation, intrinsic motivation, gamification, and goal setting is very low when it comes to maintaining changed behaviors over a longer period of time. This is often because individuals experience an initial interest and motivation to change, and over time, the interest dissipates due to lifestyle, time availability and other external factors. Furthermore, they indicate that research must consider embedding interaction and engagement into technology to simulate a behavior change process.

Thus it can be concluded that food waste in the households is not only a human problem, or a software problem alone, and neither hardware but rather a combination of them all. There is a need for a solution that efficiently combines the hardware with the state of the art software and on top of that requires a minimal effort and change of habit from the peoples' side to effectively help them reduce the amount of food they waste.

Research points at a couple of main reasons for food being wasted. Over-buying reportedly is the predominant reason followed by shopping routines without planning, not having an overview of what already is at home.[18][19] [17] [20] From a critical perspective wasted food is mainly a result from a society where over-production of food is predominant and the practice of over-buying by consumers and individuals is intended by the industry and the market (big packages, offers, etc.)[18]

Most of the solutions identified during our literature review rely heavily on users' input. (See **??**) Having to manually enter the food items into the system proves to be a big turn off for the majority of the people.[21, 22]

1.2 Research questions

To address the established problems, a set of questions were constructed using the Global/Question/Metric (GQM) paradigm.

Purpose	*Investigate*
Issue:	*whether we can decrease food waste*
Object:	*generated in households*
Viewpoint:	*by automating the process of inventory management using modern technologies*

In accordance with the aim of this investigation, the following questions were constructed:

- RQ1: Can an IoT solution simplify the process of food inventory in a household?
- RQ2: What are the potentials and challenges of using such an IoT solution in everyday life?

The first research question i.e. RQ1 aims to explore different hardware and software technologies to come up with a new way of food inventory management in the households. The second research question, i.e. RQ2 further explores the opportunities and challenges that such a solution introduces and the impact it can have in a family's everyday life.

1.3 Thesis outline

Chapter 1 serves as an introduction to the food waste issue outlining its economic and environmental consequences. It talks about initial impressions and identifies the needs of a system that will ultimately help reduce food waste. Then it presents the two research questions that drive the rest of the work presented in this thesis.

Chapter 2 presents the results of the literature review by giving a more vivid picture of the problem. It analyzes the waste through all the food stages from farm to fork finally focusing down on the households. Then, several interesting solutions identified during the process of the literature review are categorized, presented and analyzed.

Chapter 3 discusses the methodologies used when conducting the research, building the prototype, designing the user test studies and interviews, tools, and methods of data collection.

Chapter 4 identifies the building blocks of the system and lays out the functional requirements of each block. Furthermore, it describes the practical steps that need to be taken to make the prototype happen.

Chapter 5, presents the technical details of the prototype, focusing on the architecture of the system in general, technical decisions, and technologies used for each of the building blocks.

Chapter 6 puts the prototype to the test by going through a technical validation and an interaction study. Then it presents the qualitative and quantitative results of those tests.

Chapter 7, analyzes the research data, the user studies to answer the two research questions outlined in the *Problem And Needs* sub-section. Chapter 8 concludes the thesis by summarizing all the work and all the journey up to the finished work. It discusses the current limitations, things that should have been done differently, the work that will be done in the future and the lessons learned during the research and development process.

2 Foundations

Food waste is a contemporary environmental, social, and ethical issue that came about as a result of societies moving from scarcity to abundance, especially, in the western countries. Being one of the most pressing issues together with climate change, food waste appears on top of the agenda at the level of the European Union (E.U.) (European Commission, 2011a) and the United Nations (UN) (FAO, 2011, 2013, 2014) and thus on the agenda of governments across the globe.[23]

Definitions of food waste, are not universally agreed upon, that makes studying and qualifying food waste difficult.[4] Multiple terms have been used interchangeably, such as food loss, food waste, biowaste, and kitchen waste.[24] In 1943 food waste was defined as the destruction or deterioration of food or the use of crops, livestock and livestock products in ways which return relatively little human food value. While in 2014, United States Environmental Protection Agency (USEPA) defined food waste as being the uneaten food and food preparation wastes from residences, commercial and institutional establishments. So wastes from homes, grocery stores, restaurants, bars, factory lunchrooms, and company cafeterias are included. Pre-consumer food waste generated during food manufacturing and packaging is considered as food loss. [23] This thesis uses the USEPA definition when talking about food waste.
Table 1 shows the different definitions of food waste during different periods of times as presented by Thyber et al.

2.1 Implications of Food Waste

The continuous population and consumption growth worldwide will lead to an increase in the global demand for food for at least 40 more years, leading to intensified use of natural resources, especially land, water, and energy.[19][23]

In the U.S. alone, every year nearly 400 billion pounds of food is circulated through the food supply chain. That same food travels from farms to distribution centers, to retailers. Finally, food service managers and grocery stores supply our institutions and homes. Much of this food, however, never makes it into the plate. Approximately 50% or 160 billion pounds, of this food, is left uneaten, sent to landfills where it makes up to 21% of the whole waste, the larger contributor.[24]

By wasting edible food, all of the resources spent growing, producing, processing and transporting the food are also wasted, resulting in potentially needless environmental impacts.[23]. The U.S. alone exhausts 19% of all the farming fertilizer, 18% of the cropland and 21% of agricultural water usage on the food that is wasted, totaling 218 billion dollars(1.3% of the GDP). Saving this food could feed all of the 42 million Americans facing food insecurity three times over.[24]

Meanwhile, in the global scale, 25% of the edible food supply is wasted each year. It comprises approximately 40% to 60% of a household's total annual garbage which accounts for approximately 20% of landfill contents in developed nations. Two-thirds of

Author	*Year*	*Definition*
Kling et.al [25]	1943	Food waste is the destruction or deterioration of food or the use of crops, livestock and livestock products in ways which return relatively little human food value.
FAO [26]	2013	Food waste is food appropriate for human consumption that is discarded (generally at retail and consumption stages).
European Commission [27]	2014	Food waste is food (including inedible parts) lost from the food supply chain, not including food diverted to material uses such as bio-based products, animal feed, or sent for redistribution.
USEPA	2014	Food waste is uneaten food and food preparation wastes from residences, commercial, and institutional establishments. So, food wastes from homes, grocery stores, restaurants, bars, factory lunchrooms, and company cafeterias are included. Preconsumer food waste generated during food manufacturing and packaging are excluded.
USDA	2014	Food waste is a subset of food loss and occurs when an edible item goes unconsumed. Only food that is still edible at the time of disposal is considered waste.
WRI [28]	2015	Only food that is still edible at the time of disposal is considered waste. Food loss and waste refers to food, as well as associated inedible parts, removed from the food supply chain.

Table 1: Food waste definition along the years.

these wastages are preventable.[29]

FUSIONS collected and analyzed data from across Europe concluding that as of 2012 an estimate of 88 million tonnes of food is wasted. The results include both edible food and inedible parts associated with food. This equates to 173 kilograms of food waste generated per person. The total amount of food produced in the E.U. during 2011 was around 865 kg/person. This means that 20% of the total food produced is wasted.[4] Economically speaking, during 2012 the costs associated with such losses are estimated at around 143 billion euros.[6]

As it can be seen in table 2 the sectors that contribute the most to food waste are households with around 74 million tonnes and food processing with approximately 17 million tonnes wasted. Farr-Wharton et al.[17] estimate that two-thirds of this waste in the households can be prevented, arguing that a person's behaviors are the leading drivers of food waste. Stenmarck et al. [6] note that the certainty of food waste during processing is the lowest since they weren't able to obtain more certain results from the respective departments.

Sector	*Food waste(million tonnes) with 95% CI**	*Food waste (kg per person) with 95% CI*
Primary Production	9.1 +/- 1.5	18 +/- 3
Processing	16.9 +/- 12.7	33 +/- 25
Wholesale and retail	4.6 +/- 1.2 10.5	9 +/- 2
Food Service	10.5 +/- 1.5	21 +/- 3
Households	46.5 +/- 4.4	92 +/- 9
Total Food Waste	**87.6 +/- 13.7**	**173 +/- 27**

Table 2: Estimates of food waste in E.U.-28 in 2012 from this quantification study; includes food and inedible parts associated with food.

This thesis focuses on food waste within households. In order to understand the presented numbers better a deeper study was conducted to identify drivers for waste and to find potential points where an intervention will help reduce those numbers.

2.2 Food Waste Drivers

The identified food waste drivers range from residential to institutional and commercial, but more detailed information on the causes is limited. In developed countries such as the United States (U.S.) and E.U., the main drivers are increased volume, availability, accessibility, affordability, caloric density of the food and the fact that there seems to be a little understanding regarding where food comes from, what its production entails and nutrition facts that are listed on the products are properly understood only by a fraction of the consumers.[30] Furthermore, cultural and personal choices affect decisions regarding what is too good to throw away.[23]

Farr-Wharton et al.[17] found out a few reasons as to why people waste food during the 3-month study they conducted examining the customer decision-making behavior regarding food wastage. Poor food storage and information availability were among the top reasons. They argued that a lack of food supply and location knowledge are among the key factors for promoting domestic food waste. For instance, people stockpile food because they did not know they had already owned enough.[17] [31] In a previous study of similar nature, Farr-Wharton et al.[32] organized the food by color-coding sections of the fridge. They allowed their study participants to assign the colors the way they want. Only by providing more clarity about where each food should be located resulted in the reduction of the amount of food waste in the households.

Ganglbauer et al.[33] found out that consumers had various reasons why they end up throwing food like bulk purchases, poor planning, lack of communication with other household members, inability to track inventory, and busy and erratic lives. Farr-Wharton et al.[17] show that households with two or more members can be unaware of available food and its location, which may have been purchased by others. So one good intervention would be to provide household members with improved awareness of the household food supply and the food's location

In another study, Ganglbauer et al. [19] found out that people generally feel bad about throwing food away, but end up in the trap of overbuying. Some of the participants pointed out that sometimes they imagine cooking great meals. They buy the necessary ingredients but don't have time and energy to do the cooking. Another food waste driver identified in the study is the packaging size. The big packages being cheaper than the small ones make people buy more than they need, and eventually, end up throwing most of it away. Ganglbauer et al. point out that over-buying can also happen due to lack of planning e.g. not knowing which goods are already available at home. Gunders2012 et al. also identify confusion over date labels and lack of education of the general public regarding date labels and overpreparation i.e. preparing more food than needed among the main drivers for food waste in the households. [29]

Ganglbauer et al.[19] identify some parallels between food waste reduction and an ecologically sustainable and healthy diet. However, the reduction of food waste benefits mostly the environment, rather than the person as is the case when losing weight. The results are less obvious therefore, hindering people from taking action. Food waste also has some similarities with energy-related issues. Nevertheless, when saving energy, monetary savings can be achieved. While once the food is bought the investment is already done. The motivation-reward structures around food waste are quite different.[19]

2.3 Examples From the Literature Review

This subchapter summarizes the most promising and interesting prototypes identified during the literature review process. Some of the approaches have been used or improved upon in the prototype presented in this thesis. The identified solutions can be grouped into four categories: the *Prototypes Using Smartphone's Camera as Embeddable Device*, *Prototypes Requiring Manual Input*, *Prototypes Utilizing Different Sensors* and finally, *Prototypes Leveraging Social Media.*

2.3.1 Using Smart Phone Cameras as Embeddable Device

Thieme et al. and Ganglbauer et al.[34] leveraged the usage of smartphones cameras to monitor the food consumption behavior within the research participants. Thieme et al. built a social persuasive system that promotes behavior changes in food waste and recycling habits within society named *"We've BIN watching you"*. In their study, they installed the smartphone into the bin. (See figure 1) A picture was taken every time the person disposed of the food.

BinCam users participated in the so-called *"Bin League"* too. The system rewarded the users if they reduced the amount of the food disposed on the bin. Concretely, a decrease of recyclable materials in the bin led to a growth of the leaves of the tree and the reduction of the food waste increased the household's amount of gold.[34] The results at the end of the study showed that *BinCam* system didn't change participant's attitude towards recycling and food waste because the selected people were already good recycles or at least contemplated improving their waste management. However, they suggest that the system was able to raise the awareness of the participants and put a mild feeling of guilt and social pressure for the food they wasted. [34]

Figure 1: BinCam Prototype

Altarriba et al. [35] developed a similar bin called *"The Grumpy Bin"* which consists of two compartments. The first compartment contains a camera. When the user throws something, the camera takes a picture of it and then it releases it to the second compartment of the bin where the actual disposed food resides. Once the food is thrown, the user is asked to give the reason why he/she did so. The picture alongside the user comment is then uploaded to Instagram. *"The Grumpy Bin"* was created to raise awareness of the food waste issue.

A similar study was conducted by Ganglbauer et al.[18] The smartphone, in this case, was placed inside the fridge enabling the participants to see what's on their fridge threw the mobile app. (See figure 2) The app was designed to be handy when shopping. As

Figure 2: Fridge Cam

mentioned in the *Food Waste Drivers* section 2.2, the user interviews showed that bad shopping practices, not being aware of what's already in the fridge, and overbuying were the most frequent reasons why people waste food. Ganglebauer et al. suggest that keeping a shopping list can significantly reduce this problem. They also point out that the reason that keeps people unmotivated to reduce the food they waste is that they do not see immediate benefits out of its like for instance, losing weight. Ganglbauer et al. argue that the future research efforts should focus towards coordinated shopping and try to make the process as easy as possible requiring less effort from the user's side.

2.3.2 Users Required to Manually Enter the Data

Farr-Wharton et al.[21] took a similar approach with the previously mentioned works. They tried to make participants aware of the food they have in their fridges. However, instead of using a smartphone inside the fridge or the bin, they asked participants to manually add the food they have bought at the market into the app. Furthermore, the app provided users with food expiration information (manually added by the developers). The results showed that the main reason why people waste food is due to their lack of knowledge of what's on the fridge and where the food is located within the fridge. Also, they acknowledge that having the users enter all the information manually is not a good design practice therefore, they defined their future work to be focused on using different approaches to automate the food entry.

In an earlier study, Ganglebauer et al.[19] designed a mobile app that asked the participants to take pictures of the food they wasted and to add the reason why they did so. Alongside this information, participants had to add the price of the product too. The conclusion was similar to the above-mentioned study. The major reason for food waste was overbuying. The study suggested that keeping a shopping list can reduce the amount of waste. Besides, having an application that suggests recipes would also be helpful towards waste reduction.

Reightberger et al.[22] developed a mobile app which connects to web services and lets the users take pictures of their shopping tickets, and receive feedback on their choices. The main goal of this research was to promote better food choices within households. Since none of the markets agreed to share information like food nutrition facts Reightberger et al. decided to use the *"Wizard of Oz"* [1] technique asking participants to only submit their shopping tickets. The results were displayed visually, using graphs and a pyramid system. The higher a participant stood in the pyramid system indicated better food choices. The study showed that there was a significant change in people's shopping behavior over 4 weeks however, the lack of automation was a serious limitation for the study.

[1] https://en.wikipedia.org/wiki/Wizard_of_Oz_experiment

2.3.3 Using Sensors

Lim at al.[36] built a digital scale (See figure 3) to help participants measure the amount of food they waste. A form of feedback was given to the participants through light indicators. The green light indicated that users wasted less food than the previous times while the red light indicated the opposite. At the end of their study, they created questionnaire study using five-point *Linkert scale* [2] to ask the participants how much did the digital scale, change their food-related behavior. The results showed that this system successfully increased the awareness of the users that took part in this study.

Figure 3: Bin With a Weight Sensor

A similar approach to Lim et al. was taken by Gartland et al.[37] They purposed a weight-sensitive bin which weighted the waste and displayed it on a touch screen using wireless technology. The touch screen calculated the current weight disposal based on its weight. Besides the weight information, they suggested the price of the waste but without giving further information on how they calculated it. At the end of the study, they concluded that people have to be motivated and need to see an immediate profit to take actions.

Fujiwara et al.[13] built their version of a smart fridge that includes a weight sensor and takes voice commands using technologies such as Alexa. The system learned more about the products by users placing the product in the weight sensor and then saying the name of the product out loud so that the system can register it. They argue that their final results suggest that the proposed smart fridge has a big potential for smoother foodstuff registration thanks to its hands-free nature by resolving the implementation issues in the smartphone application when registering.

[2] https://en.wikipedia.org/wiki/Likert_scale

2.3.4 Using Social Media

Lineahan et al.[38] suggest that some people do not see the need for change therefore, persuasive technologies should be further utilized to make people aware of the importance of the food issues. Although their work is less relevant to ours, it still has some valuable suggestions which benefit our thesis. Lineahan et al. developed two prototypes namely *"Social Receipt"* and *"Plate and Rate"*, to encourage people to make healthier food choices. *"Social Receipt"* was not successful because participants didn't find the application sufficiently engaging to either user inconsistently or allowed it to affect their food purchasing. On the other side *"Plate and Rate"* was more successful because it was more engaging and included game-like activities on Facebook.

Comber et al.[39] conducted interviews and shop-along as part of contextual inquiry with 10 households, to better understand the complex household food practices. Their findings were in complete accordance with previous research papers mentioned above. Overbuying and not using shopping lists were the two main reasons households throw away food. To reduce food waste, people should buy less, control the expiratory dates and create shopping lists.

Yalva et al.[2, 40] developed a mobile application called *"EUPHORIA"* (See figure 4) which connected people and suggested different recipes depending on the ingredients they had available. The application also allowed the logging of food and waste related daily practices and persuaded groups of people to share their food. The application also tried to suggest the right recipe according to the user's preferences. However, to guess the user's preferences the application firstly needed a considerable amount of input. Yavla et al. believe that when the technology is smart enough to exactly track the types and amounts of ingredients consumers have, their application will play a bigger role in food waste reduction.

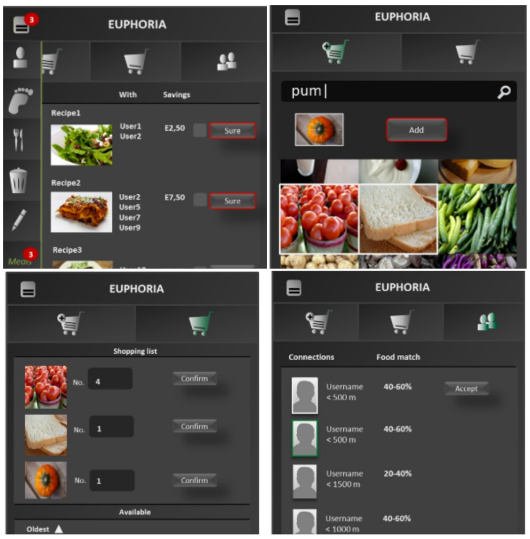

Figure 4: Euphoria mobile app

From all the analyzed works this far, the *"Foodsharing.de"* [3] (See figure 5) web platform has been the most successful approach to engage people to share their food and contribute to lowering of the food wasted. In this study, Ganglbauer et al. successfully leveraged social media like Facebook to promote their cause and help people share unused food through their developed platform. At the period when this research was conducted, Foodsharing.de has 15.000 active users and had been featured in different TV snews reporting as a successful campaign and awareness-raising platform.[41]

Figure 5: Foodsharing.de

In yet, another study by Ganglbauer et al.[18] suggests different ways that help reduces the food waste. Some effective ways to reduce food waste mentioned in this paper are as follows: connect moment of consumption with later implications of food waste, connect people who can share strategies, stories, food resources and values, promote actual gardening practices etc.

[3] https://foodsharing.de/

3 Methodology

This chapter presents the methodology used to define the research problem, construct the research questions, complete the literature review, suggest a solution and test it to answer the constructed research questions presented in the *Introduction* section 1.

3.1 Research Strategy

An in-depth understanding of the food waste issue in households is a necessary prerequisite to identify potential intervention opportunities. For that reason, with the help of our mentor Jorge Zapico, a research strategy was developed. (See Figure 6)ACM and IEEE digital libraries were the primary sources of articles and scientific papers. The word *"Food Waste"* in combination with the word *"Technology"* was used to retrieve all the research that is relevant to this work. Furthermore, the papers older than 2009 were excluded. Except for [25] and [26] which date as far back as 1943. They are used only as a reference to how the food waste definition has evolved over the years.

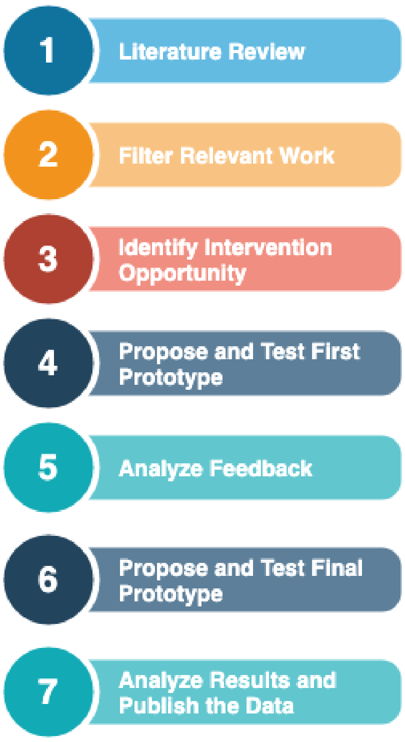

Figure 6: Research Steps

The papers that met the criteria were analyzed and added into a spreadsheet. (see Appendix A). The spreadsheet contains categories which are details of interest to our thesis and are useful in answering the constructed research questions. For instance: *what were the limitations identified in the paper*, *ease of use of the proposed solution*, *reasons for food waste*, etc. Each paper is ranked on a scale from 1 to 5 on each of these categories based on our judgment.

