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Digitalization against food waste

Evaluating the effectiveness of a mobile app against food waste in households

Master Thesis

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Abstract

Food waste is a subject of importance for our modern society and is directly linked with environmental, economic and social impacts. Between one-third and one-half of the worldwide food production is never consumed. This equals to approximately 88 million tons of annual food waste in just the European Union. The household sector is responsible for over half (53%) of this food waste due to a lack of meal planning, storage overview, awareness of the issue as well as the false perception of the date of minimum durability. A successful decline in consumerism could ultimately lead to decreases in the harvested area, water utilization, and greenhouse gas emissions associated with worldwide food production.

Hence, managing food waste is a great effort to improve both the environmental and economic sustainability. Providing people in households with an efficient food management tool could ultimately reduce the overall food waste amount. Thus, a personal mobile app was conceptualized and developed that helps users with food management at home. The conceptualizing process of the app was heavily problem-oriented, thereby before creating the first prototype, the core issues of food waste in households were defined through literature review and quantitative questionnaires. Through focus groups, usability testing and long-term assessments the effectiveness of the mobile app was evaluated.

During the long-term assessment, households utilized the mobile app in their daily routine for two months. User data such as exact timestamps of storage updates, amounts of wasted as well as consumed food items and the overall food waste percentage was tracked. This collected data confirms that the food waste value of participating households was consistently higher when gathered through the mobile app than their estimated values during the initial interviews, even though they admitted to wasting even less during this period. The final results included a visible increase in awareness of the topic of food waste and a positive change in behaviour concerning food management. Food waste-related motivations, simple usage and an appealing user interface were key factors that kept participants engaged long-term.

Kurzfassung

Lebensmittelverschwendung ist ein Thema von Bedeutung für unsere moderne Gesellschaft und steht in direktem Zusammenhang mit ökologischen, wirtschaftlichen und sozialen Auswirkungen. Zwischen einem Drittel und der Hälfte der weltweiten Nahrungsmittelproduktion wird niemals konsumiert, was allein in der Europäischen Union etwa 88 Millionen Tonnen Nahrungsmittelabfälle pro Jahr entspricht. Der Haushaltssektor ist für über die Hälfte (53%) dieser Lebensmittelverschwendung verantwortlich, was auf einen Mangel der Mahlzeitplanung und der Lebensmittelübersicht sowie das das fälschliche Verständnis für das Mindesthaltbarkeitsdatums zurückzuführen ist. Ein erfolgreicher Rückgang des Konsumverhaltens könnte letztlich zu einem Rückgang der Erntefläche, der Wassernutzung und der mit der weltweiten Nahrungsmittelproduktion verbundenen Treibhausgasemissionen führen.

Daher ist die Bewältigung von Lebensmittelverschwendung eine große Herausforderung, um sowohl die ökologische als auch die wirtschaftliche Nachhaltigkeit zu verbessern. Indem man Menschen in Haushalten effiziente Instrumente für die Verwaltung von Lebensmitteln zur Verfügung stellt, könnte letztlich die globale Verschwendung reduziert werden. Aus diesem Grund wurde eine mobile App konzipiert und entwickelt, die Benutzern bei der häuslichen Lebensmittelverwaltung unterstützen soll. Der Designprozess der App war überaus problemorientiert, so dass vor der Erstellung des ersten Prototyps die Kernprobleme von Lebensmittelverschwendung in Haushalten durch Literaturrecherche und quantitative Fragebögen definiert wurden. Durch Fokusgruppen, Usability-Tests und Langzeittests wurde die Effektivität der mobilen App in Haushalten bewertet.

Während der Langzeitstudie nutzten die Haushalte die mobile App zwei Monate lang in ihrer täglichen Routine. Dabei wurden Nutzerdaten wie beispielsweise die Zeitpunkte der Vorrats-Aktualisierungen, die Mengen an verschwendeten sowie konsumierten Lebensmitteln und die Summe der Lebensmittelabfälle in Prozent verfolgt. Diese gesammelten Daten zeigen, dass die Lebensmittelverschwendung der teilnehmenden Haushalte bei der Erfassung über die mobile App signifikant höher war als die angenommenen Werte während der ersten Interviews, obwohl sie zugaben, in dieser Zeit weniger als üblich verschwendet zu haben. Zu den Endergebnissen gehörten eine sichtbare Steigerung des Bewusstseins für das Thema Lebensmittelverschwendung und eine positive Verhaltensänderung im Umgang mit Lebensmitteln. Motivationen mit Bezug auf Lebensmittelverschwendung, einfache Bedienung und eine ansprechende Benutzeroberfläche waren Schlüsselfaktoren, wodurch Teilnehmer langfristig engagiert blieben.

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1 Introduction

Food waste is a major problem of our modern world, directly linked with environmental, economic and social impacts. Around 88 million tons of food waste is produced annually in the European Union of which about 53% of it is just by households, followed by food processing with around 19%. The remaining 28% consist of food services with 12%, food production with 11% as well as wholesale and retail with only 5% (Stenmarck et al., 2016, p.4).

Technology to help people plan, share and keep an overview of the stock is one of the dominating categories of interventions against food waste in households (Hebrok & Boks, 2017, p.20). So not only are households the sector contributing the most to food waste, but they are also the most approachable as well as receptive for the utilization of unfamiliar digital solutions. Through the development of a user-centred digital application that supports people during their daily routines related to food management, the overall food waste in the household sector could be marginally reduced, thus, leading to a possible reduction in unnecessary overconsumption.

This successful decline in consumerism could ultimately lead to decreases in the harvested area, water utilization, and greenhouse gas emissions associated with food production. In addition to environmental issues, results obtained by Munesue et al. have quantitatively shown that a 50% reduction in food losses and food waste in developed regions during the postharvest handling and storage, processing and packaging, distribution and consumption stages could reduce the number of undernourished people in developing regions by up to 63.3 million (Munesue et al., 2015).

Therefore, through utilizing modern technology, households, the sector contributing currently the most to food waste, can be supported by simple means such as a virtual storage overview. Moreover, supportive features such as the possibility to create shopping lists could simplify the process of adding food items to the storage and furthermore encourage people to plan ahead. This reduction in overconsumption could subsequently reduce the global over-production of food long-term.

1.1 Objectives

The objective of this work is to explain the core issues of food waste and consequently create a user-centred digital solution through iterative development for households. Subsequent qualitative evaluations of the developed solution will determine to what degree it can effectively support people in their homes with food management to conclusively reduce domestic food waste.

To address the primary objective of this thesis, the following research question must be answered:

- How can a mobile application be developed and assessed to reduce food waste in households?

In the process of working on the main research question, additionally, the following matters will be addressed:

- How effective are mobile applications at supporting people with food management in households?
- Which methods can be employed to evaluate the successful outcome of the mobile application?

1.2 Methods

The global issues of food waste, especially those in households, and its environmental impacts were researched with relevant literature and directly validated through quantitative questionnaires as well as qualitative user interviews and focus groups. After the primary insights were established, a mobile app against food waste in households was developed using an iterative development approach with the support of voluntary testers within the previously defined target group. To ensure a working solution that will resonate with the affected users, books, journals, papers in addition to existing solutions were reviewed. These reviews were especially supportive in the process of defining a Minimum Viable Product (MVP) which would be able to achieve maximum effectiveness with a minimum of functionality.

After every major development cycle of the mobile app, new features were tested and evaluated in qualitative usability tests, where the time to perform certain actions, thoughts on the user interface as well as feature requests were recorded. Following the final usability testing of the MVP, the app was distributed to six households, varying from one to five members, in order to assess the developed solution in realistic scenarios. Due to limited development resources, the app was solely published on the Google Play Store for Android device, however since

Android is overall more commonly used than iOS, this issue was considered as manageable at this stage (*Mobile Operating System Market Share Worldwide*, n.d.).

Before the households were introduced to the mobile app, an initial interview was conducted to gather insights into the current user behaviour in regards to food management including the organization of groceries, an estimated amount of food waste, most commonly wasted products and possibly already established solutions for this issue. To ensure enough time for a visible change in user behaviour, the testing period was adjusted to approximately two months and was succeeded by a second interview to understand how the mobile app was utilized by the participants as well as to assess its effectiveness. During the long-term assessment, participants had the opportunity to directly report issues, ask for support and suggest features at any given time through built-in tools or direct messaging-services.

1.3 Structure

The structure of this thesis represents the iterative development process of the application: 1) research, 2) development, 3) evaluation.

Chapter 2 – Related Work

Initially, the current state of the food waste problem, with an emphasis on Europe, will be presented through literature research. Additionally, mobile apps to reduce food waste in households that thematically relate to this work will be highlighted. Lastly, development methods to increase user engagement and thereby the possibility of a positive change in user behaviour through mobile apps will be stated.

Chapter 3 – Solution

Chapter 3 will focus on the implementation of the solution by first defining the main user needs to subsequently design an interactive prototype and a corresponding Minimum Viable Product (MVP) with Adobe XD. Finally, the implementation of the MVP with Flutter as the frontend technology and Firestore as a serverless backend will be presented.

Chapter 4 – Assessment

The planning and development processes of the mobile app against food waste in households were accompanied by several evaluation methods including field studies, focus groups, usability testing as well as long-term assessments. Chapter

4 will reveal how these various methods were designed, conducted and their major outcomes.

Chapter 5 – Discussion

Chapter 5 will focus on stating and explaining the findings of this thesis, showing how they relate to the used literature and the research questions, and stating an argument.