From all the data collected during the literature review process, it was obvious that lack of planning, overbuying, not knowing what already is in the fridge, lack of understanding of the expiration dates, and not being motivated enough to take action were among the most common food waste drivers. Chapter 2 discusses these food waste drivers in details. In addition to that, several interesting solutions were identified and categorized depending on the approach they take to tackling the issue. (also see chapter 2). Then, the drawbacks that these solutions come with were analyzed to spot possible intervention points and offer a solution. The main problem identified in the current state of the art is that the majority of the proposed solutions don't become part of everyday life. They rely heavily on user input, thus users do not feel motivated enough to keep using such applications after the research period.

Having grasped the extent of the problem, and the current state of the art helped us list down a few possible alternative solutions. As the research effort progressed, it became obvious that there is a gap between the state of the art technology, and our interaction with the food. Technology is a powerful tool of transformation that has been leveraged to great success in many areas of our lives but not yet when it comes to helping us make better food choices. Smart fridges look impressive but they are not yet so smart after all.

3.2 User Validation of the First Prototype

The initial validation of the prototype was designed to help us reduce the scope of the work and validate our initial proposed solutions. A short presentation explaining the food waste issue alongside those solutions was shown to 9 participants. Some of the responses were surprising but helped shape our final solution. The results of this survey can be seen below, while the full survey itself, is available in Appendix refappendixb

3.3 User Validation Results

The first conceptual design was tested and validated by 9 marketing and innovation students here at Linnaeus Universit (LNU). After the initial presentation, they were asked to take a survey. The survey was designed to help us understand how age and student life affects someone's motives to not want to waste food, and whether they already use some application to manage their food inventory. Studies show that different age groups have different wasting patterns and priorities. Although this information isn't fully utilized in this study, is a piece of important information for our future work. The second part of the survey listed several features which users had to rate on a scale from 1 to 5, depending on how much they would want this functionality to be included in the final product.

Results showed that 55.6% of the participants belonged in the 18 - 24 age category while the rest i.e. 44.4% in the 25 - 30 category. Of them, 88.9% were female while only 11.1% male. 44.4% of the participants indicated that they have economical motives to waste less food. 33.3% stated that they are driven by their moral ethics while only 22.2% by environmental consequences. 100% of the participants do not use any app to manage their food.

The text and figures below show the answers to the second survey. The results will be further commented on the *Discussions* section 7, and are available in Appendix B.

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When asked about how would they rate having a device that mounts into their fridge and allows them to scan the items without having to type them manually, 3 out of 9 voted 5 (from 1 to 5). While only one voted 1. See figure 7

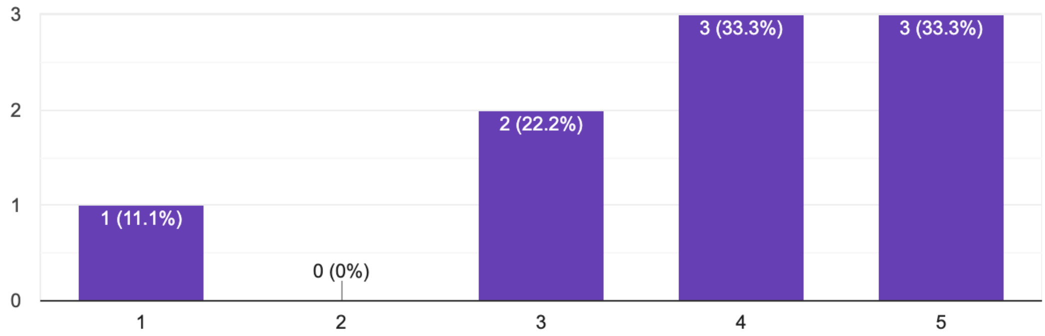

Figure 7: Having a Barcode Scanner

2 of the participants want to see the nutrition facts of the food items they own i.e. they voted 5 out of 5. 2 others wouldn't want to see any nutrition facts i.e. voted with 1 point. See figure 8

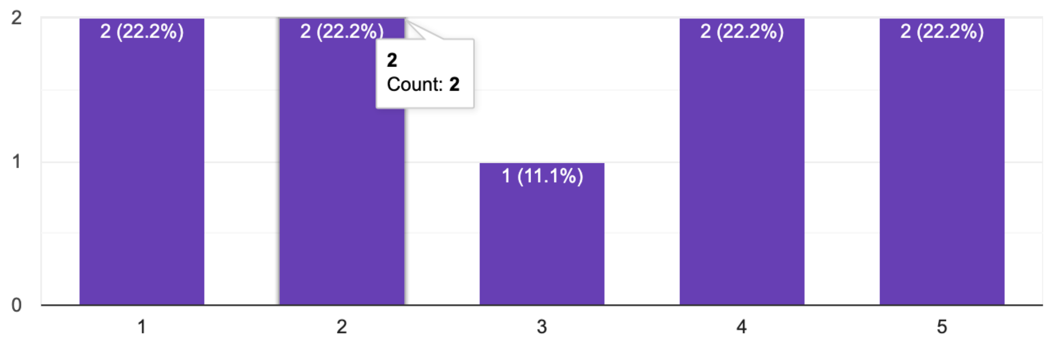

Figure 8: Seeing Nutrition Facts

Being able to be notified before an item expires appears to be one of the most favorite features, as it can be seen in figure 9

An interesting feature that could have been explored was the ability to pre-plan meals for the week and then generate the necessary groceries into a shopping list. The responses were scattered between the scale of 1 to 5. See figure 10. It is worth noting that only 7 people answered this question.

4 out of 9 people want to have the possibility to scan an item and mark it as wasted or finished. While one person wouldn't want to have this feature in the final product. See figure 11

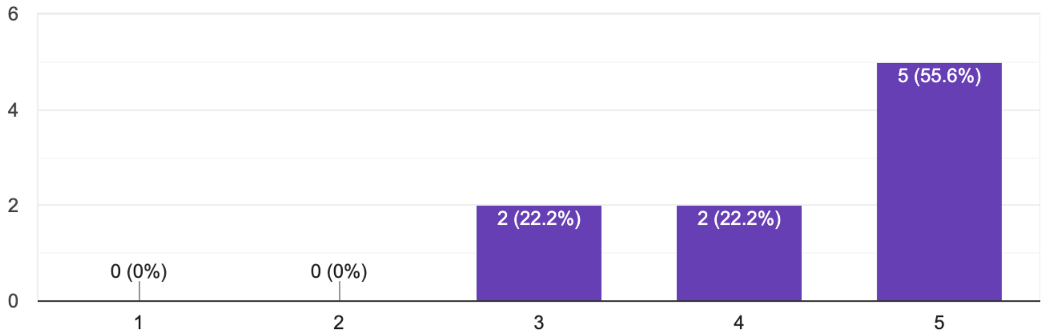

Figure 9: Getting Notified When an Item is About To Expire

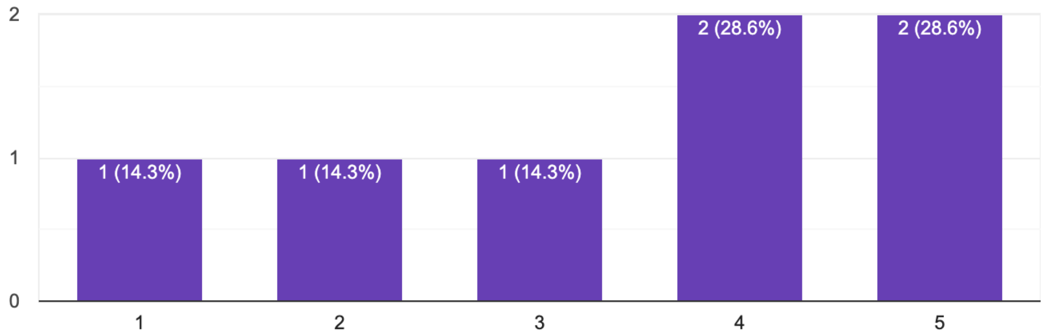

Figure 10: Generate Shopping List From Recipes

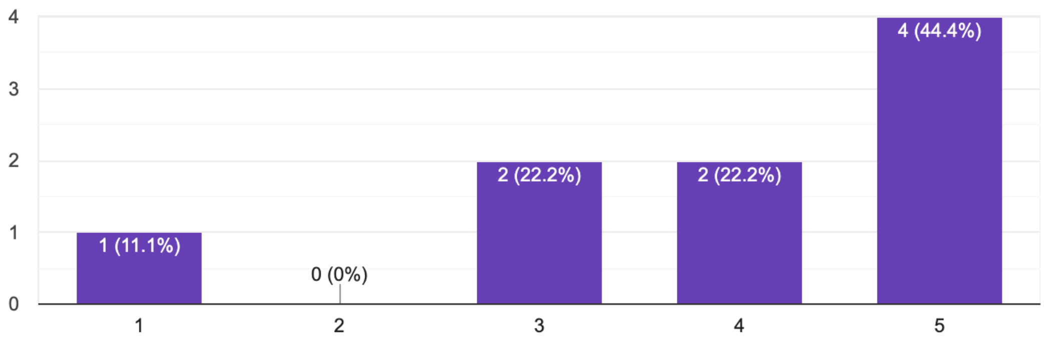

Figure 11: Scan and Mark Item as Finished/Wasted

One person would want to see how much money he/she spends on food i.e. voted 5 out of 5, while 4 people voted 4. One person didn't seem interested to know about the money he/she spends on food. See figure 12

The most voted feature was having the possibility to see how much money one spend on food that is wasted. 5 participants rated it as a 5, 3 participants as a 4, and the final participant as a 1. See figure 13

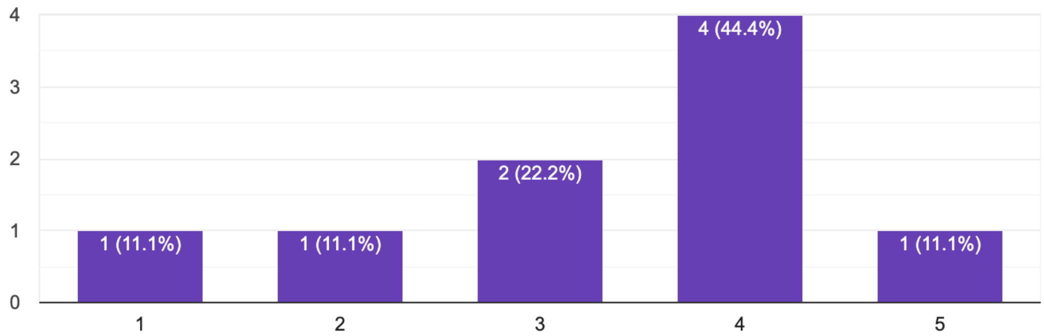

Figure 12: See How Much Money You Spent on Food

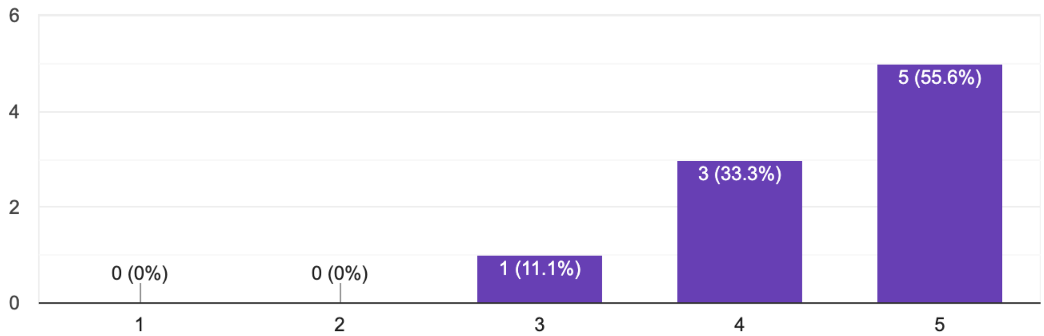

Figure 13: See How Much Money You Lose on Food You Waste

3.4 User Testing of The Final Prototype

Two different tests were designed to make sure that the prototype has the capabilities to help us answer the constructed research questions. The first test being the technical validation and the second the User Interaction study.

3.4.1 Technical Validation

A technical validation was designed and introduced to a group of participants to make sure that the developed prototype is functioning without any major flaw or bugs. A list of actions was defined as an interaction protocol consisting of steps that the participants should take in testing the system.

Each volunteer was given an introduction to the problem alongside the solution so that they understand the issue we are trying to solve. Each user interaction lasted approximately 20 minutes. Notes were taken during the whole process. They were also encouraged to think-aloud while using the prototype so that potential design improvements can be integrated early on the process. After all the instructions were performed, the participants took part in a formal interview to get their final thoughts and feedbacks.

3.4.2 User Interaction Validation

The user interaction validation test was created to understand how users interact with the newly developed prototype. The purpose of this test was to make sure that the proposed system is easy to use and can be understood. The majority of the reviewed without much effort.

Each participant went through a one-on-one session with the researcher. The participants unfamiliar with this work were given a quick introduction. Then, once the goal of this prototype was properly explained, the participants went through the basic use cases as they were giving think-aloud feedback while interacting with the system. The researcher took notes on the comments and behaviors of the participants while eventually answering questions.

3.4.3 Data Collection

The technical validation and user interaction study were designed to collect qualitative and quantitative data necessary to help answer the constructed research questions.

For the technical validation, the following data collection methods were used:

- **Self Constructed Pre-Validation Questions** - to see the knowledge testers have regarding the food waste issue in households, how aware they are of the extent of the issue and whether they take any steps to minimize the food they waste in their households.

- **System Logs** - coming from the prototype itself when the participants complete their tasks when interacting with the system.
- **Post Validation Interview** - a qualitative interview where the users express their opinion on the issue and the system in general, focusing mostly whether they think this prototype is helpful and whether they see it as something with the potential of being fully integrated with their daily life at some point in time.

For the interaction study, the following data collection methods were put in place:

- **Self Constructed Pre-Validation Questions** - to see make sure the users were able to figure out how to use the prototype.
- **System Logs** - coming from the prototype when the user interacts with the system to analyze their behaviors.
- **Post Validation Interview** - in this interview users were asked to give their feedback and thoughts on the overall system, and whether they think it would help them reduce the food they waste, what should be improved, and which features should be included in the future for them to commit to the product.

4 Concept and Interaction Design

The majority of the reviewed solutions encountered during the literature review show positive results however, fail to be a long term solution. The amount of manual work required by such solutions outweighs the benefits they offer. So, a long term effective solution would be a system that considerably reduces this friction namely, reduces the manual work and maximizes the benefits it has to offer.[21, 22]

4.1 The Conceptual Design

After thoroughly analyzing the literature, the obvious starting point was to create a system that at its core reduces the work required from the users while helps families keep track of the food in their households. There were a few options considered to automate food inventory management.

4.1.1 Scanning the Grocery Tickets

All of the grocery shops give out the receipts upon payment at the cashier. The ticket is a print out of all the items a person bought plus the amount and the total cost. There are a lot of services that can extract out a text from a picture. So, aiming to build an application that can take a picture and translate it into valuable information was the first option to be considered. Therefore, several tickets from different grocery shops in Vaxjo, Sweden were collected and analyzed. At some point, it became apparent that they all come in different varieties. Every grocery shop offers a slightly different ticket with different item acronyms, for instance: *Cola*, *CocaCola*, *C.Cola* etc. Therefore, creating a system that can correctly identify items would be a challenge. Besides, even if hypothetically one could correctly identify the items in the ticket that information has to be linked somehow with other metadata describing each item. For instance, if a person buys a Coca Cola and the app correctly identifies the text, it still is not capable of understanding what Coca Cola is, what nutrition information it has and when is it's the approximate expiration date.

4.1.2 A System That Improves With The Time

Another viable option was to create a system which contains the most bought grocery items such as milk, eggs, bread, butter, etc. Then, when users buy groceries, they open the app and search for the items they bought. In case any of the items do not exist in the system they manually enter it making it instantly available to all the other users of the application. The more people use the system and enter the missing items, the faster the input becomes. For instance: John goes to his local grocery shop and buys bread, milk, eggs, and chocolate. It turns out that the type of chocolate he bought is not present in the app. He takes a minute and inputs it manually. Next time any user of the app buys that same chocolate, they simply search and then select it. Although such a system improves with time, it still requires a lot of manual work. As the literature review suggests, this cannot be a long term solution. Therefore, this option was also ruled out.

4.1.3 Emedded IoT Devices

Farr-Wharton et al. [42] explored the role of mobile applications in reducing domestic food wastage in which the need for some sort of hardware embedded onto the fridge emerged. During the study, many of the participants expressed their problem with having to go back to their mobile phone every time they finish or throw an item from the fridge. The majority of the participants expressed their preference to undertake the majority of interaction with the application through a device embedded within, for example, the refrigerator and use a mobile application for interaction during grocery shopping. One user suggested this might reduce the burden of data removal from the application's inventory because it would allow users to easily see what food is available within the fridge before opening the door.

The cashiers at the grocery stores are capable of processing a big number of payments in a very short time. That is because they have pre-registered all the items they sell and can easily scan them using a barcode scanner. Furthermore, they don't need to add any information manually because each barcode is linked to exactly one product description which contains the necessary information for the final price to be calculated. Having a system that connects directly to the retailer's database similar to *EcoPanel* from Zapico et al. [43] could fully automate the inventory management process.[44]

Any solution that will make a significant contribution to the reduction of food waste in households will inevitably involve hardware. That was the necessary push to look for pre-existing solutions. The obvious choice was smart fridges. But, as previously discussed, a state of the art smart fridge is still not capable of automating the process of inventory management. On top of that, they usually are very expensive and people tend to not change their fridges that often.

Another option is to create an embedded device using a micro-computers such as an *Arduino* [4] or a *Raspberry Pi*[5]. *Arduino* is an open-source hardware and software company, project and user community that designs and manufactures single-board microcontrollers and microcontroller kits for building digital devices and interactive objects that can sense and control both physically and digitally. Its products are licensed under the GNU Lesser General Public License (LGPL) or the GNU General Public License (GPL), permitting the manufacture of Arduino boards and software distribution by anyone. Arduino boards are available commercially in preassembled form or as Do It Yourself (DIY) kits.[45]

The *Raspberry Pi* is a series of small single-board computers developed in the United Kingdom by the *Raspberry Pi* Foundation to promote the teaching of basic computer science in schools and developing countries. The original model became far more popular than anticipated, selling outside its target market for uses such as robotics. It does not

[4] https://en.wikipedia.org/wiki/Arduino
[5] https://en.wikipedia.org/wiki/Raspberry_Pi

include peripherals (such as keyboards and mice) and cases. However, some accessories have been included in several official and unofficial bundles.[?]

Put it simply the *Arduino* and *Raspberry Pi* are easily extended boards that can connect to different sensors. Working with them is not that complicated even for a software engineer. So, having a barcode scanner module and a touchscreen that connect to a micro-computer seemed like the best bet. But, for such a system to work, it should come with pre-existing data so that the user won't have to manually enter them. Currently, in Sweden, most of the grocery chains such as *ICA Max*, *Willys*, and *Coop* have their products publicly available online. A software application could potentially read that data from their respective web pages and store it in the database. It should all be done in a manner that does not overwhelm or disturb the normal functioning of those web pages.

4.2 User Scenarios

Several user scenarios were created to better understand the functional requirements of such a system. Since the study aims to reduce the household food waste, the scenarios are designed around a family that is a potential user of the proposed application.

4.2.1 Coordinated Shopping List

A basic function that the prototype should offer is the ability for a family to coordinate their shopping list. That implies, all family members should have live access at any point to the family shopping list and should be able to add and remove items from and to it. For instance, John and Maria both have a busy and stressful life juggling family and work. They don't get to spend much time together, and when they do they don't discuss matters such as the groceries they need to buy. John wakes up in the morning and prepares himself breakfast. He realizes that the milk has run out. John clicks on the touch screen mounted on the fridge and searches for the brand of the milk his family uses. Having added it to the shopping list, he leaves for work. His wife Maria wakes up a bit later and prepares breakfast for the kids. Dropping her kids off to school she realized she promised them she would cook pizza on the weekend. Having no time herself to stop by the grocery shop she opens the mobile app and adds the ingredients they need into the shopping list.

After a long day at work, John knows that he should probably head to the local market and buy all the groceries needed. He stops by the grocery shop and opens the app where he sees the ingredients that Maria has added. When he checks the items off, the touch screen in the fridge lights up and shows that the items were purchased. At the same time, Maria gets notified about this activity on her phone.

4.2.2 Managing Inventory

John heads back home. He has a bag full of groceries he just bought. The fridge is aware of this and waits for John to confirm that the items checked in have been placed in the fridge. He can either confirm the list or scan the items one by one, as the cashier would do in the grocery store and puts the items in the fridge.

4.2.3 Nudging the Family Into Taking Action

More than a week has passed by since the last time John and Maria went to the grocery store. However, the system detects that the eggs and the cheese are still not finished since they are not marked as such. The system is aware that eggs and cheese last approximately a week in the fridge. An indicator turns on so that John and Maria are gently reminded they need to take some action every time they pass by their fridge. John and Maria also get notified about the situation on their phones. John decides that the next morning he will have cheese and eggs for breakfast.

4.2.4 Mark Items as Finished or Wasted

]

John is planning to cook the chicken for dinner. He takes it out of the fridge and using the touchscreen marks it as finished. Unfortunately, the system has been warning the family for a few days that the butter is about to expire. Having no choice but to throw it he marks it as wasted. The system adds it to the items that went to waste. John and Maria can see the items they have thrown and their approximate cost. When the system is mature enough, it will be able to suggest them to buy a smaller butter package. That way, they would be able to reduce the chance of wasting butter and in return decrease the possibility of food waste while saving money.