Chapter 6 – Conclusion

Finally, in Chapter 6 the major findings will be restated and analyzed how they contribute to the state-of-the-art of digital solutions against food waste in households. Furthermore, the limitations of this work as well as future directions will be explained.

2 Related Work

The current state of the food waste problem, with an emphasis on Europe, is presented through literature research. Additionally, mobile apps to reduce food waste in households that thematically relate to this work are highlighted. Lastly, development methods to increase user engagement and thereby the possibility of a positive change in user behaviour during the usage of mobile apps are stated.

2.1 Food Waste Research

A situation report with regards to food waste in Austria published by the World Wildlife Fund (WWF) states that about 42% of all avoidable food waste is produced by private households (Pladerer et al., 2016). Although this number is significantly lower than the 53% of food waste by households in the European Union as stated by Stenmark et al. (2016), the fact that the household sector contributes the most to food waste is supported nevertheless. Pladerer et al. (2016) additionally indicated that the population lacks knowledge about the actual meaning of the date of minimum durability and its delimitation from the date of use.

Systematische Erfassung von Lebensmittelabfällen der privaten Haushalte in Deutschland (en. Systematic acquisition of food waste from private households in Germany) attempted to determine the quantities of food waste produced in private households using a diary study over twelve months (Hübsch & Adlwarth, 2017). Although in their study only 24.6% were households with three or more members, these accounted for 38.9% of the amount of avoidable food waste. While bigger households wasted more food on average, the largest per capita waste is identified for one-person households. If differentiation is made according to age, it was found that younger households stand for a disproportionately large amount of avoidable food waste (Hübsch & Adlwarth, 2017).

Hebrok & Boks (2017) found three dominating categories to address the food waste situation in households through an extensive literature review that focused on possible and existing opportunities for intervention with regards to food waste. First, a technology to help people plan, share and keep an overview of stock, second, different packaging and storing solutions to extend shelf life and third, awareness campaigns (Hebrok & Boks, 2017).

An online survey among over 800 respondents of two European research centres in Italy JRC/Ispra and Germany KIT/Karlsruhe with a focus on household behaviours such as shopping, eating and food preparation habits showed that

there are substantial differences between the food waste amounts calculated based on statistical data and the food waste amounts measured in household surveys. Additionally, the article described the lacking representation of lower-income classes, households with a lower educational level, people below 18 years and people above 60 years, because of the used methods and the nature of an online survey (Jörissen et al., 2015).

Giordano et al. (2019) estimated and analysed the determinants of food waste, through a diary and questionnaire study. Moreover, by comparing food waste values that were declared in questionnaires and reported in diaries, average deviations are determined. The results confirmed that the average food waste value is significantly higher when gathered through diaries, while questionnaires can catch less than one-third of food waste determinants (Giordano et al., 2019).

Motivations, attitudes and values are important factors when it comes to creating a positive change in user behaviour. They can encourage people to reduce food waste but heavily vary from person to person. For instance, the majority of people care more about saving money, thus being more motivated than they care about food shortages elsewhere in the world (Quested et al., 2013).

2.2 Mobile Apps for Behaviour Change

In an attempt to capture and reflect on reasons, experiences, and occurrences connected with food waste, Ganglbauer et al. (2015) established a digital mobile food waste diary for people to download. Eight hundred and three entries were submitted over a timespan of 18 months which concluded to the most popular reasons for food waste, most of them being linked to the phenomenon of overbuying (Ganglbauer et al., 2015). In the limitations of their work, they described the lack of qualitative studies caused by the absence of an obligation to register with an email address and password and therefore having no possibility to recruit the diary users for an in-depth interview study.

“Save the Kiwi” was a mobile app concept with a high emphasize on behaviour change and persuasive design theories. Instead of providing people with a platform to document already wasted food in the form of a diary, Aydin et al. (2017) focused on the lack of real-time food storage information in households. Furthermore, through positive as well as negative reinforcement, “Save the Kiwi” attempted to achieve emotional reactions and thus increased motivation (Aydin et al., 2017).

Helf & Hlavacs (2016) critically reviewed the health app landscape from several perspectives and propose seven primary solution directions to solve problems during the development and usage of mobile health apps for life change. Through gamification, success metrics and dynamically tailored interventions in mobile

apps as an instrument to increase user engagement, behavioural changes can be accompanied by positive experiences (Helf & Hlavacs, 2016).

An empiric approach by Tang et al. (2015) evaluated the major characteristics, features and behaviour change techniques to increase user engagement in the field of mobile e-health weight management apps. Two trained researchers asked 19 participants between the age of 18 to 40 years in semi-structured interviews about their experience with e-health weight loss apps, or weight loss maintenance apps. While nine participants had used or were currently using an e-health app, ten volunteered to use one of our recommended free apps, the remaining were offered free apps which they used for three weeks. The article suggests that the designers of weight loss apps should especially emphasis on related motivations, simple usage, appealing user interfaces and personal tailoring. Furthermore, features to increase user engagement and thus possibly positive behaviour change include goal-setting, self-monitoring, feedback, awareness of emotional consequences, symbolic rewards and social support (Tang et al., 2015).

Similar to Tang et al. (2015), the article *Mobile Health Apps to Facilitate Self-Care: A Qualitative Study of User Experiences* by Anderson et al. (2016) examined how consumers use apps for health monitoring, their observed benefits from the usage as well as suggestions for improvement. The twenty-two participants were using health apps to monitor health-related information such as diabetes, asthma, depression, celiac disease, blood pressure, chronic migraine, pain management, menstrual cycle irregularity and fitness. The study combined the three distinct frameworks TAM (Technology Acceptance Model), HITAM (Health Information Technology Acceptance Model) and MARS (Mobile Application Rating Scale) to evaluate health apps based on engagement, functionality, information management and ease of use (Anderson et al., 2016).

With a comprehensive study of user reviews of available mobile apps that support a reduction in alcohol consumption through electronic screening and brief intervention (eSBI) in combination with focus groups, Milward et al. (2016) concluded that future mobile app development should consider tailoring primary app elements to the needs of young adults. Especially broader well-being monitoring tools and online community functions could support a positive change in behaviour.

Furthermore, there are currently several mobile apps on Apple´s App Store as well as Google´s Play Store that attempt to provide tools for food management in households. Even though not all of these apps are directly aiming to reduce food waste, some of the included instruments such as shopping lists, storage overview and household communication tools can indirectly support people to positively change behaviour regarding food waste. Bring, a mobile app for iOS and Android,

lets users create shopping lists and subsequently share them with all household members. Additionally through notifications partners can communicate before and during the shopping process (see Figure 1). The NoWaste app aims to reduce food waste in households by providing an overview of the current inventory lists for the freezer, fridge and pantry (see Figure 1). While both of these stated apps merely focus on a single stage in the food management process, there are further mobile apps that try to combine these features. Out of Milk combines the creation of shopping lists before shopping with a comprehensive pantry list after shopping and allows users to share this information with friends and family (see Figure 1).

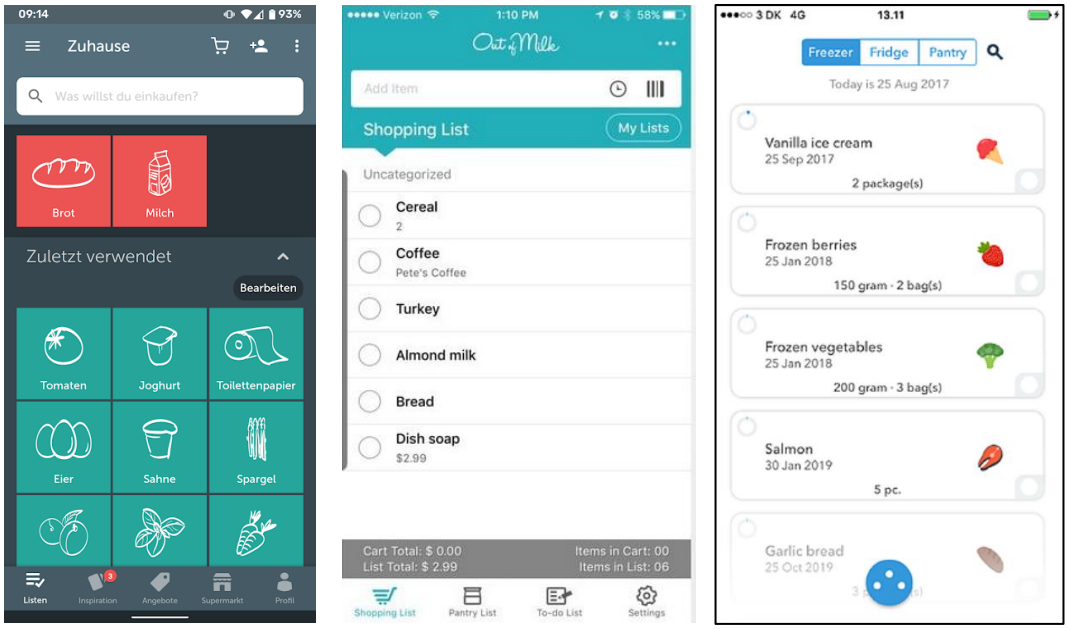


Figure 1. Screenshots of Bring (left), Out of milk (centre) and NoWaste (right)

3 Solution

The following sections highlight the implementation process of the solution. Initially, the primary user needs are defined to subsequently design an interactive prototype with Adobe XD. Afterwards, a first iteration of the prototype with just enough features to satisfy early testers is presented in the form of a Minimum Viable Product (MVP). The MVP is then implemented with Flutter as the frontend technology and Firestore as a serverless backend. The idea for this solution started to be conceptualized in collaboration with a group of international students before the start of this thesis. However, as part of this thesis, literature and market research, as well as the development of the mobile app, were started from scratch following a scientific methodology.

3.1 Defining the User Needs

Before the design and development processes were initiated, the target group and their main user needs were defined. Focusing on only one person or user group is not practical since applications usually have a variety of users and user roles which all need to be satisfied (Kujala & Kauppinen, 2004). After identifying the primary target group, the most common user needs among included people were outlined which lead to well-defined requirements. Kujala & Kauppinen (2004) also stated that all assumptions and preliminary descriptions about users should be tested as well as verified by field studies.

“At its best, user identification is based on both quantitative and qualitative information including market segmentation studies and field studies etc.“ (Kujala & Kauppinen, 2004).

3.1.1 Finding the User Group

Following the user group identification theory of Kujala & Kauppinen (2004), the user group was roughly defined through assumptions, increasingly refined following the literature research and finalized with a quantitative questionnaire along with qualitative user interviews before and during development. It was assumed that larger households produce more food waste considering there is a greater variety of diverse opinions and tastes among household members. Since usually not every member is involved in the food management process consisting of planning the purchase, buying the food and preparing the meals, someone´s taste might not be always satisfied. Also, due to the higher consumption in larger

households, more food products are bought and the food storage becomes more complex and thus harder to maintain. Furthermore, technical affinity, especially with mobile devices, was an important prerequisite to fully utilize the mobile solution. These assumptions led to the following group of potential users:

- Households with two or more members
- People between 18 and 50 in charge of food management
- In possession of an Android phone with access to the Google Play Store
- Affinity with technology

These assumptions were then set aside and reiterated through literature research. Even though larger households produce more food waste in total, households with only one person waste the most per capita (Jörissen et al., 2015) (Quested et al., 2013) (Hübsch & Adlwarth, 2017). According to Quested et al. (2013) people in four-person households generate approximately half the amount of food waste per capita compared to single-person households. Small households frequently mentioned large package sizes as a major driver for food waste (Jörissen et al., 2015). On the contrary, frequent causes for food waste in larger households include personal preferences of house members (I don´t like it) and cooking or serving too much due to miscommunication (Giordano et al., 2019). Hübsch & Adlwarth (2017) and Quested et al. (2013) stated that people over the age of 60 years waste the least.

Table 1. Alterations of the user group after research

Assumptions	Research
2P+ households	Include 1P households
People in charge of food management	Include all consumers (except children)
Age between 18 and 50 years	Age between 18 and 59 years

3.1.2 Identifying the Primary Needs

Through quantitative questionnaires geared towards the previously defined target group, the primary user needs were identified and defined more precisely. The questionnaire was compiled as a result of the literature review stated in Chapter 2 (see Appendix A). The demographic part of the questionnaire was largely influenced by Jörissen et al. (2015) and Giordano et al. (2019). While Jörissen et al. (2015) manage to effectively group participants by age and household sizes, Giordano et al. (2019) also take children in their field study into account. Motivation is a key factor for engagement and behaviour change, therefore, feasible motivators were investigated during the questionnaire by conducting the works of

Quested et al. (2013) and Aydin et al. (2017). The results of the questionnaire are shown in Chapter 4.1.

3.2 Prototype of the Solution

An interactive digital prototype was created with Adobe XD, a vector-based graphics software for designing interactive user interfaces for web and mobile apps (*Adobe XD*, 2016). The prototype was designed to simulate a mobile app that would help users to reduce the overall food waste during the three primary steps of food management in private households:

1. Shopping list to plan purchases
2. Storage overview to keep track of food
3. Recipes and member details to plan and prepare meals

3.2.1 Adobe Experience Design

Adobe Experience Design also is known as Adobe XD is a minimalist desktop app to design seemingly realistic user interfaces and prototype user flows through interactions (Schwarz, 2017). All screens of the prototype are represented by artboards within an unlimited canvas. When selecting an artboard or an element within an artboard, all its attributes are displayed in the inspector on the right side of the workspace. In contrary, included assets such as colours, fonts and UI elements are listed on the left side of the workspace. In the navigation bar, the user can switch between the designing window where artboards are created as well as designed and the prototyping window where the connections between screens are determined through different user-interactions (see Figure 2).

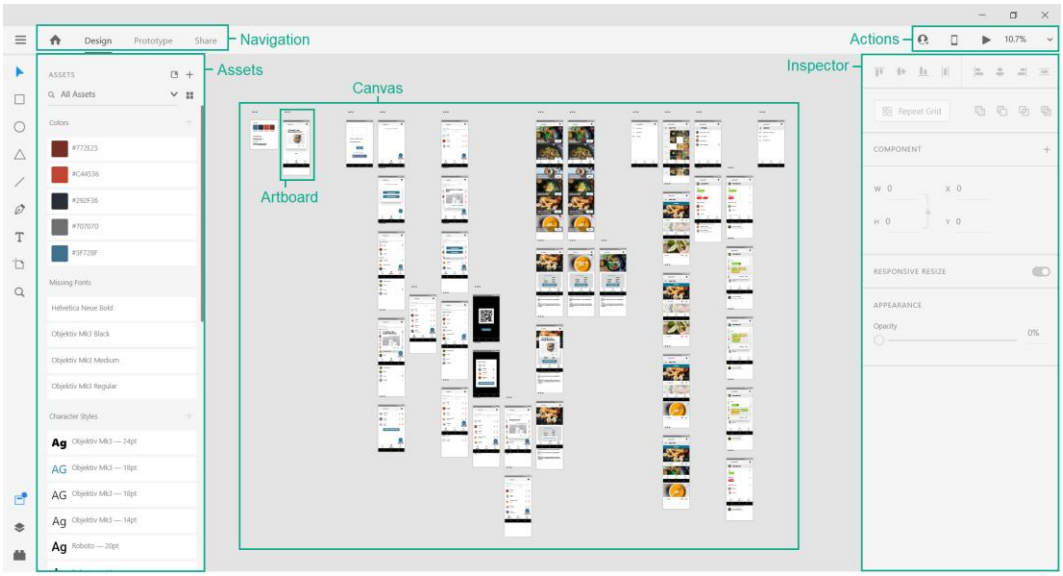


Figure 2. Screenshot of Adobe XD with the artboards of the prototype

3.2.2 Flow Chart

The flow chart demonstrates all the screens required for the intended solution, the screens they connect to and how the users will ideally navigate through the app. The initial prototype is made up of eleven screens in total without accounting for the additional notification dialogs. The four primary screens, being the shopping list, storage, recipes and household, are accessible from anywhere in the app with just one tap either through the bottom navigation or the top toolbar to ensure utmost efficiency while navigating through the app (see Figure 3).

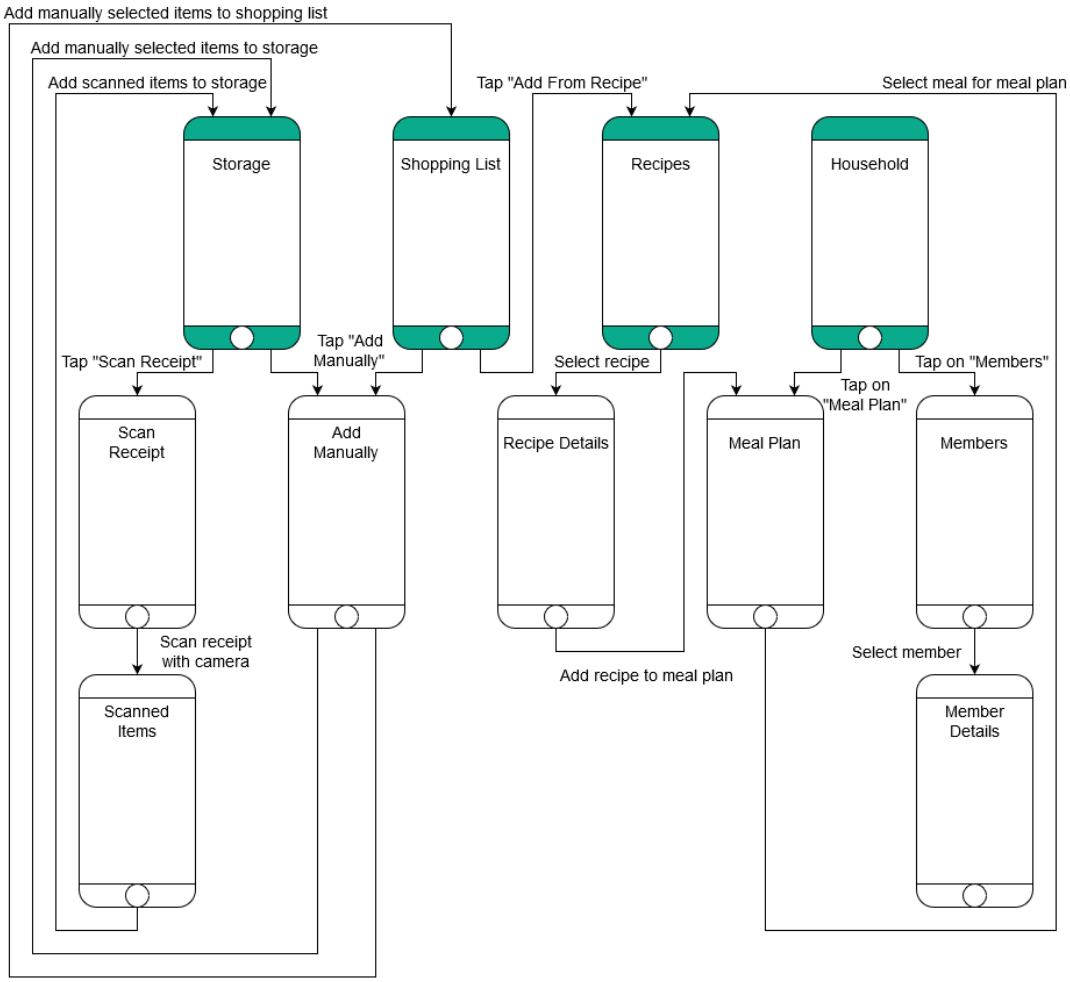


Figure 3. Flow chart of the prototype screens

Even though no login or register screen was realized for the flow chart nor the following interactive prototype, the required screen was eventually implemented during the development process of the mobile app.