4.3 Functional Requirements

A list of functional requirements can be derived from the user scenarios presented above. The requirements can be divided into two parts. The hardware/device and software requirements.

4.3.1 Hardware Requirements

- **HRQ1** - *The device should have a barcode scanner so that the users can identify items and take appropriate actions such as add grocery to the inventory, remove, read more ec.* (addressing scenarios 4.2.2 and 4.2.4)
- **HRQ2** - *The device should have a touch screen so that the user can see the inventory and interact with it.* (addressing scenarios 4.2.2, 4.2.3 and 4.2.4)

- **HRQ3** - *The device should be mounted onto the fridge so that it will look as if it is part of the fridge* (addressing scenario 4.2.3)
- **HRQ4** - *The device should "nudge" the users whenever some food is about to expire or any other action is required* (addressing scenario 4.2.3)

4.3.2 Software Requirements

- **SRQ1** - *The application should allow the users to have coordinated shopping list.* (addressing scenario 4.2.1)
- **SRQ2** - *The application should allow users to add items to shopping list.*(addressing scenarios 4.2.1 and 4.2.2)
- **SRQ3** - *The application should allow the users to remove items from shopping list* (addressing scenario 4.2.4)
- **SRQ4** - *The application should allow users to check an item from shopping list and move it into inventory* (addressing scenario 4.2.2)
- **SRQ5** - *The application should add an item to inventory*(addressing scenario 4.2.2)
- **SRQ6** - *The application should allow users to view item details* (addressing scenario 4.2.1)
- **SRQ7** - *The application should notify users when an item is about to expire*(addressing scenario 4.2.3)
- **SRQ8** - *The application should show users recipes*(addressing scenario 4.2.3)

5 Implementation of the Prototype

This chapter discusses the technical implementation of the prototype. It consists of two sub-chapters namely the hardware implementation and the software implementation. The hardware sub-chapter talks about the implementation details of the touchscreen device that is mounted on the fridge, while the software sub-section discusses the implementation details of the backend, that is, the mobile app and the web application that also runs in the hardware device.

5.1 Hardware Implementation

The *Concept and Interaction Design* chapter established that hardware is a necessary component of this solution. The functional requirements state that the hardware device should allow the users to interact using touch gestures the same way they would interact with a tablet/iPad or mobile phone, and scan the items effortlessly to add them to their inventory or to see the details of that particular item such as expiration date, description, price, etc.

5.1.1 Choosing the Correct Board

From this specification, several hardware components were identified. First of all, a microcontroller/mini-computer that will host the touch screen and the barcode scanner should be chosen. The two obvious choices were Arduinos and Raspberry Pi. Two similar-looking devices but with different capabilities. A simple search on the web shows that there is a general rule of thumb when choosing between Arduino and Raspberry Pi. Arduino is good at controlling small devices such as sensors, motors and lights and is much simpler to use than a Raspberry Pi. There are a number of different Arduino boards all with slightly different capabilities as can be seen in the table 3.

Arduino boards would fit perfectly if the prototype did not require a touchscreen. They can power a small LCD screen but, in this case, Raspberry Pi was a better choice, albeit not a perfect one for reasons described in the Conclusion section. Table 4 shows the Raspberry Pi specs.

5.1.2 The Barcode Scanner Module

The barcode scanner module is another crucial component of this prototype. Finding such a component was easy however, it arrived with no instructions, or any online resource explaining how to integrate it with a Raspberry Pi. After a period of trial and research, a new barcode scanner module was ordered. This time, it was made sure that the company selling the barcode scanner had online instructions on how to integrate it with other devices.

As it can be seen in the figure 14 the module is very small with 53.3mm x 21.4 mm dimensions. It is capable of reading 1D and 2D codes, by using the intelligent image recognition algorithm in a fast and accurate way both on paper or screen. Through

Name	*Processor*	*Voltage*	*CPU Speed*	*Analog In-/Out*	*Digital In-/Out*	*Flash[kB]*
101	Intel® Curie	3.3V/7-12V	32MHz	6/0	14/4	196
Uno	ATmega328P	5V/7-12V	16 MHz	6/0	14/6	32
Mega 2560	ATmega2560	5V/7-12V	16 MHz	16/0	54/15	256
Ethernet	ATmega328P	5 V/ 7-12V	16 MHz	6/0	14/4	32
Due	ATSAM3X8E	3.3V/7-12V	84 MHz	12/2	54/12	512
Mega ADK	ATmega2560	5V/7-12V	16 MHz	16/0	54/15	256
MKR1000	SAMD21 Cortex-M0+	3.3V/5V	48MHz	7/1	8/4	256

Table 3: Different Arduino Boards

SoC:	Broadcom BCM2837
CPU:	4 X ARM Cortex-A53, 1.2GHz
CPU:	4 X ARM Cortex-A53, 1.2GHz
GPU:	Broadcom VideoCore IV
RAM:	1GB LPDDR2 (900 MHz)
Networking:	10/100 Ethernet, 2.4GHz 802.11n wireless
Bluetooth:	Bluetooth 4.1 Classic, Bluetooth Low Energy
Storage:	microSD
GPIO:	40-pin header, populated
Ports:	HDMI, 3.5mm analogue audio-video jack, 4X USB 2.0, Ethernet, Camera Serial Interface (CSI), Display Serial Interface (DSI)

Table 4: Rasbperry Pi Model 3B+ Specs

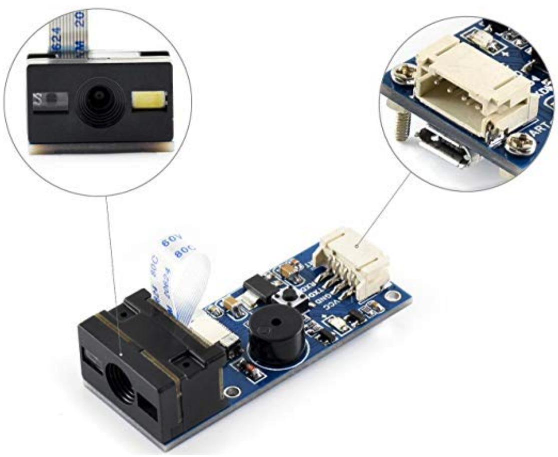

Figure 14: Barcode Scanner Module

the onboard USB and UART interface, it can plugin directly into a computer, or easily integrate with devices such as Raspberry Pi due to its small form factor. Table 5 shows the specs of the module.

Interfaces:	USB and UART
Operating Voltage:	5V
Operating Current:	135mA(scanning), 58mA (Standby), 2mA((Sleep)
Operating Temperature:	0 Celcius - 60 Celcius
Operating Humidity:	5% - 95% (Non Condensing)
Decodes 1D code:	Code bar, Code 11, Code 39, Code 93, UPC/EAN, Code 128/EAN128, Interleaved 2 of 5, Matrix 2 of 5, MSI Code, Industrial 2 of 5, GS1 DataBar (RSS)
Decodes 2D code:	qr code, data matrix, PDF417
Ports:	HDMI, 3.5mm analogue audio-video jack, 4X USB 2.0, Ethernet, Camera Serial Interface (CSI), Display Serial Interface (DSI)
Scanning Angels:	Roll 360 degree, skew +/- 65 degree, pitch +/- 60 degree
Dimensions:	53.3 mm x 21.4 mm
Field of View:	28 degree (horizontal), 21.5 degree (vertical)

Table 5: Barcode Scanner Module Specs

5.1.3 Choosing the Right Touchscreen and Switching To Tablets

The touchscreen is the most prominent part of this IoT solution. It is the interaction point between the users and their fridge. Therefore using a responsive and fast touchscreen is a must. There are a wide variety of touchscreens available that can be integrated with the Raspberry Pi and their prices vary depending on the quality and the size of the screen. In this particular case, a larger screen estate would be a better choice. However, since this is only a prototype, a 7" touchscreen would be just fine. Figure 15 shows the most widely used Raspberry Pi touchscreen. It is a perfect solution for creating portable and embedded projects where keyboard and mouse would be in the way. The full-color display outputs up to 800 X 480 and features a capacitive touch sensing capable of detecting 10 fingers. Furthermore, only two connections from the Pi to the display are necessary; namely the power from GPI0 (or USB) connection to the DSI port. The adapter board handles power, signal, conversion, and touch input conversion.

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Figure 15: Barcode Scanner Module

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Finally, the IoT device, in this case, the tablet with the barcode should be able to be mounted in the fridge. One of the ways to do so is by using a magnetic case enabling the tablet to stick into the fridge.

5.2 Software Implementation

The second sub-chapter discusses the software implementation of the prototype. The software is what gives life to the device and enables it to fulfill all the functionalities that it promises. The software implementation is further divided into three parts. The backend, mobile application, and the frontend/fridge application.

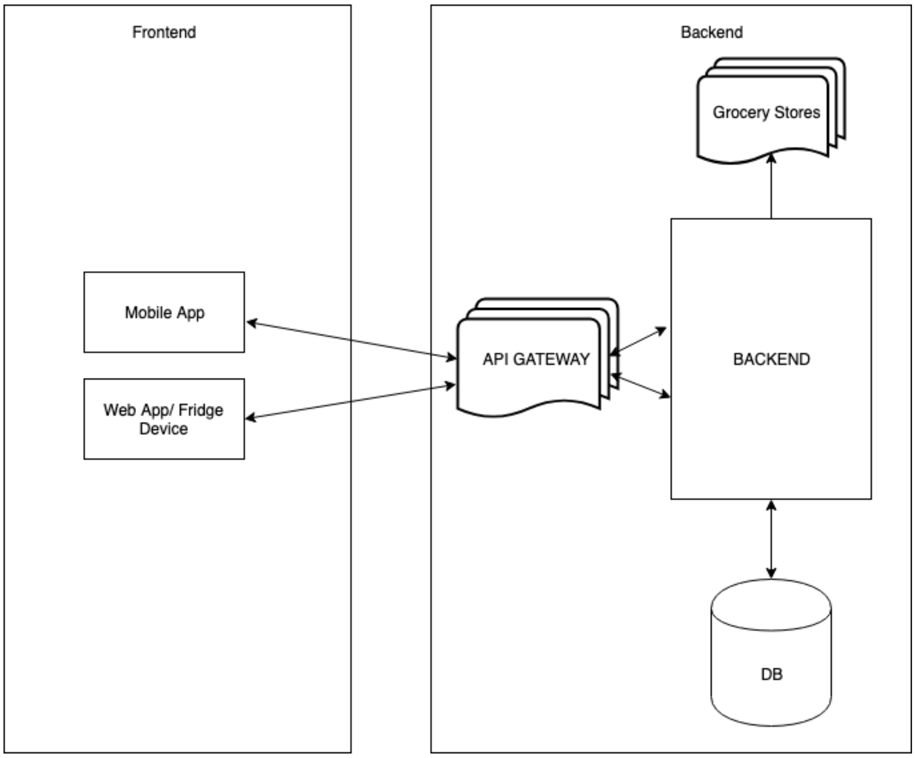


Figure 16: Architecture Overview of the System

5.2.1 The Backend

The backend is written in *Nodejs* using the *Express Framework*. One benefit of *NodeJS* is that it enables developers to use *Javascript* for both the frontend and the backend. Furthermore, *NodejJS* has an event-driven architecture capable of asynchronous I/O operations. It is built on top of Google's V8 Javascript engine and it is supported by a wide and active community. *Express* is a minimal and flexible *Node.js* web application framework that provides a robust set of features for web and mobile applications. *Express* provides a thin layer of fundamental web application features, without obscuring the *Node.js* features. With a myriad of HTTP utility methods and middleware at the disposal, creating a robust API is quick and easy.

5.2.2 The Data Layer

MongoDB was used as the database of the system. MongoDB is a document based non-relational database which stores the data in flexible JSON like documents where fields can vary from document to document and the data structure can change over time. Currently, there are 6 tables in the database namely, *accounts*, *fridges*, *inventory*, *items*, *recipes* and *shoppinglist*. Figure 17 shows the structure and the contents of each of those tables.

This prototype uses a non-relational database, therefore the tables are not linked between themselves. The *fridge* table is the table that holds the information on the main account. Fridge in this context is the IoT device that is attached to the fridge. Currently, it consists of *name*, *username*, and *password* fields. A *fridge* can have multiple *accounts*.

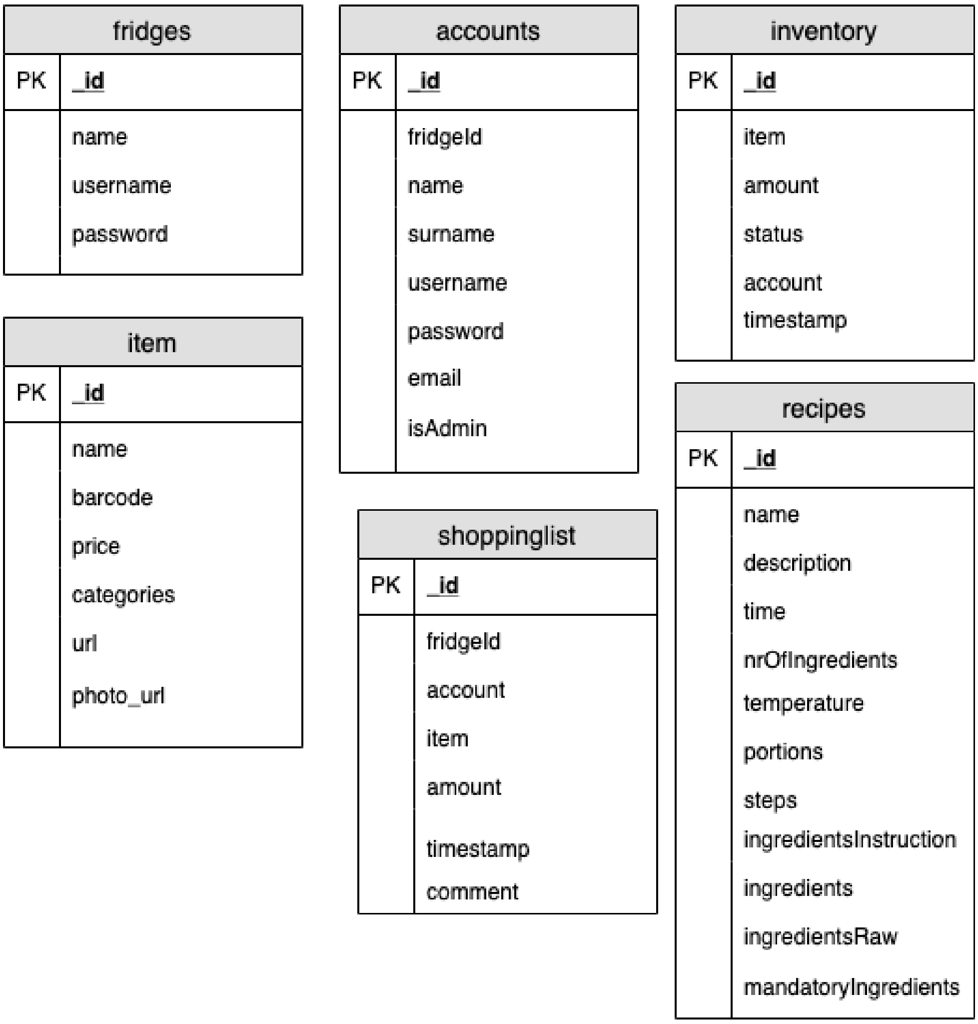


Figure 17: Database Tables

accounts hold the user's accounts information. For instance: a family of 4 can have 4 accounts i.e. each member one account. They all belong to the same fridge. Ideally, one of the members is the admin of the *fridge* account. That would give him/her more user privileges in the system.

The data scraped from the grocery stores is stored in the *item* table. Currently, only a small set of items is scraped from the *Coop's* website so that it can serve as a proof of concept. Each item in the table has a *barcode* field. Barcode is what is used by the IoT device when scanning an item. Each item belongs to a couple of categories. The *photo_url* as the name suggests holds the URL where the photo of that item is found. The *url*, on the other hand, is the URL from where the data was scraped. The *price* field holds the approximate price of that item. That is the price at the point when the item was scraped. Price is something that varies at different times and in different grocery stores, therefore, it is considered and presented as approximate. Nonetheless, it is an important piece of information that ranked high as a feature request by users that participated in the prototype test. Hopefully, using the price as information will give more realistic information and awareness to the families on the food they waste and drives them to take more action.

The *recipes* table as the name suggests holds recipes that can be browsed by the users. Each recipe has its *name*, *description*, *time* (the time it takes for the recipe to be cooked), *temperature*, the *nrOfIngredients* it requires, the *mandatoryIngredients* (ingredients that must be present for that recipe), the *steps* which basically are the instruction steps that one needs to take in order to cook that particular recipe and the *ingredientsRaw*. The difference between *ingredients* and *ingredientsRaw* is that the later one has stripped out the other details of the ingredients from the recipe and it contains only the ingredient. For instance, the *ingredients* field would hold the information 1 tablespoon of sugar while the *ingredientsRaw* would have it as sugar.

The table *inventory* basically holds the items that the users have bought. An *inventory* row contains and *item*, an *account* which basically is the account who checked it in in the system, the *amount* of such item e.g. 3 milks, *timestamp* being the time of check-in and finally the *status*. The *status* field can have three values *IN_STOCK*, *FINISHED* and *WASTED*.

The final table *shoppinglist* contains the family shopping list information. A *shoppinglist* item belongs to a *fridge* and to an *account* i.e. the person who added the item into the shopping list. It also contains the *item* and the amount of that item. Finally, users can add a comment to the shopping list item stored in the *comment* field.

5.2.3 The API Gateway

The API Gateway is the layer that manages the requests from the clients. It reads the requests with its request parameters then calls the appropriate business logic to get the required data. When the data is ready it packages and sends it back to the user who requested it. There are a few request methods that the API Gateway can handle such as *GET*, *POST*, *PUT*, *DELETE*, *HEAD*, *CONNECT*, *OPTIONS*, *TRACE*, and *PATCH*.

```
 router.get('/accounts', (req, res) => {
   if (req.session.fridge) {
     const fridgeId = req.session.fridge._id;
      account.getAccounts(fridgeId, (response) => {
         res.json(response);
      });
   } else {
     res.json({status: 'no_session'});
   }
});
```

Listing 1: Retrieving all the accounts of the fridge

The above snippet is an example part of the backend API gateway. It accepts a GET request, checks if there is a session. If yes, it gets all the accounts that belong to the fridge and returns them to the user. If the session doesn't exist, it returns an object with the status *no_session*.

Endpoint	Method	Request Params	Response
/login	POST	username, password	Fridge Object
/logout	GET	-	Status Object
/accounts	GET	-	Accounts Array
/accounts	PUT	New Account Values	Updated Account
/accounts	POST	New Account Values	Accounts Array
/accounts	DELETE	Account ID	Accounts Array
/items	GET	-	Items Array
/items/:id	GET	Item ID	Item Object
/items/filter	GET	Filter String	Array of Items Matching Filter
/inventory	GET	-	Inventory Array
/inventory	POST	Inventory Values	Inventory Array
/inventory/:status	PUT	Wasted / Finished	Inventory Array
/inventory/:barcode	GET	Item Barcode	Inventory Object
/shopping-list	GET	-	Shopping List Items Array
/shopping-list	POST	Shopping Item	Shopping List Items Array
/recipe	GET	-	Recipes Array
/insights	GET	-	Statistics Object

Table 6: API Endpoints

Table 6 shows the main API Gateway endpoints. Besides the HTTP requests, the system also utilizes *WebSockets*. *WebSockets* enable two-way communication. You can send messages to a server, and receive event-driven responses without having to poll the server for a reply. This comes quite handy when the system needs to show live updates as one person of the family is interacting with the application. For instance, when John adds an item to the shopping list, the IoT device updates instantaneously and Maria gets notified. Similarly, when he checks-in an item Maria's phone gets the update because both of their accounts listen to the same socket channel. WebSockets are designed for messaging applications and NodeJS takes full advantage of them.

5.2.4 Extracting Data From Grocery Stores

The main goal of this thesis is to automate the process of inventory management, and that cannot be achieved by asking the users to manually enter all the information of the items they buy. There are some web applications and public APIs that offer a wide range of grocery items that can be filtered and searched by name or by barcodes however there is no database that is specified for the products sold in Sweden. Luckily, the grocery chain stores such as *Coop*, *ICA Max*, *Willys*, and *Citygross* list their products online, in their respective web sites. For this thesis, a set of data from the Coop's website was scraped using the *cheerio.io* scraping library. This set should be big enough since it contains the most used daily products therefore, enabling us to comfortably test the system and serve as a proof of concept. The entire extraction process was conducted safely and in a way that it won't disturb in any way or form the normal functioning of the Coop website. The data was extracted periodically, in a couple of days and currently, there are over 6 000 items in the database. Snipped 2 shows a code snipped that is responsible for fetching the categories found in the official Coop website.

```
const url = 'https://www.coop.se/handla-online/';
pageLoad.fetch(url).then(function (data) {
   var $ = cheerio.load(data)
   $('.js-sidebarNavList .SidebarNav-headingLink ').each(function(i,link){
      categories_links.push($(link).attr("href"));
   });

   return categories_links;
});
```

Listing 2: Fetching all COOP categories

Snipped 3 shows a part of the code that is responsible for reading the article URLs.

```
categories.forEach(function(i){
    pageLoad.fetch('https://www.coop.se/'+i).then(function(data){
        var $ = cheerio.load(data);
        $('.Grid-cell .ItemTeaser-content .ItemTeaser-link ').each(function(
    i,link){
            articles_urls.push($(link).attr('href'));
     mn++;
});
```

Listing 3: Extracting Article URLs

Finally, going through all the article URLs gathered in snipped number 4 the article data is extracted and stored in the database.

```
let ArticlesData = new Articles({
  url:'https://www.coop.se'+i,
  name : $('.ItemInfo-heading').text(),
  price : $('.ItemInfo-price > span').attr('content'),
  photo_url : $('.ItemInfo-image img').attr('src'),
  barcode : barcode,
  categories:categories
});

Articles.create(ArticlesData, function (error, user) {
  if (error) {
    let string = error.message;
    console.log(string)
  } else {
    console.log("Article saved successfully")
  }
});
```

Listing 4: Extracting Article Info and Storing them in DB

5.2.5 The Frontend

Finally, after having completed the backend and inserted a considerable amount of data into the database the frontend clients were ready to be built. From the software functional requirements, it was apparent that there will be a need for a mobile app and for a web app which will also serve as the app in the IoT device. The obvious language choice for web apps is Javascript. However, to build any serious application a *Javascript* framework must be chosen. There are a couple of popular frameworks out there such as *React*, *Angular* and *Vue*. All serving the same purpose. A longer experience using *Angular* was one of the main reasons why *Angular* was chosen over *React*. In addition to that, using the *Ionic Framework*, the same *Angular* code could be used to build mobile apps. Although there are some drawbacks to hybrid mobile applications for this particular use-case Ionic was the better choice.