3.2.3 Shopping list

The shopping list screen visualizes a simple list of food items with the possibility to check off bought items or remove unwanted items. By tapping the floating „Add Item“ button in the bottom right corner, users can fill the shopping list with food items. The user can choose to either add items manually from a list of predefined items or add them collectively from a selected food recipe (see Figure 4).

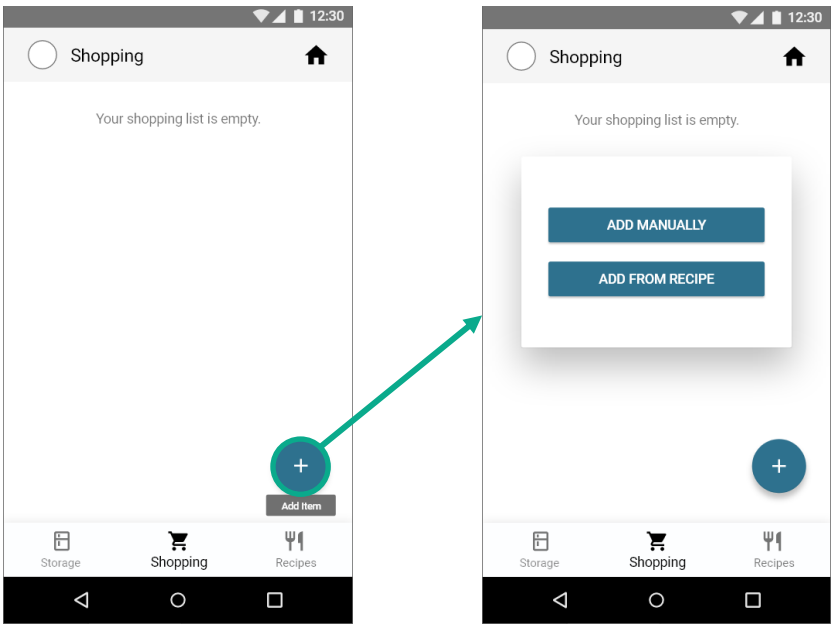


Figure 4. Tap "Add Item" on the prototype shopping list screen

When the user chooses the option „Add Manually“, a list of food items appears, including thirty predefined items that were researched to be among the most wasted food items of each category such as meats, fruits, vegetables as well as baked and dairy products. The user can then select all the required items and add them to the shopping list. Even though the predefined list of food items is fairly limited, it is planned to provide methods to let users extend the list with custom-created items. Furthermore, through a dialog, the user gets notified whenever he/she attempts to buy new products that are already saved in the storage to avoid unnecessary duplicate products (see Figure 5).

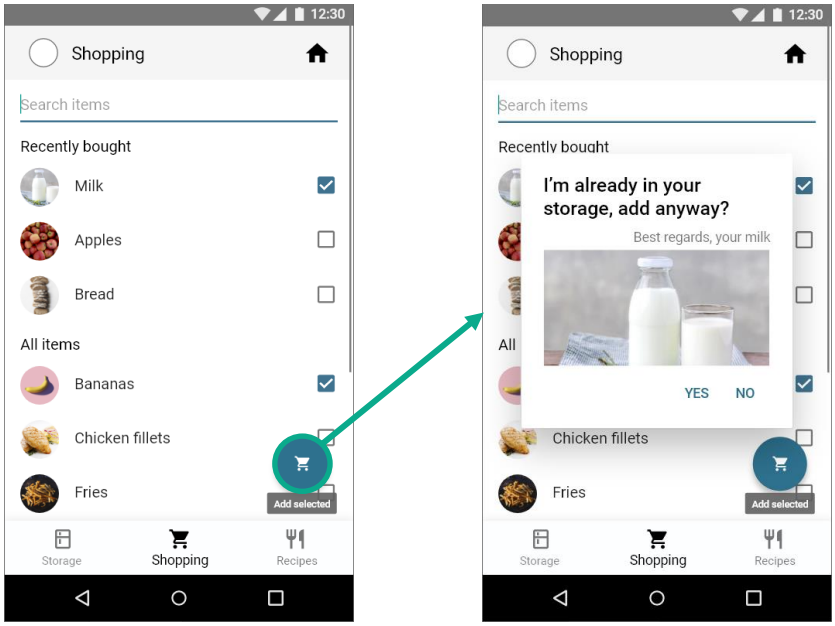


Figure 5. After tapping "Add Manually" on the prototype shopping list screen

After all necessary food items are selected and added to the shopping list, the user is presented with a simple overview (see Figure 6). The intend was to let users check off food items that are already in the shopping cart, similar to a real paper list, and collectively add them to the storage once the shopping process is finished. For the images of the food items, suitable free stock images were chosen for the time being.

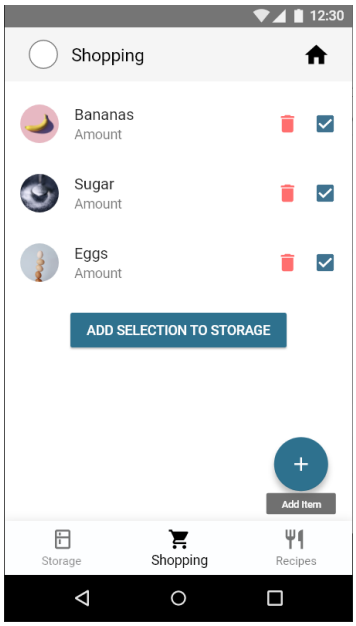


Figure 6. Overview of the prototype shopping list screen

3.2.4 Storage

On the storage screen, users can overview all food items that are presently stored at home along with the corresponding expiry date. Upon opening this screen, users are notified about soon expiring food items with the intention of providing recipe ideas in the process so users can consume all their food. To evoke negative emotions upon wasting food, the notification dialogs are presented as if the user would have a confrontation with the food item (see Figure 7). Thus functioning as a persuasive mechanism with negative reinforcements, which are effective in encouraging behaviour change (Aydin et al., 2017).

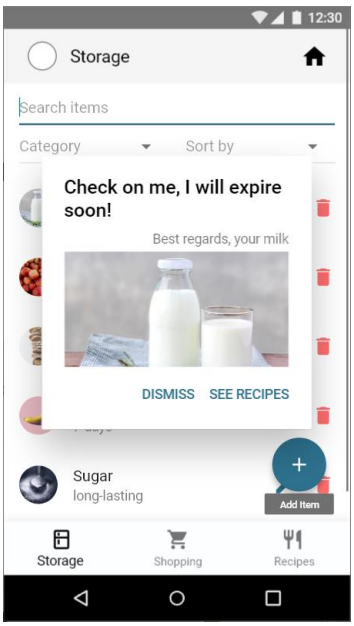


Figure 7. Expiration dialog on the prototype storage screen

In the upper portion, through text-search, category-filtering and sorting, the displayed items can be reduced to improve visibility. While text-search simply filters the food items by their name, category-filtering allows users to only display distinct categories such as meat, fruits, vegetables as well as baked and dairy products. The sorting function allows to rearrange items either alphabetically or by expiration date so users pay more attention to items that are about to expire. Although adding food items to the storage through the shopping list is considered to be best practice, users can also choose to add items manually from a list, equally to the previously stated process for the shopping list. Moreover, when users bought items without utilizing the provided shopping list, the purchase can be added collectively by scanning the receipt (see Figure 8).

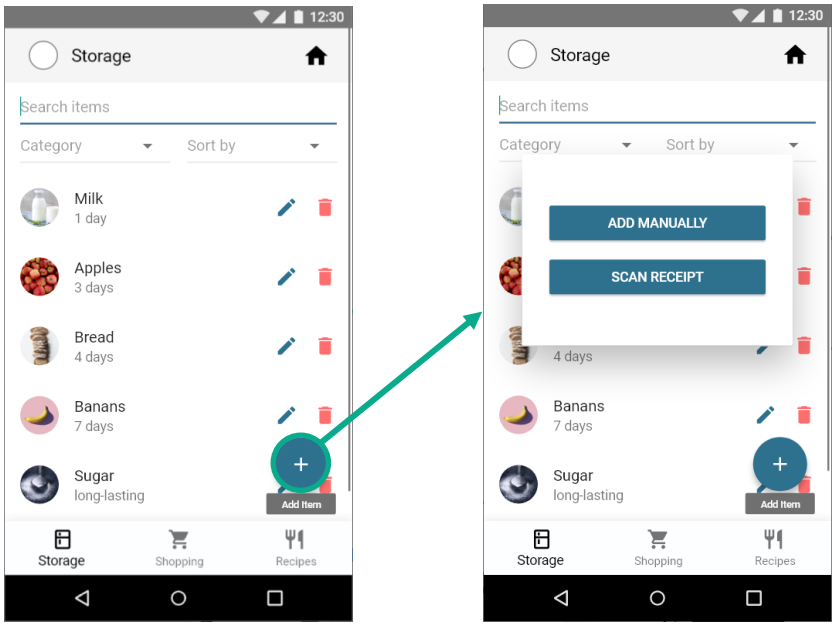


Figure 8. Tap "Add Item" on the prototype storage screen

When the user chooses the option „Add Manually“, the same list of selectable food items as previously shown for the shopping list screen appears (see Figure 5). Alternatively, in case the user forgot to use the shopping list, with “Scan Receipt” the received purchase invoice after shopping can be scanned to visualize a list of all identified items. Through checkboxes, the identified items can be selected and collectively added to the storage (see Figure 9).

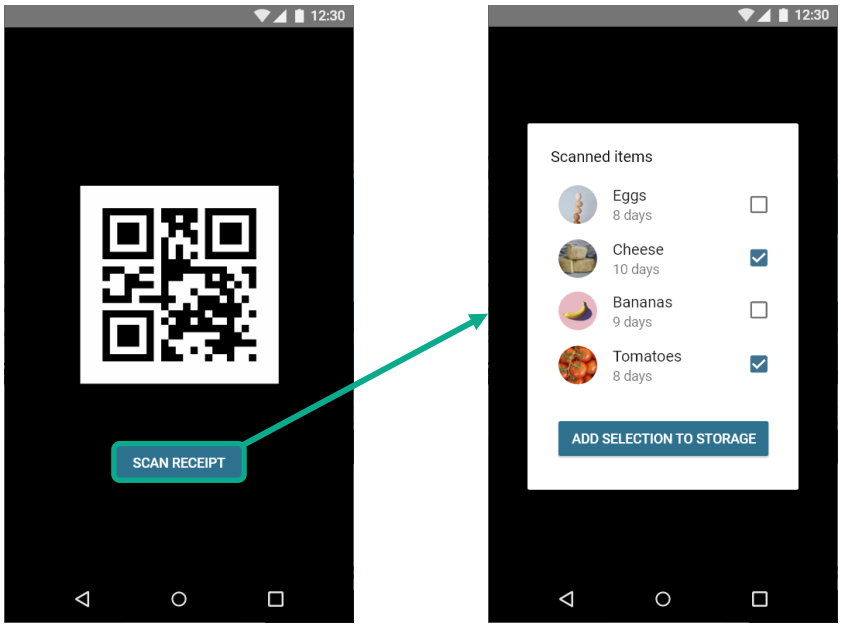


Figure 9. After tapping "Scan Receipt" on the prototype storage screen

In addition to small images, names and expiration dates of food items, each list entry features one icon-button for editing and one for removing an item. The

primary use case of editing an item is to change its expiration date, in case the user isn´t satisfied with the initial estimated expiration dates provided by the app. The number of days displayed below the title of the food item, count down from the initially estimated expiration days to zero. The interactive prototype did not provide the functionality to indicate a specific quantity state of a food item. Upon consuming or wasting a certain item, the food storage must be updated manually by removing the item. After tapping the delete-icon, a dialog opens that asks the user whether the item was consumed or wasted (see Figure 10). Therefore, consumed as well as wasted items are stored and later visualized in a simple graph to provide further statistics about the overall household consumption.

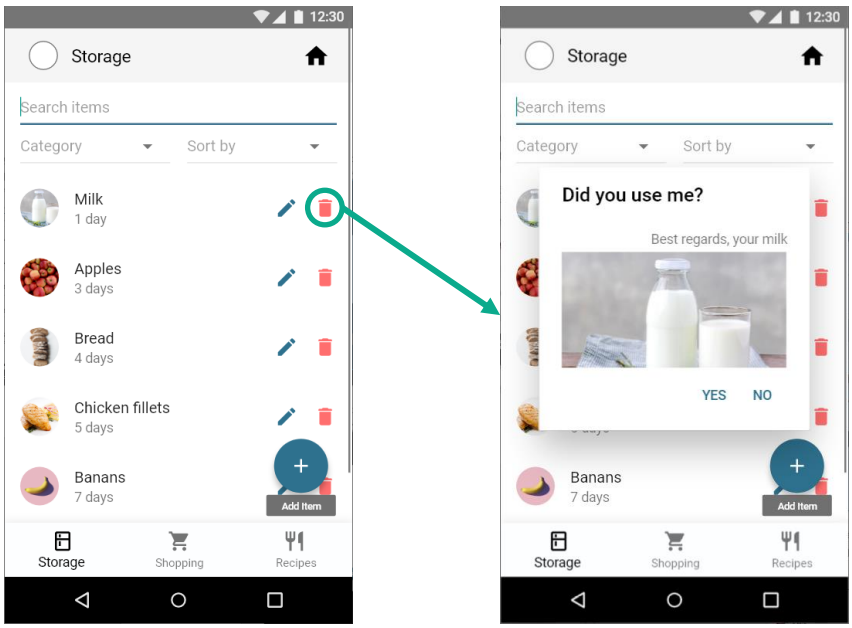


Figure 10. Overview of the prototype storage screen with remove dialog

3.2.5 Recipes

By scheduling meals ahead of time through provided recipes, food purchases are planned more precisely which results in less unnecessary items being bought. The second primary focus is to give users recipe ideas for food items they already have in their storage. Although only a small list of recipes is provided by the app initially, users will have the possibility to extend the existing data with custom-created recipes. Once a recipe is selected, the required ingredients, the total time for preparing and cooking the meal as well as the cooking instructions are displayed (see Figure 11).

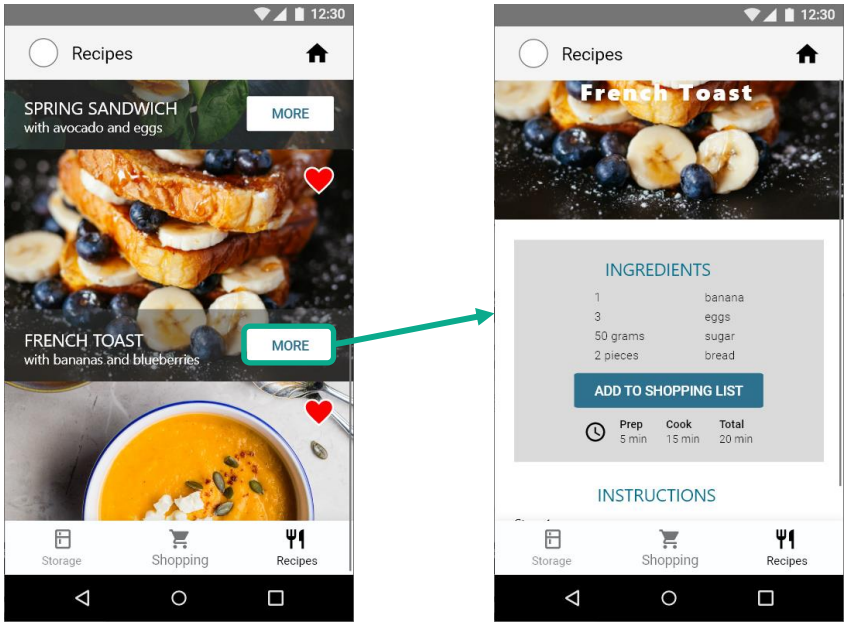


Figure 11. Selecting a recipe on the recipe prototype screen

In case one or more of the required ingredients for the selected recipe are already present in the storage, the user is notified through a dialog and can choose if the item is necessary (see Figure 12).

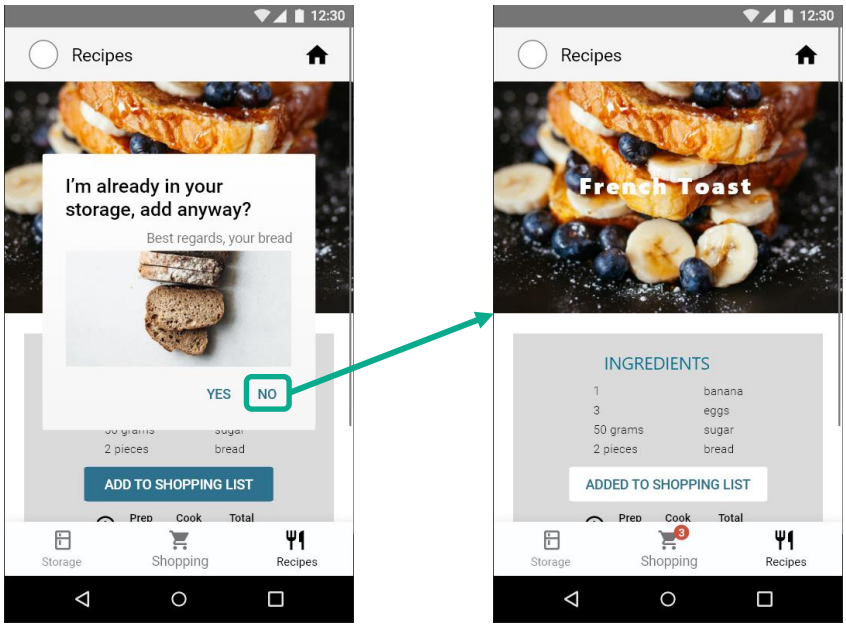


Figure 12. Adding ingredients of a recipe to shopping list

3.2.6 Household

All household members, consisting of one or more people living together in the same household, along with the meal plan can be managed within the household screen. Up to three meals including breakfast, lunch and dinner can be planned for every day (see Figure 13). Once a meal slot is selected, the user is prompted to the recipes screen where a specific recipe can be viewed and assigned.