This subchapter presents and explains the application flow through screenshots. Figure number 18 shows the account view of the web application. A fridge/family account can have many user accounts. Preferably one for each family member.

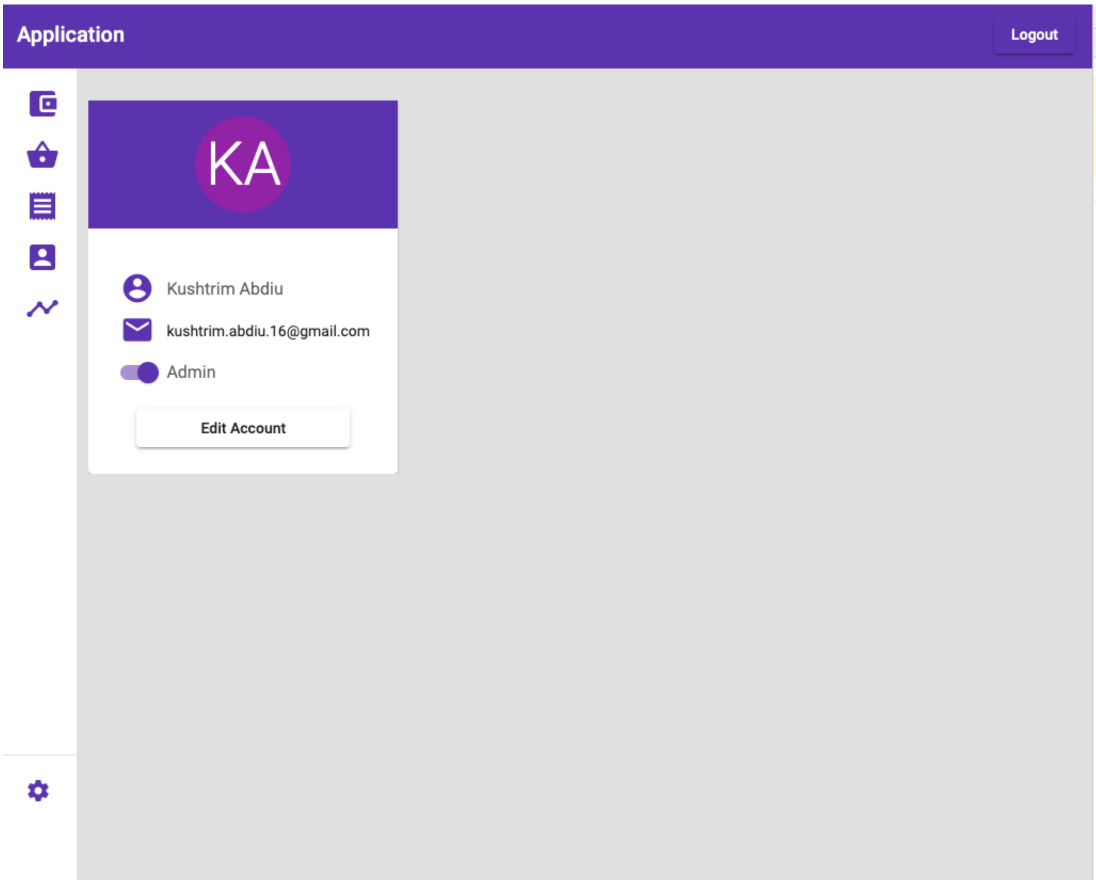


Figure 18: Web App - Account View

Once the user has an account and is logged in, he/she sees the food inventory page. All of the products in the inventory seen in the figure number 19, have been scanned or moved from the shopping list into the inventory view and none of the data was entered by the users manually.

A similar view can also be seen in the mobile app. Due to the screen size items are displayed in a list. In the mobile app, users have to swipe from right to left for the action

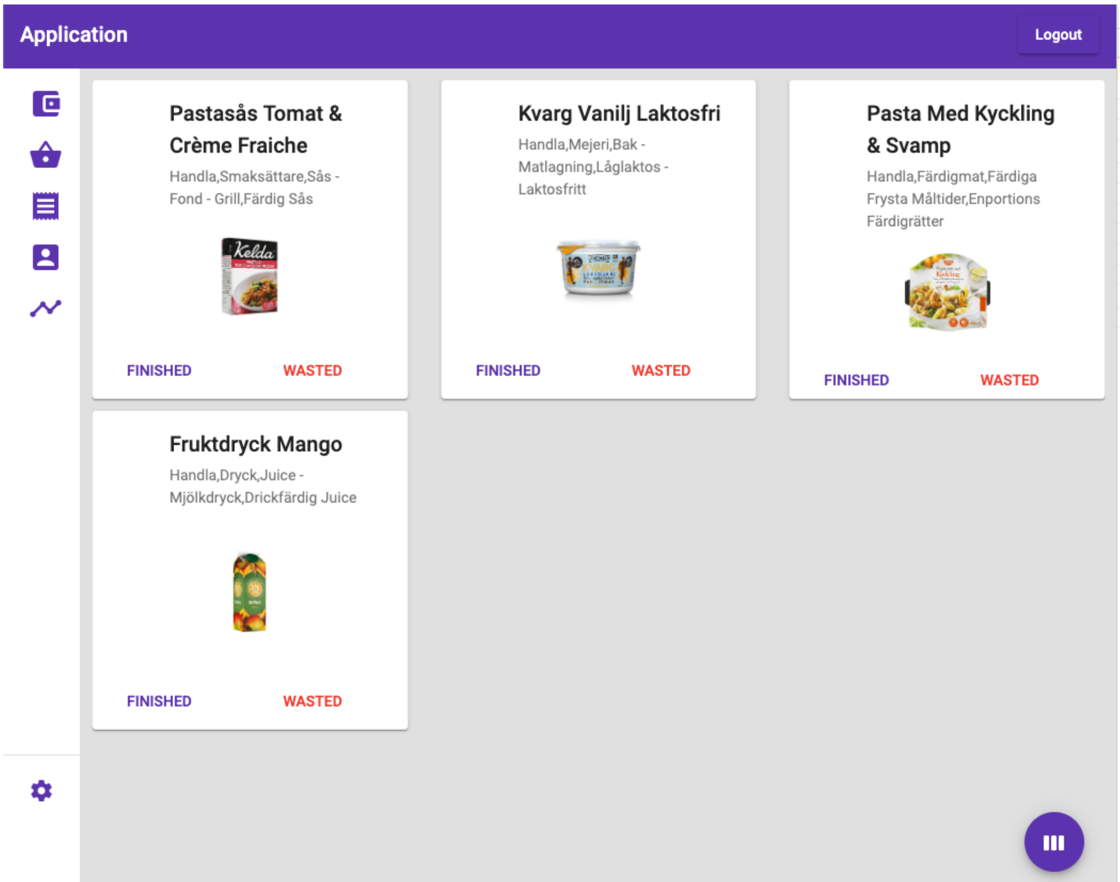


Figure 19: Web App - Fridge Inventory View

buttons to show up so that they can mark an item as *Wasted* or *Finished*. When a user wants to add an item to the inventory using the web or fridge app (figure 19), he/she clicks on the floating barcode button on the lower right corner. The application enters the scanning mode, and a scanning indicator is displayed at the top. The barcode module turns on ready to scan. In the mobile version of the app (see figure 20), the user has to click the + button located on the top right corner and search by title or scan the barcode using their mobile phone.

To see more item details (see figure 21) the user clicks anywhere on the item card and is presented with a popup that displays the item image, the approximate price, or, more correctly the price of the item at a particular time when it was scrapped in a particular grocery shop (in this case Coop). Despite being an approximate price albeit a very close one, it is a very important piece of information. If a family wastes a particular item, they can have a quantifiable indicator that affects their economy in hopes that it will make them more aware of the issue and incline them to take real actions.

To add an item to the shopping list, the user should click on the shopping list tab while on the mobile app and in the shopping list navigation element on the left side of the screen when using the web version. In the web app (see figure 22, the user can see the approximate current price of all the items in the shopping list as well as the approximate

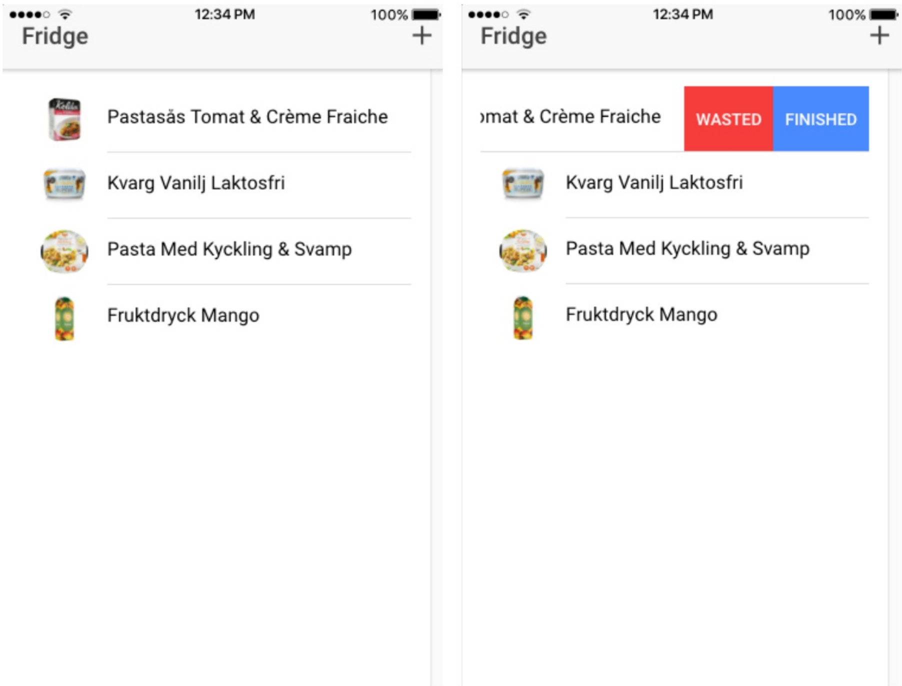


Figure 20: Web App - Mobile Inventory View

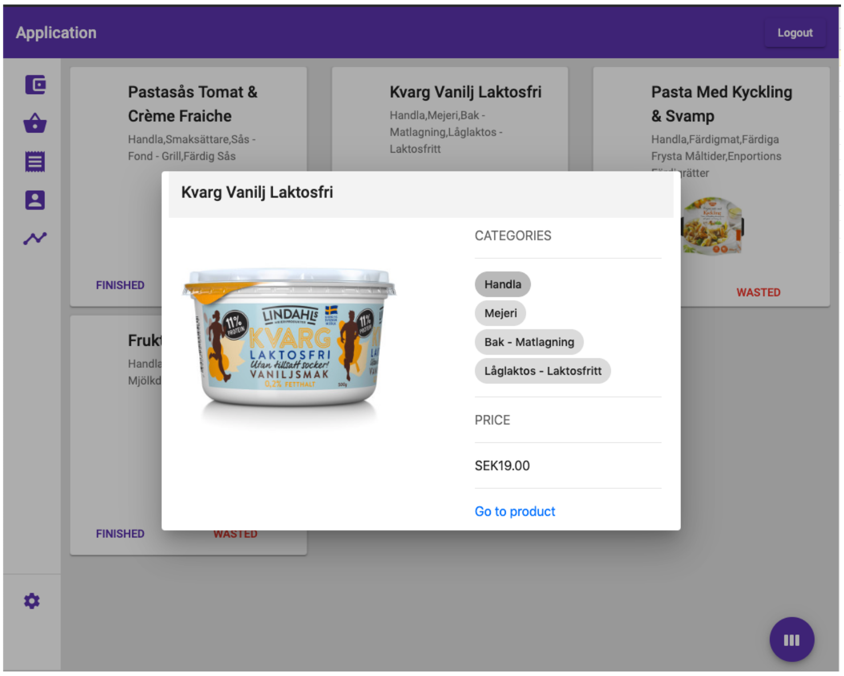


Figure 21: Web App - Item Details View

price of each item they plan to purchase. When using the mobile app, to take action upon any of the items, the user should swipe from right to left and the two action buttons show up namely, mark item as bought i.e. move it into the inventory tab or delete it from the shopping list.

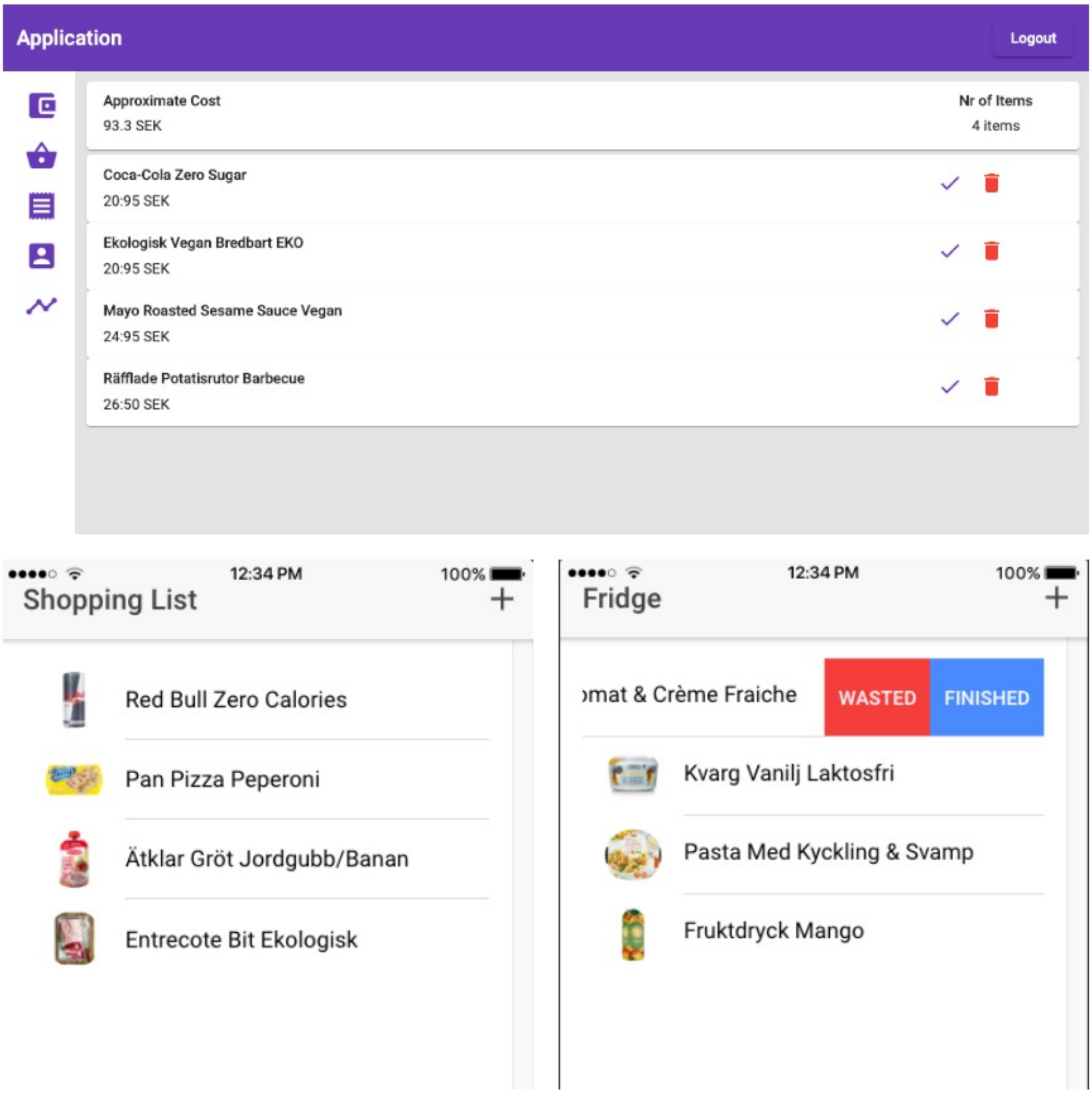


Figure 22: Web and Mobile App - Shopping List View

To add an item to the shopping list, the user should click the plus sign on the mobile app and the bottom right shopping basket floating button. A search popup will show up (see figure 23). Next typing the name of the item and selecting the appropriate article will add it into the current shopping list.

Another useful feature that this application offers is the recipe recommendations. Many additional features could have been built leveraging recipes, like for instance, showing different recipes depending on the currently available items of the fridge. However, due to time constraints, such features weren't completed. If implemented, such a feature would enable the users to get recipe suggestions based on the ingredients they currently

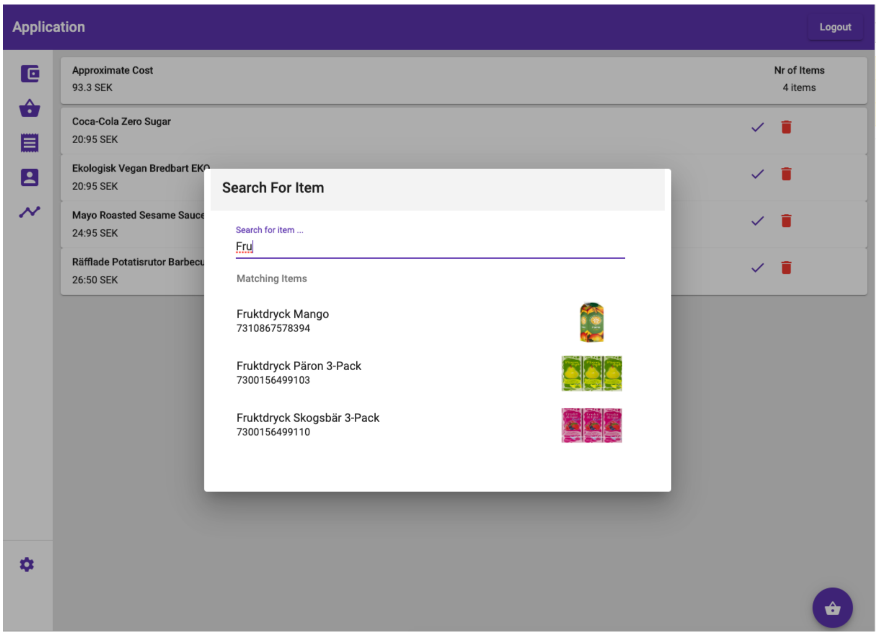


Figure 23: Web App - Add Shopping Item View

have. Though, when building such a feature, one should take into account the amount of each ingredient a recipe needs, and know whether that amount of the item is available to cook this particular recipe. This issue coupled with the time it takes to implement the solution was the reason why this feature was skipped for now. Nevertheless, users can still see a few recipes by navigating to the recipes navigation bar on the left of the web app and the recipes tab on the mobile app. (see figures 24 and 25)

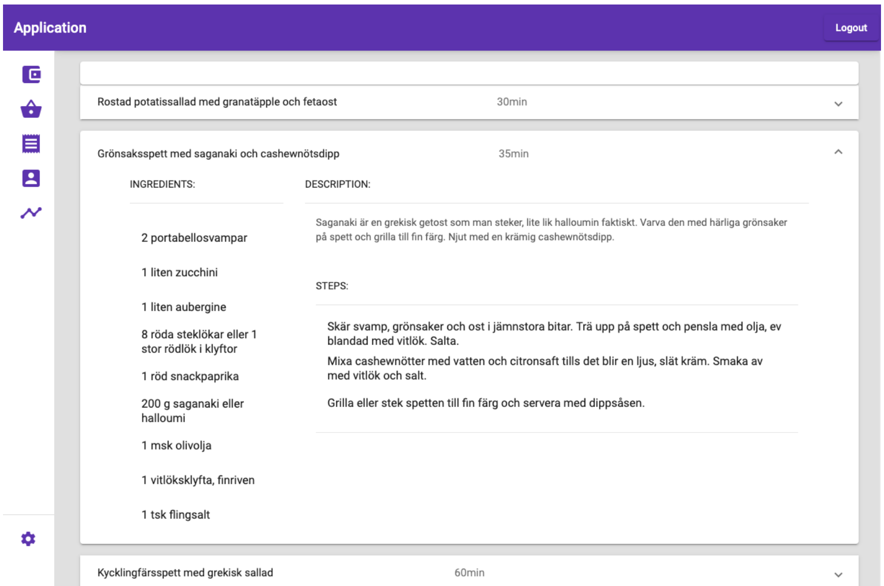


Figure 24: Web App - Recipes View

Lastly, this prototype also offers some basic statistics and insights. A user can see his/her family approximate spendings on food and on the food they have wasted. (see

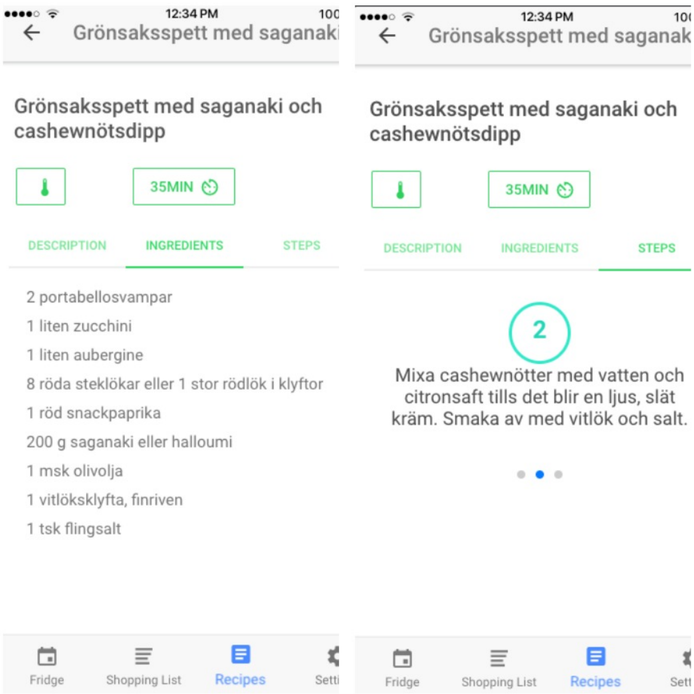


Figure 25: Mobile App - Recipe View

figure 26)

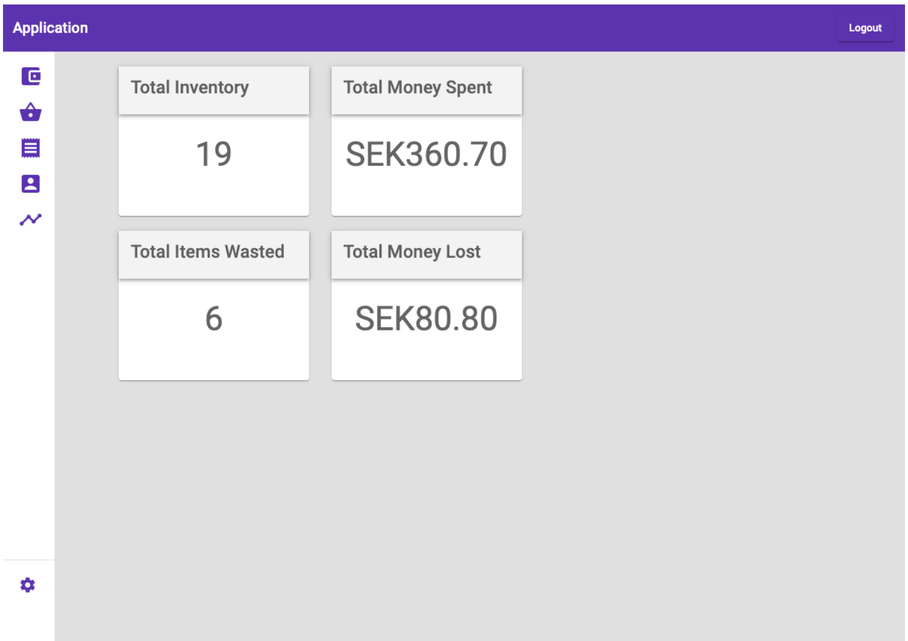


Figure 26: Web App - Insights View

6 Results and Analysis

As laid out in chapter 3, the 7th and final step of the research methodology consists of two parts.

- Analyzing the results of the technical validation - designed to test the usability and capture any eventual bug.
- Analyzing the results of the user interaction study - to help answer the research questions.

The results of these tests are presented in this chapter and show whether the proposed solution is valid and successful.

6.1 Final Prototype Validation

The conceptual validation survey in which we validated our initial proposition was instrumental in narrowing down the focus and the scope of this work. From the results, several features were chosen and moved into the implementation phase. The details of the implemented features can be seen in section 5.

6.1.1 Technical Validation

Three participants tested the prototype. They were asked to firstly try and intuitively use the system, to see if they will be able to figure out how to complete a defined set of actions. See table 7 And then ask questions and give feedback.

Step	*Complete the Following Actions*
1	Login
2	View Fridge
3	Scan Mode On
4	Scan Item
5	View Item Info
6	Mark Item as Finished
7	Mark Item as Wasted
8	View Shopping List
9	Add Shopping List Item
10	Mark Item as Bought
11	Delete Item
12	View Recipes
13	View Statistics

Table 7: Technical Validation - Actions participants had to complete using the device and the mobile app.

The participants were asked to complete the steps described in table 7 in that given order. A couple of bugs were discovered during the validation process. When the users added an item that does not exist in the system, the application would insert an empty row. To solve this issue, we simply put a checker that asks the server whether the item the user is trying to add exists in the system. If the item does not exist, the application displays the message that the item currently does not exist and as such, it cannot be added. In the future, all of the items available in *Coop*, *Willys*, *ICA*, *Hemkop*, etc. will also be present in our system, so the chances of users adding a non-existing item will be minimal. Furthermore, the application will allow the users to manually enter a non-existing item into the system, thus making it available to the other customers.

Some of the item prices fetched from the *Coop* website were noted with a *sek:-* sign e.g. *P24sek:-* and would mess up the statistical calculations. This is because *24sek:-* cannot be converted into a number and arithmetics between numbers and strings cannot be performed. For example: 100 + 20 + 24sek:- will result as undefined instead of 144. To solve this issue, we wrote a script which goes through all the price fields and removes any extra character that the price might contain, making sure that all of them exist in a numeric form.

Besides these bug reports, participants also suggested some few UI changes that can further simplify the application usage. Those details are discussed in the *Discussion* 7 section. The reported bugs were fixed before the user interaction study 6.1.2 took place.

6.1.2 User Interaction Study

Similar to the conceptual validation session 3.2, participants of this study were first introduced to the general problem of food waste and what this work is trying to achieve, then, they were asked to respond to the first survey which consisted of general questions regarding their age, the number of family members in the household, whether they use shopping lists or no, how often do they end up wasting food, why would they want to avoid wasting food, etc.

44.4% (out of 9) of the participants belong to the 35 and up, age group. 33.3% belong to the 25 - 30 age group, 11.1% were aged 30 - 35 and 11.1% in the 18 - 25. 88.9% of the participants were male while 11.1% female. The majority of the participants i.e. 55.6% live with 4 family members or more, 22.2% live with 3 household members, 11.1% live with another person and 11.1% live alone.

When it comes to their shopping behaviors, 66.7% of the people use shopping lists. 44.4% of them goes shopping more than once a week, the same percentage goes shopping only once per week, while only 11.1% goes to shopping once in two weeks. 55.6% of the participants plan their meals ahead of time. 55.6% of people occasionally end up wasting food, 22.2% often waste food and the same percentage of participants sometimes wastes food.

The participants were asked to check all the statements that describe the reasons why they end up wasting food. 7 participants have ended up wasting food due to expiration.

5 people often end up overbuying, 3 people buy things they already had and 2 people sometimes plan to cook something but then end up not doing so. When asked to select all the reasons they don't want to waste food, 7 participants selected *"Economical Reasons"*, 6 *"Environmental Reasons"*, 3 people *"Moral and Cultural Reasons"*, and 1 had *"Other"* reasons also.

In the next phase, they were introduced to the prototype with which they interacted with by completing a set of predefined actions. During this stage, each participant had a lot of questions along with some open discussions. On average, one session lasted about 25 minutes. Then after the interaction session, they were asked to fill out our last survey in which they were required to rate the statements from 1 to 5 regarding the prototype features. In case they forgot or wanted to see that particular feature in action, they could come back to us or watching the recordings of a prototype interaction.

As seen in Appendix D, the majority of the participants were quite satisfied with the UI and gave a lot of constructive feedback during the discussions. Table number 8 below shows the features and their average scores (1 - 5, depending on how much they liked it), rated by 9 of the participants who took the final survey.

Feature	Average Rating (1 - 5)
Add Real Products to Inventory and Shopping List	4.625
Get Notified Before an Item Expires	4.5
See the Approximate Price of Items in Shopping List	3.75
Mark Items as Wasted or Finished	3.87
See How Much Money You Spend	3.66
See How Much Money You Waste	4.3
See Recipes You Can Cook With Available Groceries	4.44

Table 8: Feature Ratings

7 Discussion

This chapter answers the research questions presented in chapter 1.2 by referencing and discussing the works identified in the literature review and the findings of the conceptual validation survey (see chapter 3.3) and the final prototype's technical validation and user interaction study (see chapter 6).

7.1 RQ1: Can an IoT solution considerably simplify the process of food inventory in a household?

Food inventory can be defined as the process of keeping track of the food that is available in the family household. It is usually done before grocery shopping using pen and paper. The same process can be achieved using a mobile app. The advantage of mobile apps is that they offer coordinated shopping lists. That way, all of the family can keep real-time track of the shared shopping list and inventory. Studies show that coordinated shopping lists reduce the amount of food waste.[18, 39]

However, difficulties show up when maintaining that inventory. Despite having coordinated lists, the existing mobile apps and the solutions encountered during the literature review (see chapter 2) still require a lot of manual input from the users. The dynamics of life, give most of the families a little to no time to organize and systematically keep track of what food has been eaten, and what remains buried somewhere hidden in the fridge. [33] The inventory is not updated immediately after an item is finished/wasted. That is because one needs to take out their mobile phone navigate to the app and update the list. Having a device embedded in the fridge is a more natural way of interacting with the inventory.[42]

This thesis proposes an IoT solution that considerably simplifies the process of food inventory in a household by requiring minimal upfront work and offering a better way of interacting with the food. The results of the conceptual validation survey show that 8 out of 9 participants found this solution useful (see chapter 3.3). Both the device and the mobile app are important components of the solution. They let the users add real existing items found in their local grocery stores to their shopping list with a simple search. Then, when an item is marked as bought, it moves it into their inventory. All these actions are received by the IoT device and the rest of the family, removing the risk of somebody else buying the same grocery twice thus addressing the issues outlined by [17, 31]. The device is right there when the user takes an item out of the fridge, enabling him/her to update the inventory in just one simple click. Thus, removing the need for the mobile app and addressing the limitations outlined in [42]. Being reminded (gently nudged) about an item expiring, every time the user passes by the fridge increases the likelihood that he/she will take action more than receiving a mobile notification that can be dismissed and forgotten.

7.1.1 RQ2: What are the potentials and challenges using such IoT solution in everyday life?

Having this system in place to manage the household's food inventory, with little effort makes way for more opportunities and interventions. Nevertheless, there are still ways to further automate the process, for instance, enabling voice services such as *Amazon's Alexa* [6], to enable the users to interact with their fridge by talking. All of the available commands would also be available through speech. Users could ask their fridge for its contents or, order it to add some items to their shopping list or, mark an item as finished. Moreover, the device would fit in nicely with other smart appliances such as a smart bin, similar to Winnow [46] or, the project developed by Altarriba et al. [35] called *"The Grumpy Bin"*. Hypothetically speaking, since the system already stores pictures for every item, the user would not need to manually update the status of the item, once it is thrown in the bin. The bin itself would be able to detect the correct item and mark it as finished or thrown.

[6] alexa.amazon.com

Another potential that this system offers is its screen estate. It can be used to display numerous information regarding the quality of the food a household consumes. In a study conducted by Reitghtberger et al. [22] (see chapter 2.3.2), users were shown a pyramid system and their position in it depending on the food choices they make. The higher the user stood in the pyramid, the better food choices it indicated. The results of the study showed that there was a significant change in people's shopping behavior. This feature can already be implemented in the system since all the items taken from the grocery stores already contain nutrition information. Moreover, similar to *EcoPanel* by Zapico et al. [43], who tried to narrow the gap of how much eco-products people think they consume and how much is that in reality, users could be shown how much of their buying is ecologic. Participants of the initial conceptual design were already interested in such a feature. (see Appendix B)

As established by both the literature review and the two user studies (see appendix B and D), money is an important aspect of food waste. During the conceptual validation survey, 1 person(out of 9) said that being able to see how much money he/she spends on groceries is a must-have feature voting it as a 5 (out of 5), while 4 participants voted it as a 4. However, when asked if they would like to be able to see how much money they lose by wasting food; 5 people gave a maximum score of 5, 3 were almost as certain by rating it as a 4 and the remaining participant rated it as a 3. 44.4% of the participants stated having primarily economical reasons for not wanting to waste food. Identical results were observed during the user interaction study (see chapter 6) where being able to see the amount of money lost on food that is thrown away received an average score of 4.3 out of 5. Furthermore, this observation can be linked to Ganglbauer et al.[19] who argue that one problem with the food waste reduction is that, results of such actions are not easily seen as in the case when losing weight or saving energy. Thus, we can conclude that quantifying the amount of food waste in monetary terms propels people to take concrete actions. This thesis has achieved just that while requiring no extra input from the users. Nevertheless, financial insights currently available in the system can be further expanded in the future to empower families to identify items that are usually thrown away unfinished and suggest them alternative products coming in smaller packages or avoid them altogether to prevent waste before it happens.

Numerous other features can be implemented on top of the existing functionalities. For instance, a list of local food banks can be displayed every time some food is about to expire, similar to *foodsharing.de* by Ganglbauer et al. [41] The system already has a lot of metadata about the items which could be used to build dietary functionalities such as displaying only items that comply with any specified diet or indicate items the user is allergic to.

Alongside the opportunities listed so far, the proposed solution comes with challenges in design, security, and privacy. The list of challenges is expected to raise as the project moves forward.

7 out of 9 participants in the conceptual design study(see chapter 3.3) when asked if they would use this technology in their homes, answered positively. 3 of those 7 people

put a contingency on the solution being nice looking and easy to use. Similarly, during the user interaction study of the final prototype(see chapter 6), a few remarks were made about the UI. Therefore, making the prototype simple and nice-looking is a must. Currently, when a user wants to mark an item as *bought/wasted/finished* through the mobile app, he/she has to swipe left, for the action buttons to show up. That is an unnecessary extra step that can be eliminated. Instead, the action buttons should be made visible from the list view.

The IoT battery life is another design challenge that needs to be figured out in the future. Currently, the device is removed from the fridge and charged. One advantage that smart fridges have in this area is that the displays get the electricity from within the fridge. One way to solve this problem is to have a long charger cable, letting the device charge the whole time. This may not look that nice however if the color of the charger cable is the same as the fridge's color, it should not be so obvious.

Privacy and security is another pressing issue that has to be addressed in the future. Having access to a family's fridge contents is a very big responsibility. A thorough study should be conducted to understand the extent of user data the system can store, and what does that mean for family's privacy when such a system is deployed into their home. Having any vulnerability in the system can expose the user's data to hackers. Hence, security should be a challenge to be taken seriously. Finally, family dynamics in households having smaller children should be further studied and analyzed. It is important to understand how kids interact with the fridge and by that extent with the IoT device.

8 Conclusion

This chapter is divided into four sections. Section one, re-iterates and summarizes all the thesis work, section two discusses the limitations of the presented work, section three outlines the lessons learned during this journey, and the final section discusses the directions that the project could take in the future.

8.1 Summary

Food waste is becoming an increasing threat to the environment and the global economy. A third of the food that is produced never gets eaten. If a portion of the current food wasted were to be avoided, we would have been able to feed the starving people around the world. The resources needed such as water and electricity, to grow and maintain the food that eventually gets thrown away have catastrophic consequences on the environment. The landfills are filled with uneaten food that releases methane gas to the detriment of the ecosystem.

A considerable amount of research has been conducted to first and foremost understand what food waste is and then identify the drivers of food waste, especially in households. Many other entities besides researchers such as governments and independent organizations have expressed their concerns and readiness to tackle this issue. Plans and strategies are formed such as the initiative by the Swedish government to become the leading country in food waste reduction by 2030. Such steps, however, are not enough to tackle this growing issue. There is a need for innovators and creators of all walks of life to come up with strategies and new solutions to first and foremost educate the people and make them aware of the consequences of the food waste and then offer solutions that can be adopted and implemented.

Although food waste happens from field to fork, this thesis focuses on the leading area that produces the most waste, the households. The main food waste drivers in the households are overbuying, lack of knowledge of food already available at home, uncoordinated shopping habits, etc. To contribute towards the reduction of food waste, a research methodology was defined to serve as a roadmap and a reference point for this work. A literature review was conducted to give us a clearer picture of the extent of the problem and what has been done so far to address it. During the literature review, many identified solutions were analyzed and categorized to further understand their shortcomings and to identify potential intervention opportunities.

Researchers are aware of the food waste drivers and have proposed creative solutions to address them. However, the identified solutions do not become part of the family's life and eating habits. That is mostly because such solutions heavily rely on the user's input. The challenges they come with outweigh the benefits they have to offer. Another challenge with existing systems is maintaining an up to date inventory. However, people, don't grab their phones and update their list every time they take an item out from the fridge. There is a need for an embeddable device which enables more natural interaction with the food. Smart fridges are a good candidate for filling this need however, they still are far from being useful when it comes to helping a family manage their food inventory and helping them make better food choices. They are hampered with a lot of issues because currently despite having impressive hardware they do not understand the items that come in and out of them, therefore, needing to be manually updated.

This thesis focuses on the above-mentioned limitations and proposes an embeddable device that can be attached to the fridge using a magnet case and act as the "brain" of the fridge. Furthermore, thanks to the grocery markets in Sweden such as *ICA, Coop, Willys*, etc. the proposed solution can analyze their websites and recognize all the products that the users can buy. It can display the prices of the items so that the users can have an exact idea of how much money they spend on groceries and what's the value of the food they waste. To speed up the process of inventory "check-in", the device has a barcode scanner module that allows for quick identification of the products the same way grocery store cashiers do. The device accompanied by a mobile application that can be used during grocery shopping or when away from the fridge to add/remove items in the shopping list or inventory list, coordinate shopping list with the rest of the family members, view recipes and insights, etc.

The results and analysis of both the prototype validation and user interaction studies show that the proposed solution improves the food inventory process and answers the two research questions. Furthermore, it has the potential to help families reduce food waste in their households. Nevertheless, further studies are needed to verify such claims.

8.2 Limitations

The biggest limitation during this journey was the lack of hardware knowledge and proper estimation of the time it takes to find the right hardware components and make the pieces work together. Another equally important limitation is the lack of longer user testing. That was largely due to the costs of making such a device. In an ideal situation, a bigger number of participants should have a copy of the device installed into their households for a longer period of time, to properly assess its validity. For this time being, the thesis relies mostly on the literature review, the user interaction studies and the open discussions all of which are available in this thesis.

8.3 Lessons Learned

There are a couple of lessons learned during this interesting and challenging journey we feel are worth sharing. First of all, time management and proper time estimations are very important things to be considered. Having no prior hardware experience caused us to spend too much time trying to make the hardware components work together. The barcode scanner had to be shipped from China and that took almost a month. We now believe that there are other ways to demonstrate such a concept without having a perfect prototype in place. Another lesson we learned the hard way was that some of the features we spent time developing, turned out to be not so relevant to the research questions we were trying to answer. While it is good to ship useful features it is best if things are kept simple and only what is crucial to the research question is build.

8.4 Future Work

Based on the responses we got from the participants and all those who got to hear about this research, the future looks promising and exciting. In the next steps, a stable IoT device will be built and deployed in a few households. Then, the participants will be asked to use the system for a defined amount of time so that we can learn from their interactions and further refine and improve the service. Having real users using this system on a daily bases will help us collect data regarding their behaviors and potentially enable us to give them suggestions such as *Are you sure you want to buy this item? There is an 80% chance you will end up wasting this product. Maybe buy a smaller package.* Or show them the quality of the food they buy. Let them analyze their expenses and optimize their shopping behaviors. We strongly believe that once the system is optimized and the work required to use it is significantly lowered we will be able to reduce more than half of the food waste generated in households.

References

[1] Ulf Sonesson Jenny Gustavsson, Christel Cederberg. Global food losses and food waste. 2011.

[2] Veranika Lim, Fulya Yalvac, Mathias Funk, Jun Hu, and Matthias Rauterberg. Can we reduce waste and waist together through EUPHORIA? *2014 IEEE International Conference on Pervasive Computing and Communication Workshops (PERCOM WORKSHOPS)*, pages 382–387, mar 2014.

[3] Sebastian Prost, Clara Crivellaro, Andy Haddon, and Rob Comber. Food Democracy in the Making. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18*, pages 1–14, 2018.

[4] Jean C. Buzby, Hodan Farah-Wells, and Jeffrey Hyman. The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States. *Ssrn*, (February), 2014.

[5] Food and Agriculture Organization of United Nations. Food waste harms climate, water, land and biodiversity – new fao report, 2013.

[6] Åsa Stenmarck, Carl Jensen, Tom Quested, Graham Moates, Michael Bukst, Balázs Cseh, Selina Juul, Andrew Parry, Alessandro Politano, Barbara Redlingshofer, Silvia Scherhaufer, Kirsi Silvennoinen, Han Soethoudt, Christine Zübert, and Karin Östergren. *FUSIONS - Estimates of European food waste levels*, volume 150. European Union, Stockholm, 2016.

[7] EIT Food EU. How will the eu halve its food waste?, 2019.

[8] Food Tank. How will the eu halve its food waste?, 2018.

[9] Livsmedelsverket. More to do more - Action plan for food loss and food waste reduction by 2030. (August), 2018.