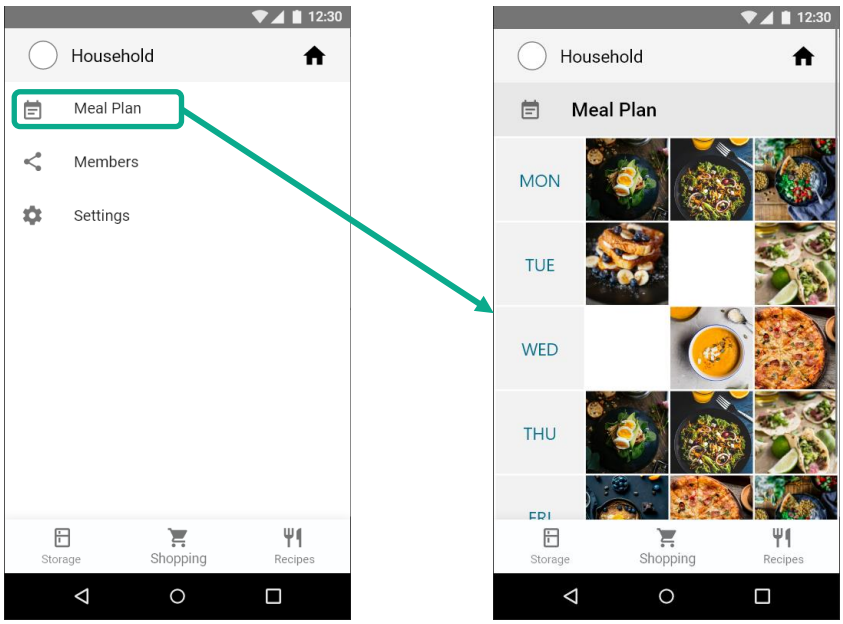


Figure 13. Tapping "Meal Plan" on the household prototype screen

In the members screen, a list of all currently existing household members can be viewed. When selecting a specific member his diets, allergies and favourite food items are displayed to support the person responsible for food management during the planning of the purchase and the preparation of the meals (see Figure 14).

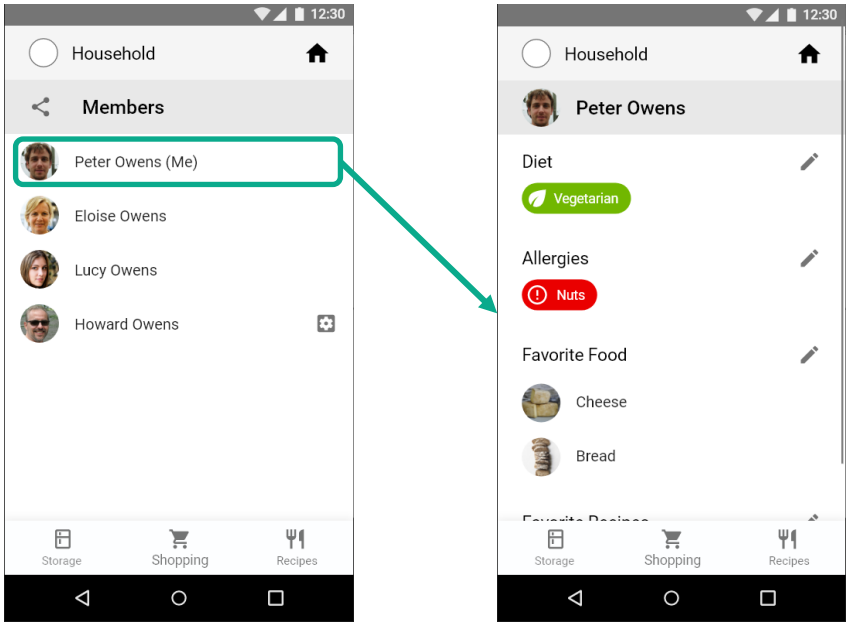


Figure 14. Tapping "Members" on the household prototype screen

3.2.7 Minimum Viable Product

Through qualitative users tests and focus groups (see Chapter 4.2), the prototype was reduced to a Minimum Viable Product (MVP) that was still able to meet the most crucial user needs and expectations. Even though an MVP has limited functionality, the product must continue to meet requirements by addressing three higher-level attributes being reliability, usability as well as delight (Olsen, 2015, p.90). Agile development during the prototyping process with an iterative and incremental approach helped to reduce the overall prototype to a more realistic MVP and additionally shortened the time from conception to implementation (Duc & Abrahamsson, 2016). The biggest change of the MVP involved the removal of the recipe functionality including the search for recipes and the creation of meal plans. This allowed for a deeper focus on the major aspect of the solution – the storage overview. By encouraging the utilization of the shopping list as the main way to populate the storage with food items, food waste can be avoided preemptively. Furthermore, by putting a bigger emphasis on the household sharing that allows for a collective usage, household members that are not strongly involved in the food management process acquire a deeper understanding on how food is handled in the household. Therefore, these are the new major aspects of the application:

1. Shopping list to plan purchases
2. Storage overview to keep track of food
3. Household sharing to use the app together

The prototype of the MVP is made up of eight screens with the three primary screens being the storage, shopping list and household (see Figure 15). The household icon replaces the navigation item for the recipes screen in the bottom navigation.

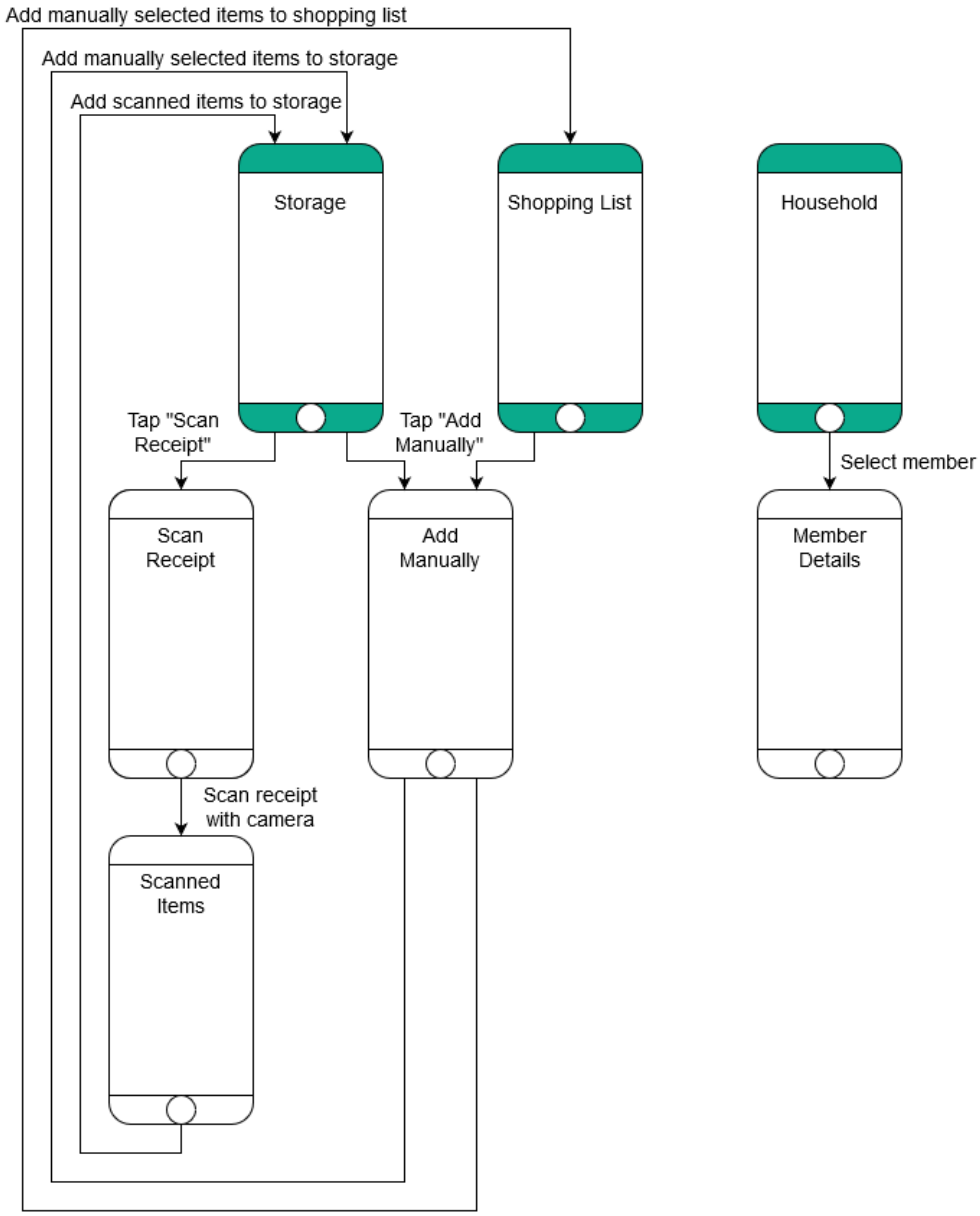


Figure 15. Flow chart of the MVP prototype screens

Moreover, a flag-icon for the purpose of marking almost empty food items was added to the storage screen. The intention was to provide a simple and efficient method to visualize items of interest for the next shopping tour without the need for frequently updating the quantities of each item (see Figure 16).