[10] Yiran Zhao, Shen Li, Shuochao Yao, Shaohan Hu, Huajie Shao, and Tarek F Abdelzaher. VibeBin: A Vibration-Based Waste Bin Level Detection System. *PACM Interact. Mob. Wearable Ubiquitous Technol. Article*, 1(22), 2017.

[11] LG Technologies. Latest lg smart fridge.

[12] Samsung Technologies. Samsung family hub.

[13] Keiichi Yasumoto Masashi Fujiwara, Kauzi Moriya, Wataru Sasaki, Manato Fujimoto, Yutaka Arakawa. A Smart Fridge for Efficient Foodstuff Management with Weight Sensor and Voice Interface. 2018.

[14] Boks Hebrok. Household food waste: Drivers and potential intervention points for design - An extensive review. *Journal of Cleaner Production*, pages 380–392, 2017.

[15] Evan Burton, Carolin Meier, and Raquel Olarte. AirShare : A Food Sharing Concept. pages 634–639, 2017.

[16] Rob Comber and Anja Thieme. Designing beyond habit: opening space for improved recycling and food waste behaviors through processes of persuasion, social influence and aversive affect. *Personal and Ubiquitous Computing*, 17(6):1197–1210, jul 2012.

[17] Geremy Farr-Wharton, Jaz Hee-Jeong Choi, and Marcus Foth. Technicolouring the fridge: reducing food waste through uses of colour-coding and cameras. *Proceedings of the 2014 International Conference on Mobile and Ubiquitous Multimedia*, pages 48–57, 2014.

[18] Eva Ganglbauer. Towards food waste interventions: an exploratory approach. *ACM conference on Pervasive and ubiquitous computing*, pages 337–342, 2013.

[19] Eva Ganglbauer, Geraldine Fitzpatrick, and Georg Molzer. Creating Visibility : Understanding the Design Space for Food Waste. pages 0–9, 2012.

[20] Adrian K. Clear, Kirsti O'Neill, Adrian Friday, and Mike Hazas. Bearing an Open "Pandora's Box": HCI for Reconciling Everyday Food and Sustainability. *ACM Transactions on Computer-Human Interaction*, 23(5):1–25, 2016.

[21] Geremy Farr-wharton. EatChaFood : Challenging Technology Design to Slice Food Waste Production. pages 559–562, 2013.

[22] Wolfgang H. Reitberger, Wolfgang Spreicer, and Geraldine Fitzpatrick. Nutriflect: Reflecting Collective Shopping Behavior and Nutrition. *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14*, pages 3309–3318, 2014.

[23] Krista L. Thyberg and David J. Tonjes. Drivers of food waste and their implications for sustainable policy development. *Resources, Conservation and Recycling*, 106:110–123, 2016.

[24] Mark Silvis, Anthony Sicilia, and Alexandros Labrinidis. PittGrub : A Frustration-Free System to Reduce Food Waste by Notifying Hungry College Students. pages 754–763, 2018.

[25] William Kling. A Nutritional Guide to Wartime Use of Agricultural Resources. *American Journal of Agricultural Economics*, 25(3):683–691, 08 1943.

[26] FAO and UNEP 1981. Food loss prevention in perishable crops. 2(43), 1981.

[27] Food waste. `https://ec.europa.eu/food/safety/food_waste_en`. Accessed: 2019-05-30.

[28] Food loss and waste accounting and reporting standard. `https://www.wri.org/our-work/project/food-loss-waste-protocol/publications`. Accessed: 2019-05-30.

[29] Dana Gunders. NRDC_2012_Wasted Food. IP: 12-06-(august):1–26, 2012.

[30] Philipp Schoessler. Feedback fridge. *Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction - TEI '11*, page 441, 2011.

[31] Arda Aydin, Anthony Micallef, Samantha Lovelace, Xudong Li, Victor Cheung, and Audrey Girouard. Save the Kiwi: Encouraging Better Food Management through Behaviour Change and Persuasive Design Theories in a Mobile App. *CHI'17 Extended Abstracts: CHI Conference on Human Factors in Computing Systems Proceedings*, pages 1–7, 2017.

[32] Geremy Farr-wharton, Victoria Park Road, and Kelvin Grove Qld. Colour Coding the Fridge to Reduce Food Waste. 2012.

[33] Eva Ganglbauer, Geraldine Fitzpatrick, and Florian Güldenpfennig. Why and what did we throw out?: Probing on Reflection through the Food Waste Diary. *Proceedings of the ACM CHI'15 Conference on Human Factors in Computing Systems*, 1:1105–1114, 2015.

[34] Anja Thieme, Rob Comber, Julia Miebach, Jack Weeden, Nicole Krämer, Shaun Lawson, and Patrick Olivier. "We've Bin Watching You" – Designing for Reflection and Social Persuasion to Promote Sustainable Lifestyles. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*, pages 2337–2346, 2012.

[35] F. Altarriba, M. Funk, S.E. Lanzani, and A. Torralba. The grumpy bin: Reducing food waste through playful social interactions. *DIS 2017 Companion - Proceedings of the 2017 ACM Conference on Designing Interactive Systems*, pages 90–94, 2017.

[36] Veranika Lim. Eco-Feedback for. pages 99–102, 2014.

[37] Alex A Gartland. Weigh Your Waste : A Sustainable Way to Reduce Waste. pages 2853–2858, 2009.

[38] Conor Linehan, Tom Leeman, Christopher Borrowdale, and Shaun Lawson. Crowd Saucing : Social Technology for Encouraging Healthier Eating SPRKLING WATER *. pages 53–57, 2013.

[39] R Comber and J Hoonhout. Food practices as situated action: exploring and designing for everyday food practices with households. *Proceedings of the ...*, pages 2457–2466, 2013.

[40] Fulya Yalva. Social Recipe Recommendation to Reduce Food Waste. pages 2431–2436, 2014.

[41] Eva Ganglbauer, Geraldine Fitzpatrick, Özge Subasi, and Florian Güldenpfennig. Think Globally , Act Locally : A Case Study of a Free Food Sharing Community and Social Networking. pages 911–921, 2014.

[42] Geremy Farr-wharton, Jaz Hee-Jeong Choi, and Marcus Foth. Food Talks Back : Exploring the Role of Mobile Applications in Reducing Domestic Food Wastage. *Proceedings of the 26th Australian Computer-Human Interaction Conference*, pages 352–361, 2014.

[43] Jorge Luis Zapico, Cecilia Katzeff, Ulrica Bohné, and Rebecka Milestad. Eco-feedback Visualization for Closing the Gap of Organic Food Consumption. pages 1–9, 2016.

[44] WH Reitberger, Wolfgang Spreicer, and Geraldine Fitzpatrick. Nutriflect: reflecting collective shopping behavior and nutrition. *Proceedings of the 32nd ...*, pages 3309–3318, 2014.

[45] Wikipedia. Arduino— Wikipedia, the free encyclopedia, 2019. [Online; accessed 03-May-2019].

[46] Winnow Solutions. We are on a mission to connect the commercial kitchen, create a movement of chefs and inspire others to see that food is too valuable to waste.

Appendices

A Research Dataset

To see the original document, click here.

Document #	Title	Year	Relevance(1-5)	Method of research	Technologies used	Social Media Used	Location (home, restaurant etc)	Acceptance	Change user's behavior (1-5)	Limitations	Ease of use (1-5)	Project Name	Statistical data	Reasons for food waste	Suggested solution	Include or Exclude
1	Color Coding The Fridge to Reduce Food Waste	2012	3	Diary	Almost No	No	HOME	Good	3.5	Results not proven well	4		Yes	Forggoteon the fridge busy life	Sort the food in the fridge according to colors	Include
2	Community Identity Through Omiyage and Location Based Social Media		1													Exclude
3	Creating visibility: Understanding the Design Space for Food Waste	2012	5	Qualitative study	mobile app	No	HOME	Good most of the people feel sorry of throwing food	2	Results not too obvious like ex. Loosing weightTidious to enter food bought in the app manually	3	Food waste diary (note what you throw price pic etc)	Yes	Overbuying	Buy less keep a list and use recepy app for suggesting	Include
4	Crowd Saucing : Social Technology For Encouraging Healthy Eating	2013	3	Experimental	web and mobile	Social Receipt NO Plate and Rate YES	everywhere	Social Reciept poor Plate and Rate good	2--4	S.R wasn't interesting or engaging because of the lack of Soc. Media	3	Social Receipt and Plate and Rate	No	Not specified	Some people do not see the need for change.. make them see it	Include
5	Designing beyond habit: opening space for improved recycling and food waste behaviors through processes of persuasion, social influence and aversive affect	2012	5	case study, gamification, experiment	camera and mobile phone, web	YES	HOME	Project ok received People feel sorry of throwing food	2	Noise, also people didn't throw things they were ashamed of	4	BinCam	Only for the particular proj.	Not too much time,	People recycle more if they are poorer..or if they win something by it	Include
6	EatChaFood: Challenging Technology Design to Slice Food Waste Production	2013	5	no info	mobile app	NO (in the future yes)	HOME	__	no info	no info	no info only a simple prototype	EatChaFood	Yes	Lack of knowledge of what food people have in fridge where the food is located and food literacy	Make people more aware where their food is and their expiration date	Include
7	Eco feedback for non consumption	2014	5	questionaire study	digital scale	NO	HOME	Good	4	just a simple prototype not much results given	5	no name	No	Not much info given	make people aware of how much they waste	Include
8	Encountering Our Emerging Urban Atmospheres	2005	1													Exclude
9	Encouraging sustainable fashion with a playful recycling system		2	iterative design	textile machine	NO	School	OK	3	not about food but nice concept	5	UNI2BIN	No			Maybe
10	Food, dude	2009	4	no info	No	N0	everywhere	__	no info	just concept no actual project	no info only a simple prototype	no prototype	no	no info	many ways to reduce food waste suggested look at paper : p58-blevis	Include
11	Global food loses and food waste extend, causes and prevention	2011	4	not research just info	No	NO	everywhere	__	No info	just info	no info	no prototype	yes	development of the country :poor loose more in food production while industrialized countries loose more at home	not much info basically look at the previous field	Include
12	Green Food Technology: Ubicomp Opportunities for Reducing the Environmental Impacts of Food	2013	2	workshop	web and mobile	NO	__	__	__	its not a research	no info	no prototype	yes	no info	no info	Include
13	Green Food Through Green Food: A Human Centered Design Approach to Green Food Technology	2013	3	__	paper version	NO	HOME	__	__	too short no info	__	__	yes	buy too much eat too much	buy less and eat less meat	Include
14	How Children Represent Sustainability in the Home	2011	1	exploratory												

Document #	Title	Year	Relevance(1-5)	Method of research	Technologies used	Social Media Used	Location (home, restaurant etc)	Acceptance	Change user's behavior (1-5)	Limitations	Ease of use (1-5)	Project Name	Statistical data	Reasons for food waste	Suggested solution	Include or Exclude
15	It Takes a Network to Get Dinner: Designing Location- Based Systems to Address Local Food Needs	2013	5	qualitative study	web	NO	everywhere	Good, people were satisfied		technology is not leveraged well, people still have to make calls to ask for food	3	LBIS	no	overproduction etc	share it with others	Include
16	Food Practices as Situated Action: Exploring and designing for everyday food practices with households	2013	3	Interviews	__	NO	HOME	__	2	short and not much information also its about eating healthy	__	__	no	bad food practices (not having shopping list, buying a lot etc)	shopping list, record expiratory date, buy less	Include
17	Mapping the Landscape of Sustainable HCI		3	Literature Review	__	NO	everywhere	__	__	__	__	__	yes	__	__	Include
18	Mate, we don�t need a chip to tell us the soil�s dry" Opportunities for Designing Interactive Systems to Support Urban Food Production		1	Interviews	_	NO	Land									
19	Negotiating Food Waste: Using a Practice Lens to Inform Design	2013	5	Case study	web	NO	HOME	good	3	some issues cannot be tackled to stop the food waste like busy life and tiredness	5	Fridge Name	yes	big food packages, bad food practises , not knowing whats on fridge, no immediate results like loosing weight or no profit from it	coordinated shopping, make the process easy to use and as automated as possible	Include
20	Cleanly - Trashducation Urban System	2010	1	Observation												Exclude
21	Community Identity Through Omiyage and Location Based Social Media		1													Exclude
22	Food and Interaction Design: Designing for Food in Everyday Life		1													Exclude
23	Power Ballads: Deploying Aversive Energy Feedback in Social Media	2011	1													Exclude
24	Visual Research Methods and Communication Design		1													Exclude
25	Food for Thought: Designing for Critical Reflection on Food Practices		1													Exclude
26	Nutriflect: Reflecting Collective Shopping Behavior and Nutrition		1													Exclude
27	PlateMate: Crowdsourcing Nutrition Analysis from Food Photographs	2011	1													Exclude
28	Social Recipe Recommendation to Reduce Food Waste	2014	5	User study	mobile app (Cross platform)	No	HOME/SHOPPING	__	3	the system needs a lot of data in order to start to function properly	5	Social Recepie Recommandation	yes	__	using notifications made users more engaged	Include
29	Think Globally, Act Locally: A Case Study of a Free Food Sharing Community and Social Networking	2014	5	Just shows information	web	YES	everywhere	Very good, most people didn't want to waste food	4	_	5	Foodsharing.de	no	overbuying, change of plans, busy life expired etc	the leverage of social network made huge success	Inculude
30	Towards Food Waste Interventions: An Exploratory Approach	2013	5	qualitative study, interviews, contenxtual inquary	mobile app	NO	everywhere	__	__	__	__	__	no	all the reasons mentioned before	look at the paper it has a lot of ways to reduce waste mostly mentioned above to	Include

Document #	Title	Year	Relevance(1-5)	Method of research	Technologies used	Social Media Used	Location (home, restaurant etc)	Acceptance	Change user's behavior (1-5)	Limitations	Ease of use (1-5)	Project Name	Statistical data	Reasons for food waste	Suggested solution	Include or Exclude	
31	Understanding Underutilisation: Methods for Studying Fruit and Vegetable Buying Behaviours	2013	1													exclude	
32	Weigh Your Waste: A Sustainable Way to Reduce Waste	2009	5	iterative design	bin with weight sensitivity	NO	home and businesses	Very good, most people didn't want to waste food	4	__	5	__	no	__	motivate people more , they need to know what do they profit (in money or simmilar) saving food	Include	
33	Nutriflect: Reflecting Collective Shopping Behavior and Nutrition	2014	3	field study, exploratory study, interview	web service with mobile interface	NO	home and shop	Good	3	data that were sent by users (shopping tickets) processed manually	4	Nutriflect	no	__	automate the process so the users will have to put minimal effort	Include	
34	Food waste within supply chains: quantification and potential for change to 2050	2010	4	Literature review and interview with experts	__	NO	Post-harvest, supply chains	__	__	__	__	__	YES	local farmers are discouraged to sell their food to supermarkets because of their high expentance , in the household for all the reasons mentioned above ,lower income less waste in the family** poor techniques in post harvesting phase etc..see the paper page 5	educating people, retailer's participation, use of technology .. unestetical food to be sold cheaper (Fairshare)	Include	
35	"We've Bin Watching You" – Designing for Reflection and Social Persuasion to Promote Sustainable Lifestyles	2012	5	Built a camera that is added to the bin and it shares pictures in Facebook everytime you throw something	Not mentioned	YES	home	Good	2	Small study and participants were vulenteers and they already were motivated to waste less food	5	BinCam	NO		Use persuasive technology but don't force people	include	
36	Comprehensive Guide to Shipboard Waste Management Options	200	1														
37	Can we reduce waste and waist together through EUPHORIA?	2014	5		mobile app	YES	HOME	__	__	Users have to input a lot data	3	EUPHORIA	YES (newest and best)	Overbuying, miss-management of the food, not knowing what to do	Target all the stages of food in housholds, change peoples behavior	include	recommends recepies
38	Technicolouring the Fridge: Reducing Food Waste through Uses of Colour-coding and Cameras	2014	5	Literature Review	Mobile app and physical application	NO	HOME	Very good	4	Violates the privacy of users and sometimes brought furstration when other memebers didnt follow through the plan	3	FridgeCam and Color Code	Some	Overbuying, miss-management of the food, not knowing what they have on their fridge	Color coding works, camera that is placed in the fridge isnt in perfect angle maybe fix it or find alternative	Include	doesnt recommend recepies
39	Why and what did we throw out? Probing on Reflection through the Food Waste Diary	2015	5	Diary/journaling through mobile apps	mobile app (android and iOS)	NO	HOME	Good	4	All the data are put manually plus users are anonymous so there is no follow up interviews	4		Some	Overbuying, visibility of stock, no shopping list, change of cooking plans, special offers	It depends for every situation since human behaviour is very complex	Include	doesnt recommend recepies
40	The Predictive Accuracy of Published Solid Waste Generation Factors	1988	1														
41	Technology at Mealtime: Beyond the 'Ordinary'	2015	1														
42	Taste and Place: Design, HCI, Location and Food	2013	1														

Document #	Title	Year	Relevance(1-5)	Method of research	Technologies used	Social Media Used	Location (home, restaurant etc)	Acceptance	Change user's behavior (1-5)	Limitations	Ease of use (1-5)	Project Name	Statistical data	Reasons for food waste	Suggested solution	Include or Exclude	
43	Spatial and Temporal Patterns of Online Food Preferences	2014	2	Analyzing data shared by ichkoche.at		NO										Maybe	
44	Save the Kiwi: Encouraging Better Food Management through Behaviour Change and Persuasive Design Theories in a Mobile App Abstract	2017	5	Literature review	Mockup mobile app	NO	HOME	Very good	4	Its just a mockup	4	Save the Kiwi	Yes	Focused only on expiration of the food from bad visibility in the shelve or fridge	App that gives feedback to the users when food is about to expire	Yes	Suggest recepy recommendation
45	Rewriting, Redesigning and Reimagining the Recipe for More Sustainable Food Systems	2014	2		Mockup web app	NO						Red Hen Recipes that					
46	Practical food journaling	2013	2	Exploratory		NO											
47	PlateClick: Bootstrapping Food Preferences Through an Adaptive Visual Interface	2015	1		Algorithm to detect food preferences	NO						PlateClick					
48	My Smartphone Knows I am Hungry	2014	1		Algorithm to detect when person is eating							StudentLife					
49	Lyssna: A Design Fiction to Reframe Food Waste Abstract	2016	3	Exploratory	Design space/idea	NO	HOME			Its just a design	3	Lyssna					
50	Learning to Make Better Mistakes: Semantics-aware Visual Food Recognition HuiWu	2016	1		Algorithm for better detection of foods												
51	Health-aware Food Recommender System	2015	1		Prototype Android App												
52	HCI & Sustainable Food Culture: A Design Framework for Engagement	2010	1														
53	Freedge: Fighting Food Insecurity With Connected Infrastructure	2017	3		Web app /mobile app/ rosberry pi etc..	NO	OUTSIDE				3		NO				
54	Foodness Proposal for Multiple Food Detection by Training of Single Food Images																
55	Food vs Non-Food Classification Francesco																
56	Food Talks Back: Exploring the Role of Mobile Applications in Reducing Domestic Food Wastage	2014	5	Test the existing apps and create an app that incorporates the good functions from the others and extends them	Mobile app	NO but it mentions the importance of it. Takes the example with foodsharing.de that was very useful because of social media	home	good	3	It was a prototype, inputing and removing data difficult process..	3	Fridge Pal the main app they tested also other similar apps such as LeftoverSwap, EatChaFood	YES	overbuying, lack of food literacy etc..	Automate the process of inputing and removing the items .. when users cook something they dont think about going in the app and removing the item from the inventory	INCLUDE	
57	Food Search Based on User Feedback to Assist Image-based Food Recording Systems Sosuke	2016	1													EXCLUDE	
58	Finding Food Entity Relationships using User-generated Data in Recipe Service Young-joo	2012	3		Algorithm	NO											
59	Fermentation GutHub: Designing for Food Sustainability in Singapore	2016	2				home			its for food fermentation		GutHub				EXCLUDE	
60	Feedback Fridge: Tangible Visualization of Nutritional Data with Preventive Effect	2011	3	A prototype	RFID technology and bags that display the quality of the food in the fridge	NO	home			It might have privacy concerns	4	Feedback Fridge				INCLUDE	

Document #	Title	Year	Relevance(1-5)	Method of research	Technologies used	Social Media Used	Location (home, restaurant etc)	Acceptance	Change user's behavior (1-5)	Limitations	Ease of use (1-5)	Project Name	Statistical data	Reasons for food waste	Suggested solution	Include or Exclude
61	Estimating Nutritional Value From Food Images Based on Semantic Segmentation	2014	1													
62	Edible Earth: Dining on Seasonal and Local Ingredients	2009														
63	A Smart Fridge for Efficient Foodstuff Management with Weight Sensor and Voice Interface	2018	5	A smart fridge prototype with voice interface to enter the data	Weight scale, smart voice device such as Alexa, iPhone app, bluetooth	NO	HOME	YES	N/A	Still expensive	4					Include
64	AirShare: A Food Sharing Concept Evan	2017	3	A design space	No prototype		Home	N/A	N/A	just a design suggestion sharing food using drones						
65	Food waste within food supply chains: quantification and potential for change to 2050 Julian	2014	5	Research within different chains	No prototype	NO	Everywhere	N/A	N/A	just a review of the works and statistics	N/A		YES	all the usual		
66	Bearing an Open “Pandora’s Box”: HCI for Reconciling Everyday Food and Sustainability	2016	3	Interviews, questionaires	NO Technology	NO	Home	N/A	N/A							
67	An Automatic Calorie Estimation System of Food Images on a Smartphone	2016	1	Prototype	Prototype Mobile App	NO	N/A	N/A	N/A							
68	Health-aware Food Recommender System Mouzhi	2015														
69	Designing Sustainable Food Systems	2017														
70	Food Dude															
71	Eco-Feedback for Non-Consumption Veranika	2014	5	Prototype	Weight Sensor	NO	Home	N/A	N/A		5	Eco-Feedback Bin	NO			INCLUDE
72	Green Food Through Green Food : A Human Centered Design Approach to Green Food Technology	2013														
73																