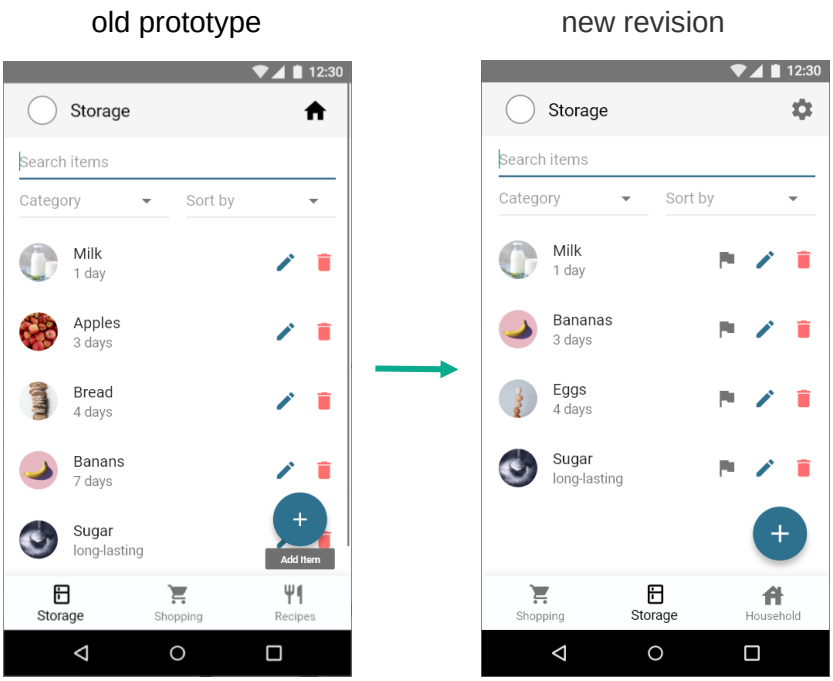


Figure 16. Update of the prototype storage screen

Lastly, icon-indicators to visualize whether food items are already present in the storage, the shopping list or whether they are flagged in the storage overview were added to the add manually screen. Additionally, by removing the bottom navigation in sub-screens, the overall amount of food items displayed at a time was slightly increased (see Figure 17).

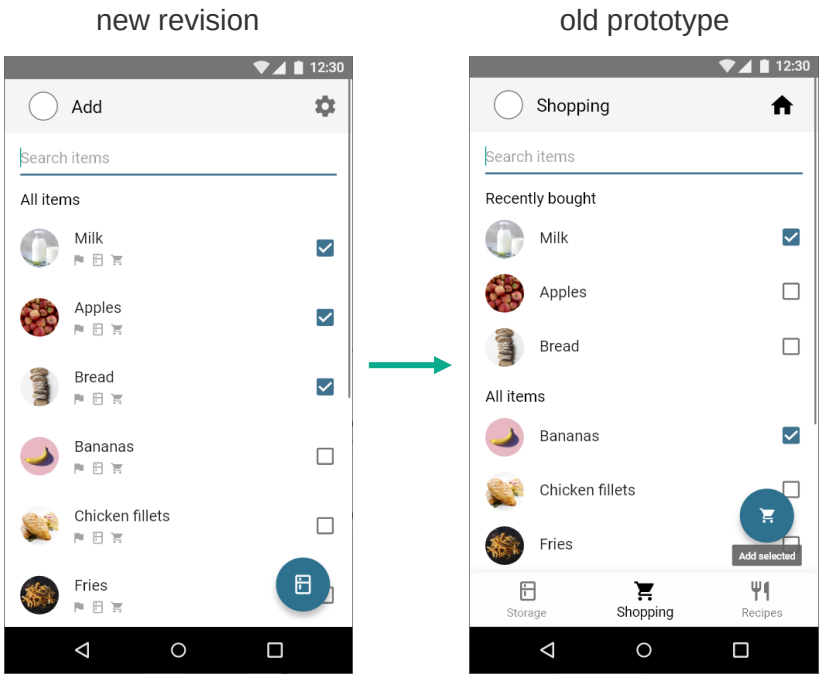


Figure 17. Update of the prototype add manually screen

3.3 Development of the Application

The mobile application, based on the model of the MVP, was developed using Flutter, a UI toolkit for building natively compiled applications for mobile, web and desktop from a single codebase (*Flutter Docs*, n.d.). User data sent from the mobile app is stored in Firebase´s Firestore, a flexible, scalable real-time database for mobile, web, and server development (*Firestore Docs*, n.d.). In addition to Android, both Flutter and Firebase are developed or backed by Google, thus resulting in great compatibility.

3.3.1 Flutter

By providing a state-of-the-art react-style framework, a 2D render engine, pre-made widgets and essential development tools, Flutter supports developers with designing, building, testing, and debugging applications. The overall goal of Flutter is to empower developers to develop apps that feel natural on multiple different platforms by embracing differences in scrolling behaviours, typography, icons, and more (see Figure 18).

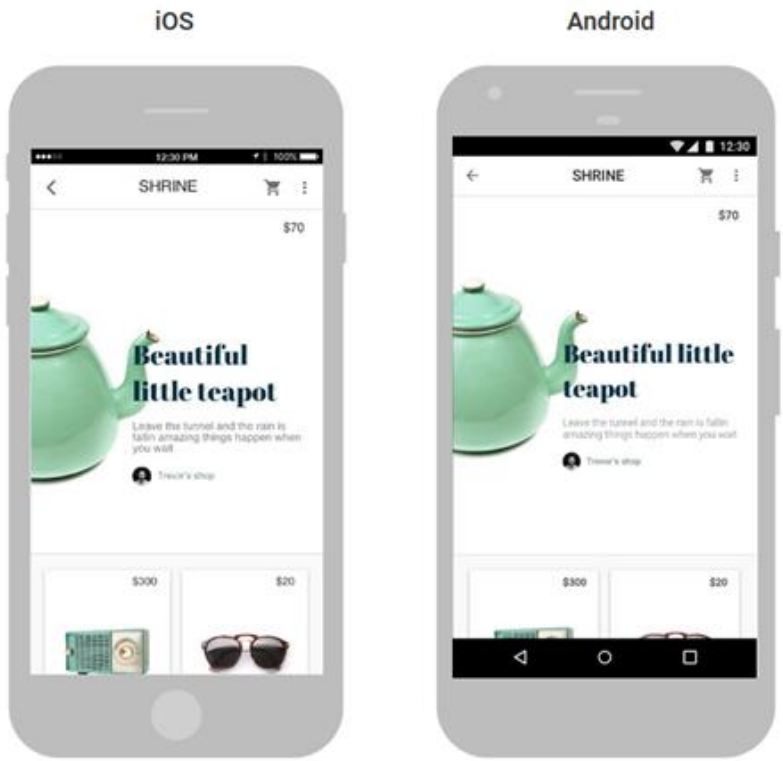


*Figure 18. Demonstration of an app on iOS and Android (*Flutter Docs*, n.d.)*

User interfaces of Flutter applications are compiled of numerous widgets. Each widget is an immutable building block of the overall user interface. Unlike other frameworks that separate views, view controllers, layouts and other properties,

Flutter utilizes the widget as a consistent, unified object model. They are used to define structural elements like a menu, stylistic elements like a font or layouts like padding. Instead of inheritance, Flutter emphasizes composition, meaning that widgets are often composed of several smaller widgets. For instance, to centre a button-widget, the button is wrapped in a pre-made centre-widget. Additionally, Flutter distinguishes between stateless widgets that do not require a mutable state and stateful widgets that have a mutable state (see Figure 19). Stateful widgets are useful when the intended part of the user interface dynamically changes, for example, due to pressing a button or modifying another state. In contrary, stateless widgets are used to describe static contexts that do not depend on anything other than the configuration information.

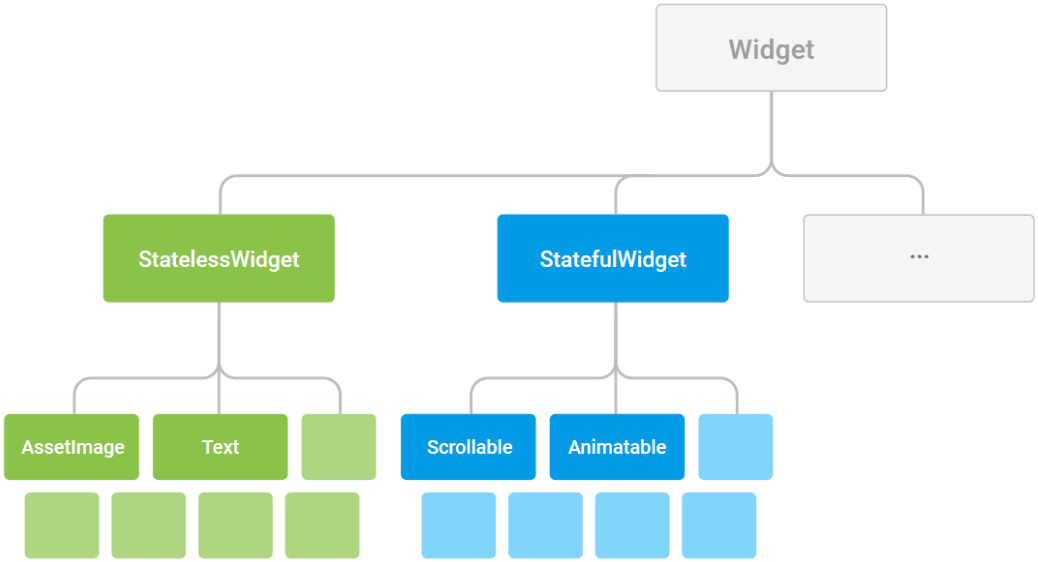


*Figure 19. Hierarchy of widgets in Flutter (*Flutter Docs*, n.d.)*

The framework itself is organized into several different layers that all build upon the previous layer. Thereby, the Material layer is built by composing basic widgets from the widgets layer below, and the widgets layer itself is built by orchestrating lower-level objects from the rendering layer (see Figure 20). Flutter provides the productivity benefits of a high-level, unified widget concept, without sacrificing the ability to dive more deeply into the lower layers (*Flutter Docs*, n.d.). The programming language used by Flutter is Dart, an object-oriented, class-based, garbage-collected language and supports interfaces, mixins, abstract classes, reified generics and type inference. Dart can compile to either native code or JavaScript code for web (*Dart Docs*, n.d.).