B Concept Validation Survey Results

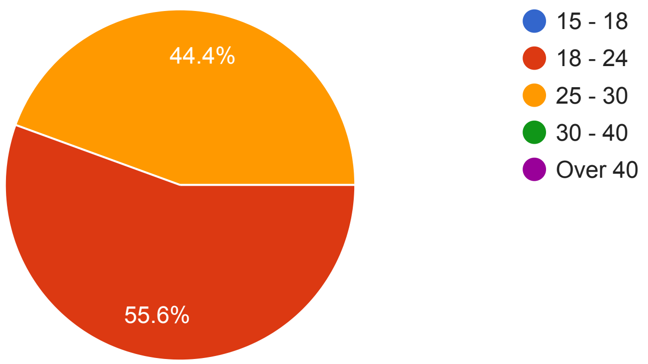
Food Waste App

9 responses

QUESTIONS

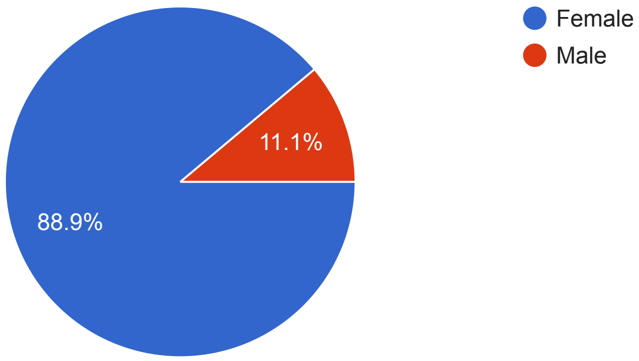
Select your age group

9 responses



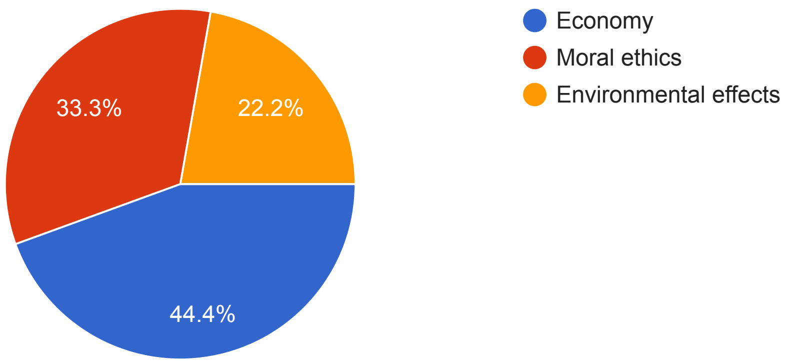
Select your gender

9 responses



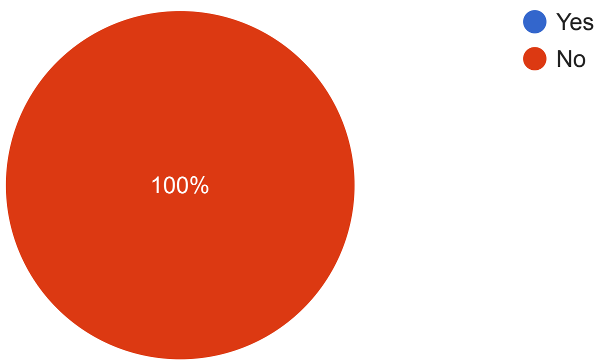
What motivates you to not waste food

9 responses



Do you use any mobile application to manage your household food and shopping planning ?

9 responses



Specify the apps that you use and what you don't like about them.

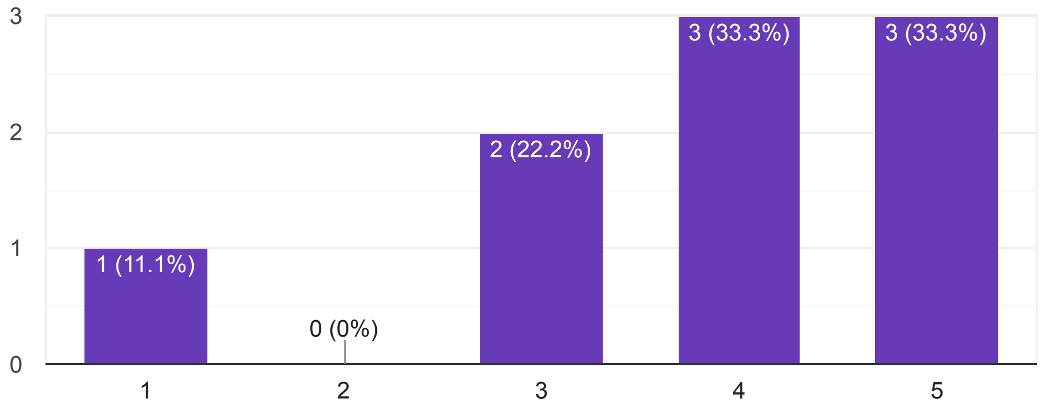
1 response

that most of them are not developed enough. Apps with a daily reminder I use frequent

VOTE OUR APPLICATION FEATURES

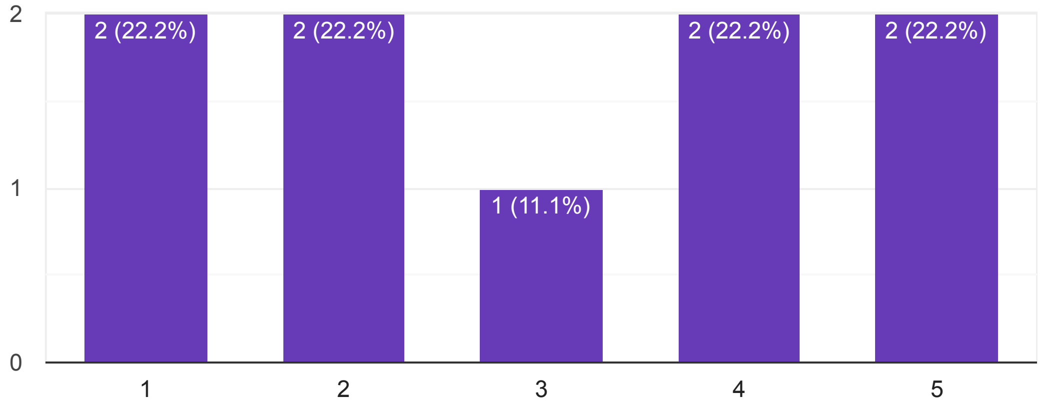
Have the sensor (with the barcode scanner) mounted on your fridge and scan your items to avoid having to type them in manually from your mobile phone

9 responses



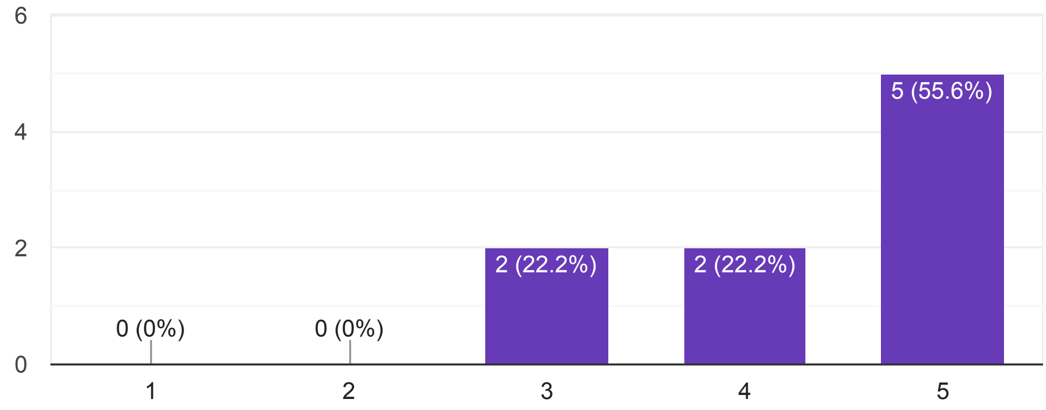
See nutrition facts in the mobile app for all the items you have in the fridge

9 responses



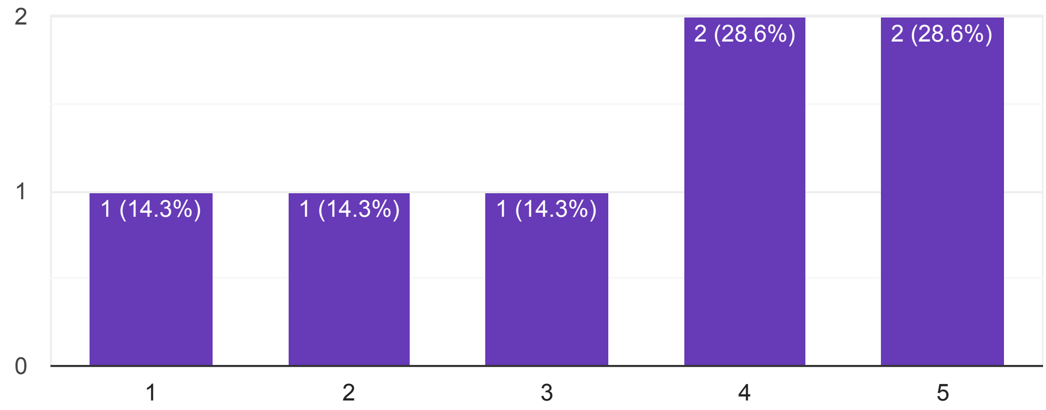
Get notified before an item expires

9 responses



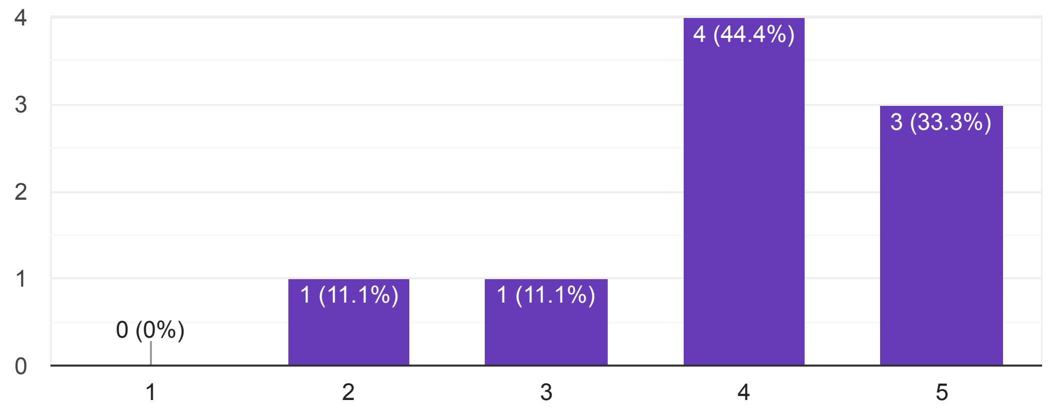
Select the recipes you want to cook for a specified amount of time and we generate the items you need to buy by adding them to your shopping list.

7 responses



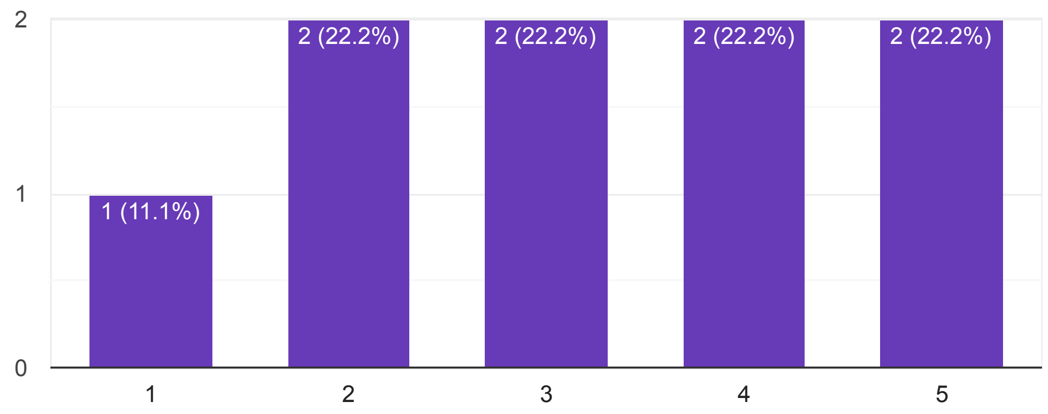
When an item is about to expire get recipe recommendations with the items you have in the fridge to avoid throwing the food away

9 responses



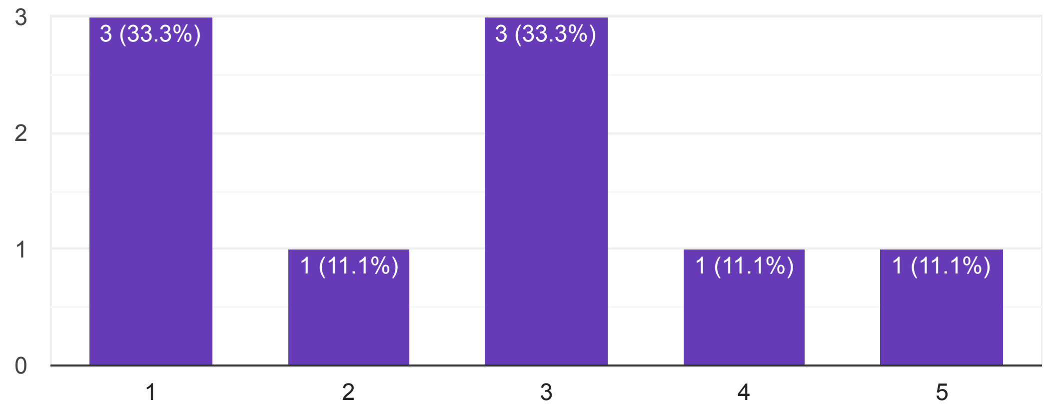
Get information on which products you buy are GMO

9 responses



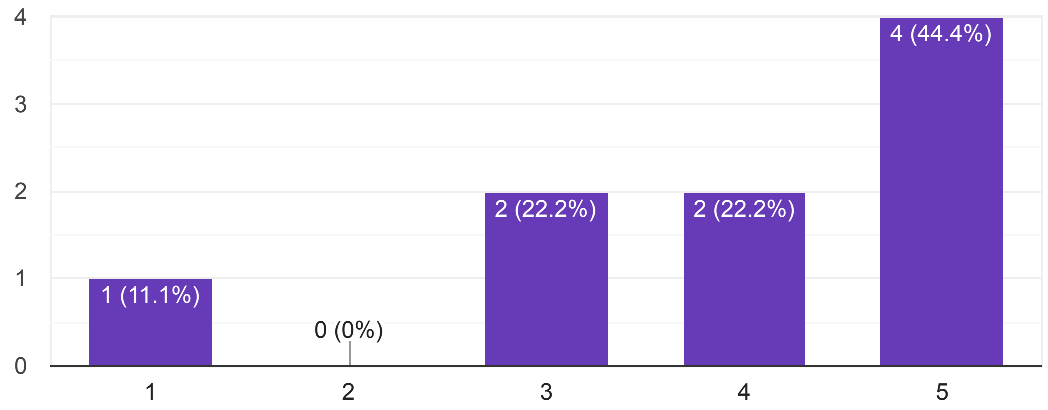
When an item is finished go to the application and indicate it as finished

9 responses



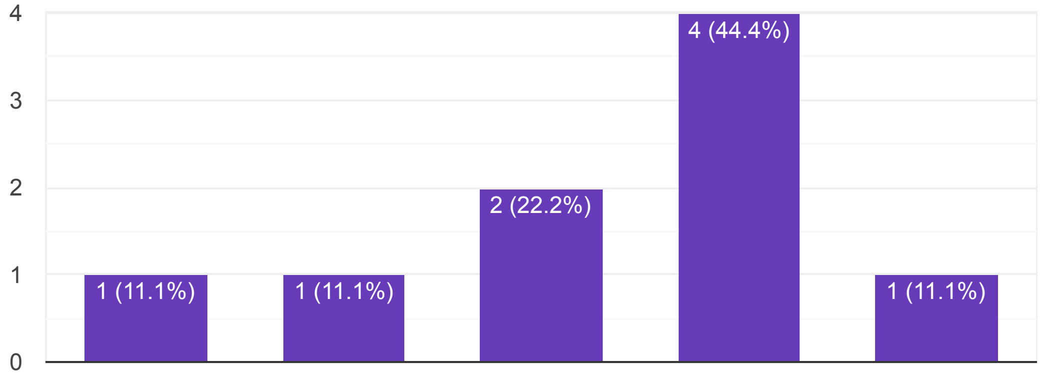
When an item is finished simply scan it in the device mounted on your fridge and press a button to indicate it is finished or wasted and we automatically update your app with the changes

9 responses



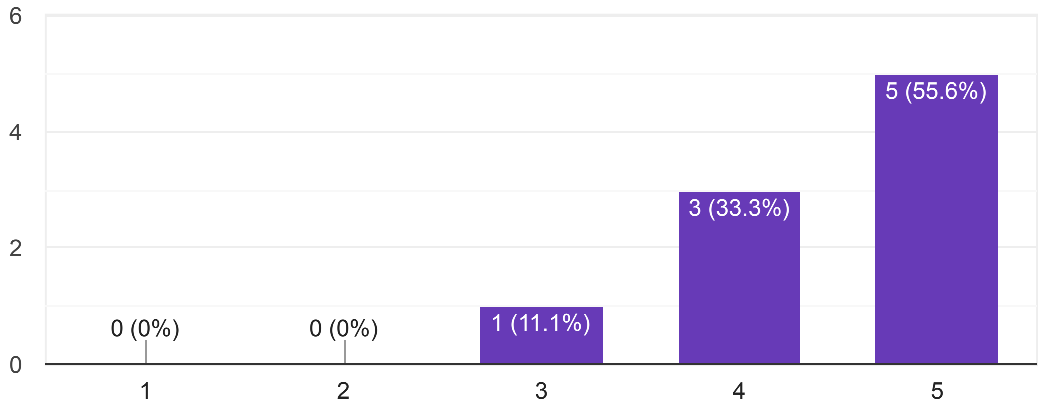
See the amount of money you spend on food

9 responses



See the cost of the food you marked as thrown/wasted

9 responses



Give us any other suggestion or thoughts you might have

Would you have used this technology in your household?

9 responses

If it is not ugly and does not use that much energy. Where does the energy for the scanner come from?

I think it would make more sense to teach people about when food is not good anymore and to tell them how to store it rather than totally disconnect them from their common sense and let an app do the job

I probably would, ye.s

yes, I don't waste that much and always eat everything I have, but I would still like to have it justa s a motivator adn I feel like this would be ana amzing technology for so many people!

I am unsure if I would actually use the device, although I totally see the point of it. I do not have many problems with waste food now, neither.

Yes, if it was easy and fast to use

Probably yes, it’s a really good idea

Yes i’d Like to use if it is not very expensive

I like the concept but i would depend om the final produkt.

Write down any extra thoughts or suggestions you might have.

7 responses

riktig bra

what about food that has no barcode (fruits, vegetables often come without > and I try to avoid packaging so no barcode...)

Do you only take into consideration when the expiration date is close? This date is not "throw away after" but rather a legal protection from the producer

I don't have any currently.

it must just be as simple as possible, but otherwise the things written in the survey has had all the services I feel that I need. The recepie idea for food that will go off is really good! and would help!

Maybe the effort of scanning everything will prevent people from using it. Is there a way to have a RFID Scanner at home? On the other hand, people might dislike this as well (privacy vs. transparent consumer debate...)

How do you get all the information of the food?and if the expiry date is passed you mention the user but sometimes it can be eaten later how do you deal with these problems like suggest them to throw or extend the time but how to ensure everything is secure and safety?

its a real good concept you got here!! unfortunately, I find it hard to believe in the idea of an external scaner when you can scan barcodes with today's smartphones. if you insted focus on making a good app where you scann products with a mobile phone it would open for more areas than refrigerated food. Exampel.frozen foods, dry goods and household products and so on. And focusing on a standalone app would reduce development / pruduction costs and open to a larger customer target group,in my opinion.

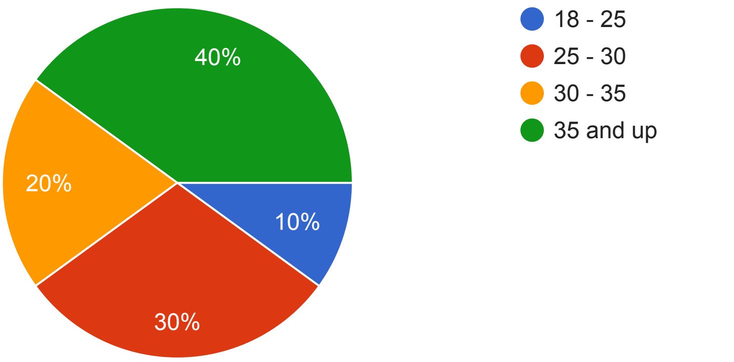
C Final Prototype User Validation Pre-Session Survey Results

Food Waste - Pre-Session Survey

10 responses

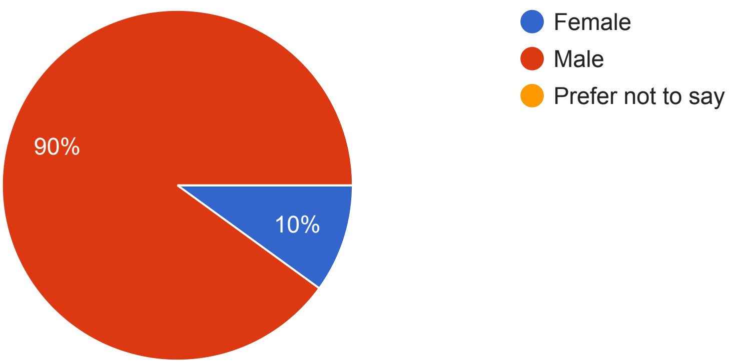
Your age

10 responses



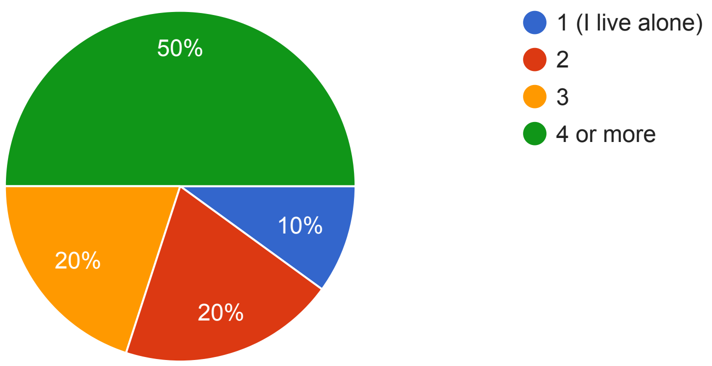
Your gender

10 responses



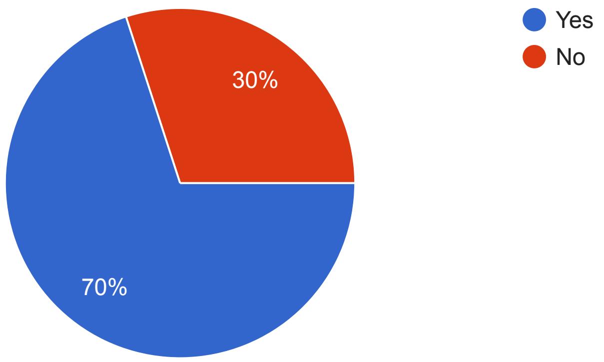
How many members are there in your household?

10 responses



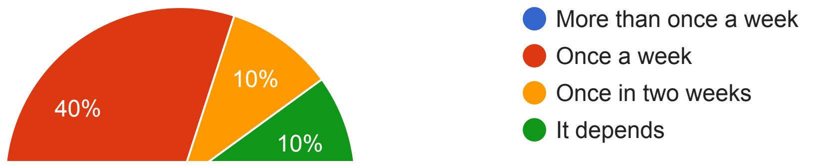
Do you use shopping lists for your groceries?

10 responses



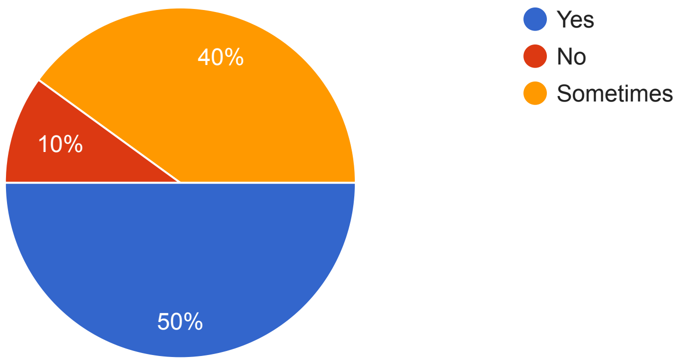
How often do you go grocery shopping?

10 responses



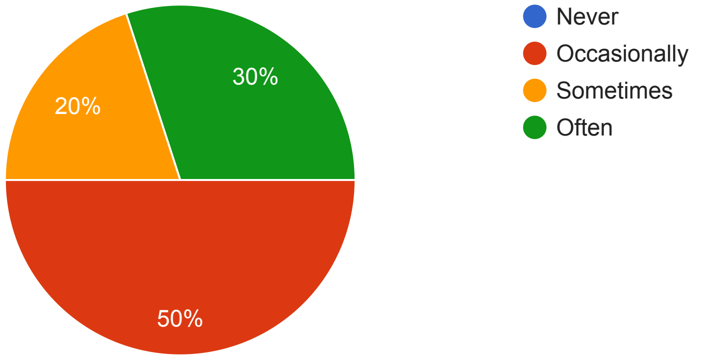
Do you plan your meals ahead?

10 responses



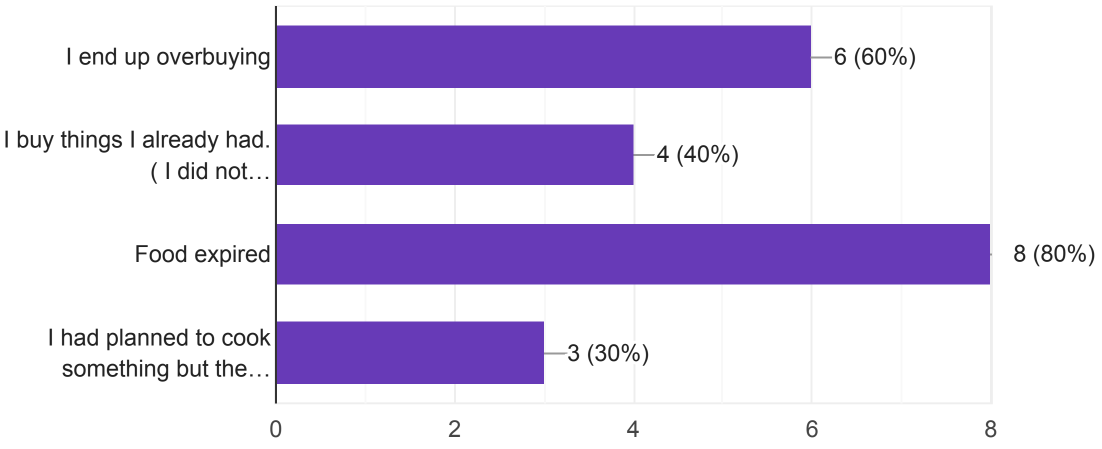
How often do you end up wasting food?

10 responses



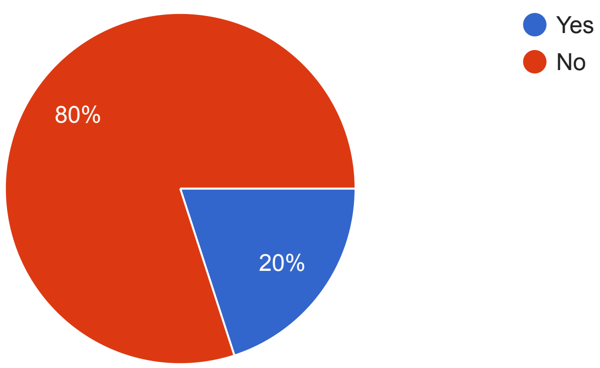
Select all the reasons why you waste food

10 responses



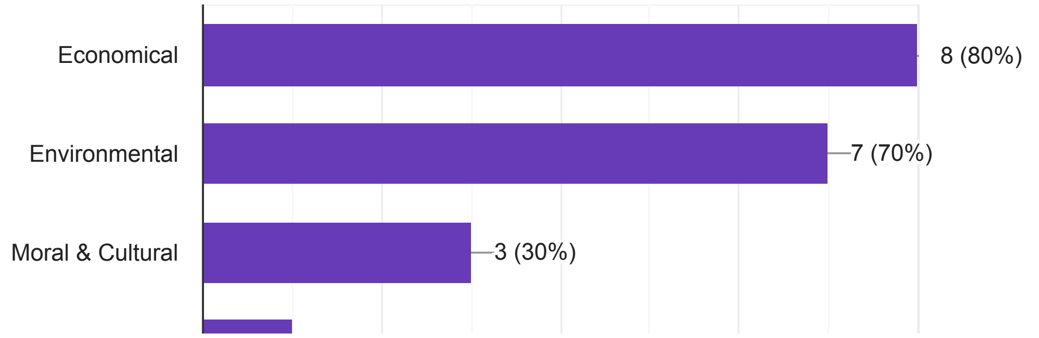
Do you use any shopping list app?

10 responses



Select the reasons why you don't want to waste food

10 responses


Economical
8 (80%)
Environmental
7 (70%)
Moral & Cultural
3 (30%)

D Final Prototype User Validation Post-Session Survey Results

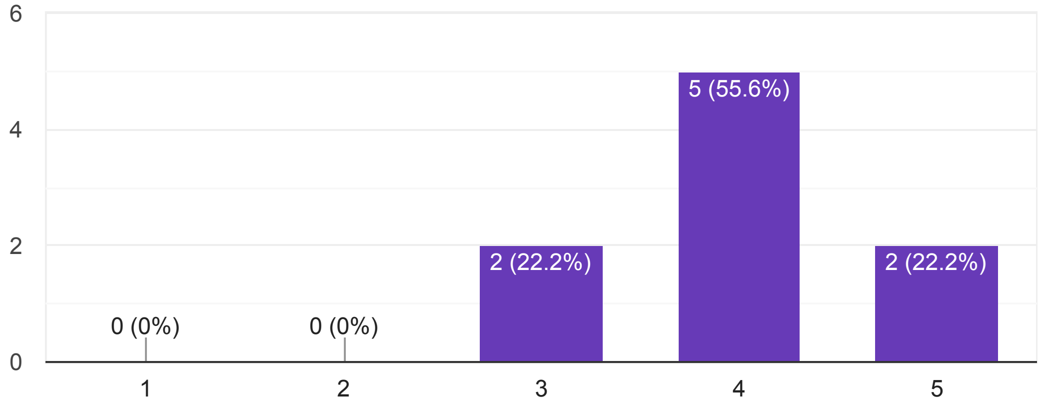
Food Waste Post-Session Survey

9 responses

Rate the User Friendliness of the System

The UI feels intuitive

9 responses

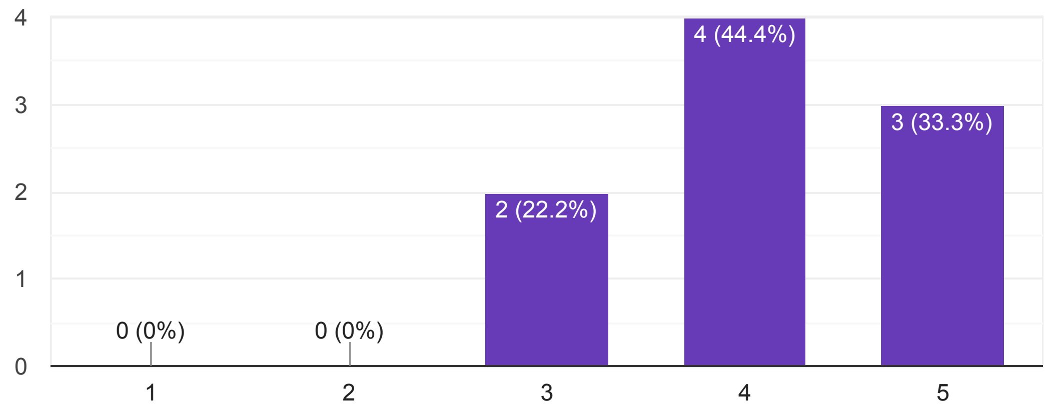


I find it easy to add items to inventory

9 responses

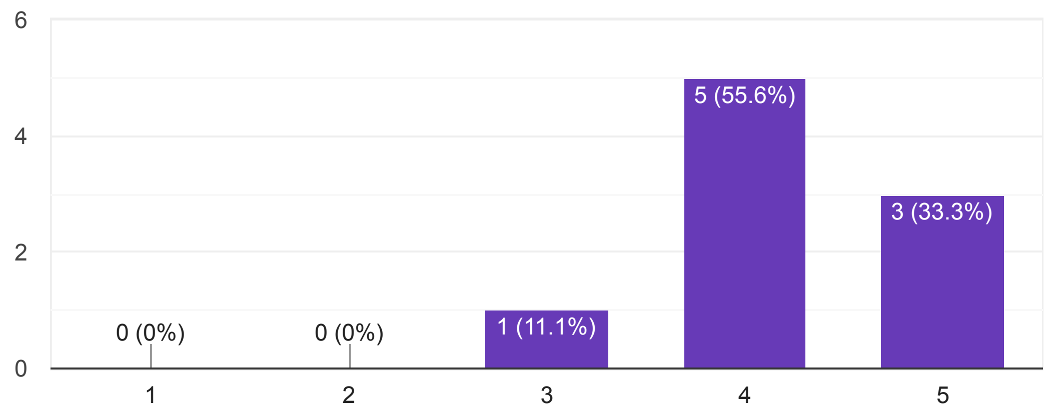
I find it easy to scan the items

9 responses



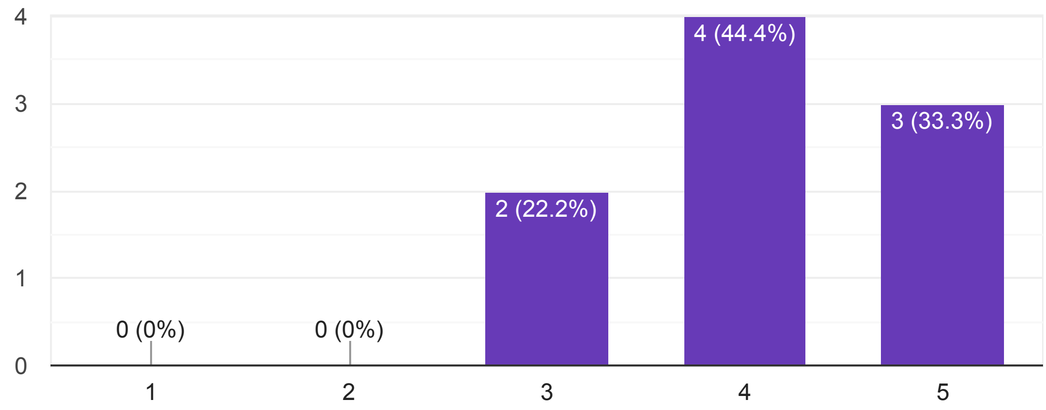
I find it easy to add items to my shopping list

9 responses



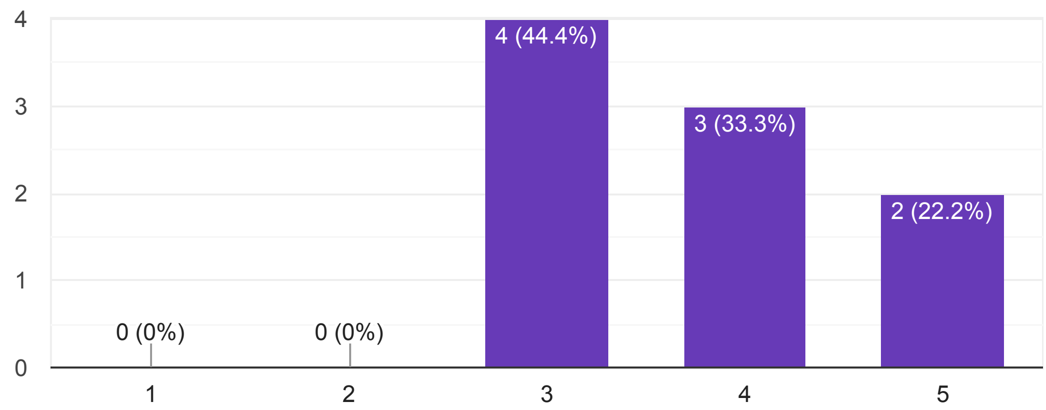
I find it easy to look at recipes

9 responses



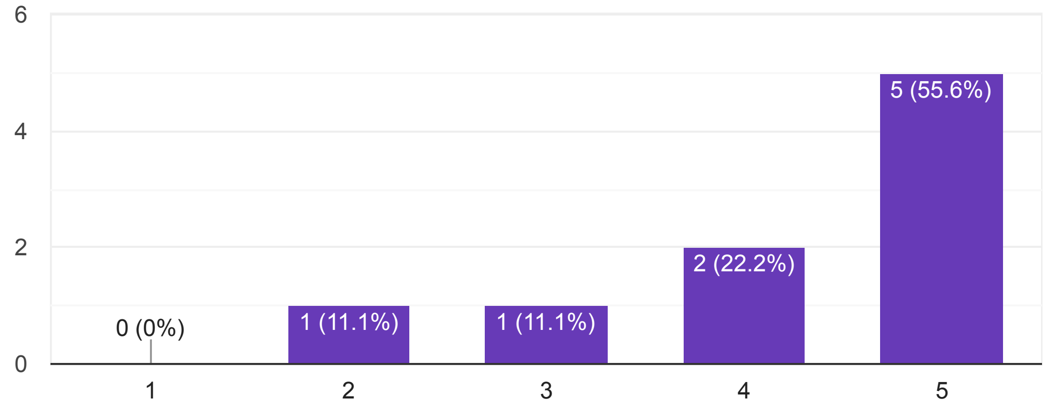
I find it easy to look at insights

9 responses



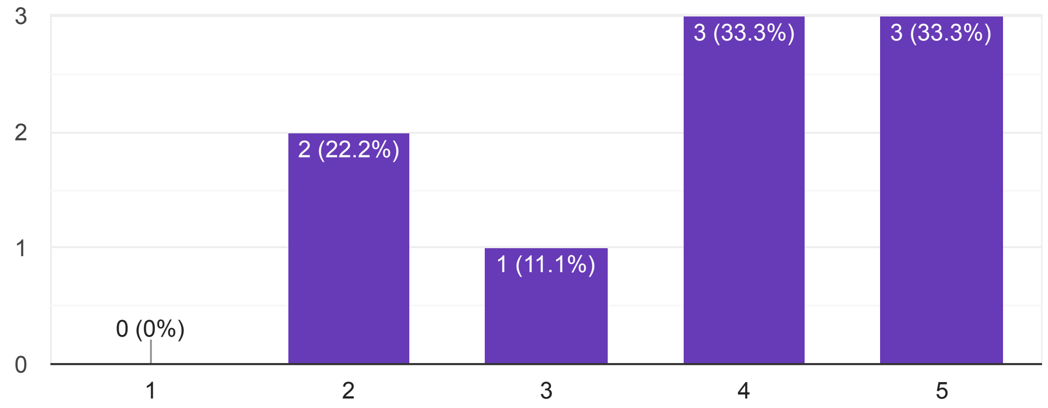
I think having a touchscreen attached to my fridge makes food inventory management easy

9 responses



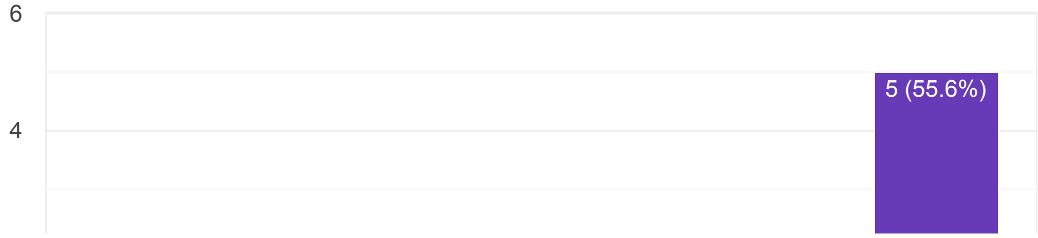
This solution significantly automates food inventory management

9 responses



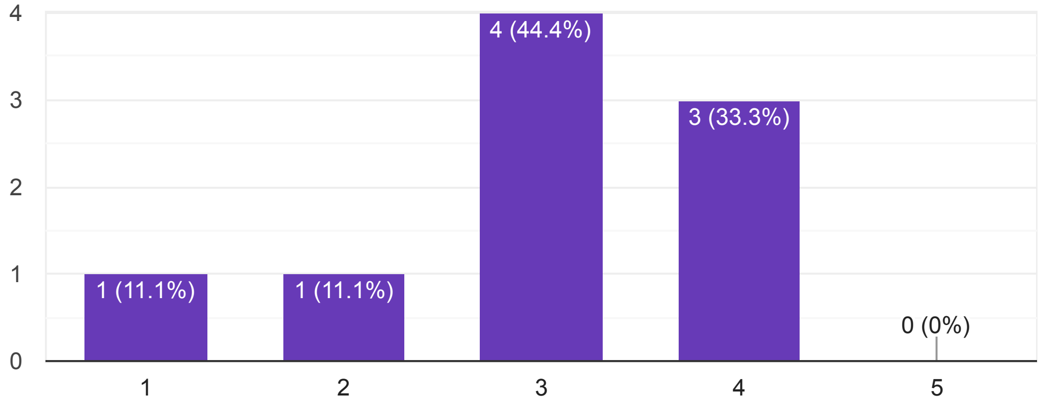
Having a mobile app alongside the touchscreen device is a must

9 responses



The process of scanning of the items/adding them through the app is tedious

9 responses



Rate the features

Being able to add real products to the shopping list instead of manually typing in the item names

9 responses

E Prototype Demonstration Video Links

Description	Link
Web and Device Application - Part 1	LINK
Web and Device Application - Part 2	LINK
Web and Device Application - Part 3	LINK
Web and Device Application - Part 4	LINK
Mobile Application - Part 1	LINK
Mobile Application - Part 2	LINK

Table 9: Prototype Video Demonstrations