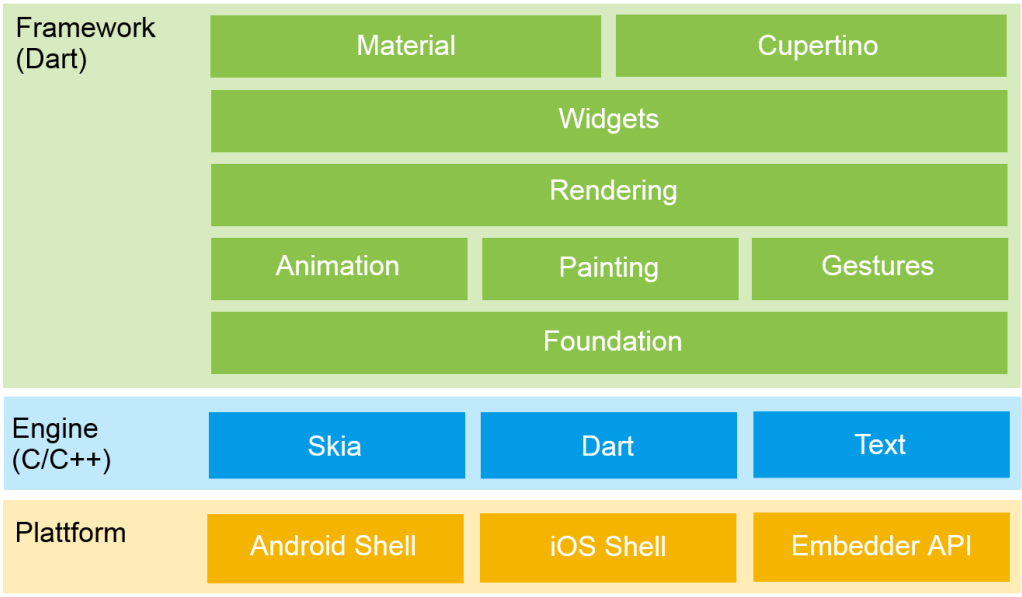


Figure 20. Technical layers of the Flutter framework

Even though Flutter would allow simple deployment for Android as well as iOS from a single-codebase, due to the limitation of resources in this work, the mobile app was only deployed for Android phones on the Google Play Store.

3.3.2 Firestore

Firebase is a development platform including nineteen different products such as hosting, storage, authentication, machine learning that are all geared towards the development of mobile and web applications. Among those products is the Firestore, a cloud-hosted real-time NoSQL database that keeps data in-sync across multiple client apps through realtime listeners. Additionally, through offline support for mobile and web, applications are responsive regardless of network latency or Internet connectivity (*Firestore Docs*, n.d.).

The data in Firestore is stored in documents, which themselves are organized into collections. Collections are solely containers for documents, for instance, a users collection that contains various users, each user represented through a user document (see Figure 21). Documents are lightweight records with unique names that can contain numerous key-value pairs like subcollections, nested objects and primitive fields. Firestore has a free quota including 50,000 document reads and 20,000 document writes per day, thus the communication between the app and the database had to be fairly efficient to reduce unnecessary requests.

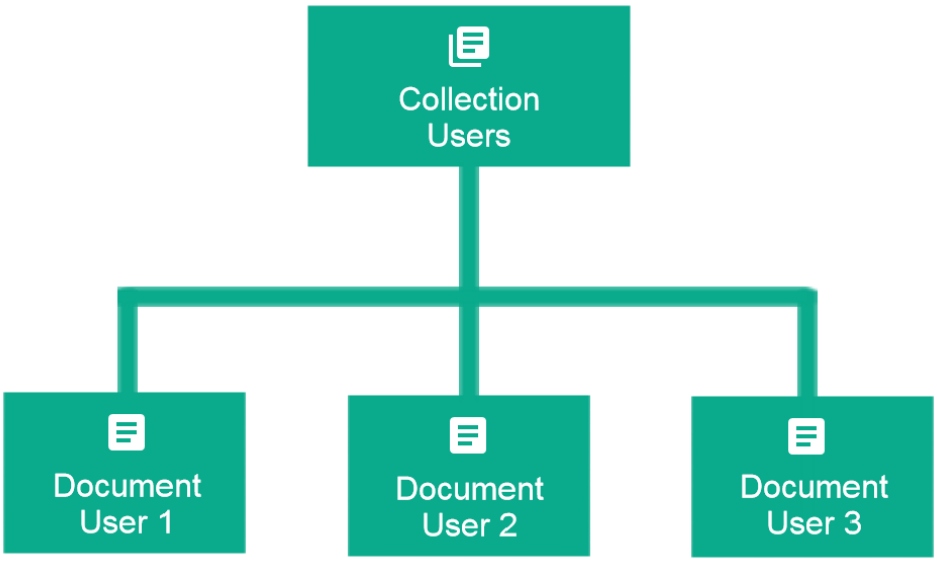


Figure 21. Relationship between collections and documents in Firestore

When requesting the data of one or multiple documents stored in Firestore, a snapshot is created containing the initial contents of the documents. Then, each time the contents change, another call updates the snapshot and keeps the data in sync. Firestore provides powerful query functionality for specifying which documents need to be retrieved from a collection. The provided query method takes three parameters being a document field to filter on, a query operator and a value (see Figure 22). Query operators include <, <=, ==, >, >=, array-contains, in, or array-contains-any.

```
collection("users").where("isOnline", "==", true)
```

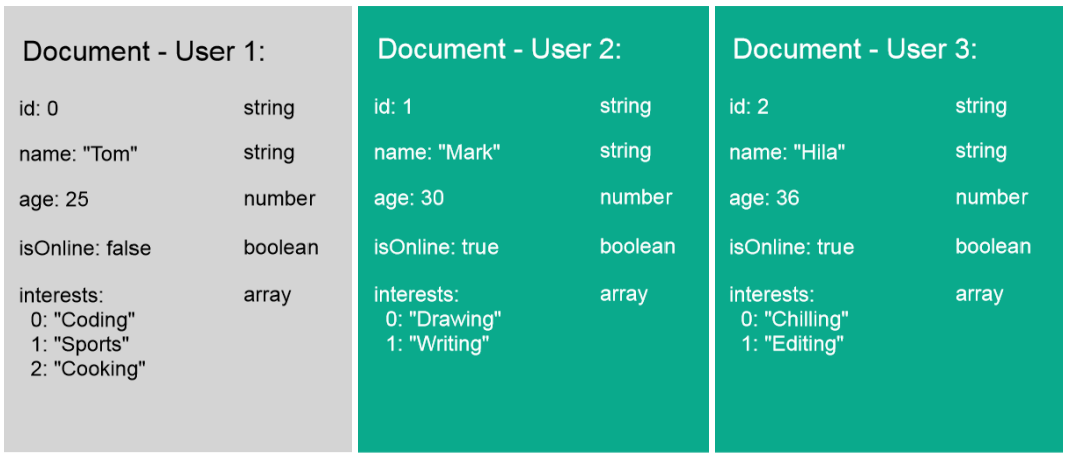


Figure 22. Example of querying user documents in Firestore

3.3.3 Model Diagram

There are three primary models required for the Minimum Viable Product including the *Household* model representing the collective household, the *Member* model representing individual members of a single household and the *Item* model representing the food items (see Figure 23).

Household

Users have the option of either creating new households or joining existing ones, implying that each household only requires one set of credentials. Every *Household* has a unique id that reflects the id of the corresponding document stored in Firestore and several aggregations of the *Member* as well as the *Item* model in the form of lists. While there is only one list of the *Member* model, containing each individual member assigned to the *Household*, there are multiple lists of the *Item* model such as the current storage, shopping list, user-created items and the entire list of wasted items to gain more insights into food waste behaviour. Additionally, the overall number of used items is stored to calculate the average amount of food waste in percentage.

Member

Instead of each member being an individual user with unique credentials, members are merely additional optional data to the household. The *Member* model contains crucial information of each member through providing a list of the current diets, possible allergies and favourite food items. These properties are intended to support the people in charge of food management to improve planning by learning about the eating habits of each household member.

Item

All food items are represented by the *Item* model containing multiple properties for sorting as well as querying such as a name, category, days since it was added to the storage and a quantity state being one of the three states *low*, *half* or *full*. By providing an estimated amount of days until the food item will expire and a timestamp of the date the item was added to the storage, users can be notified when items are about to reach the critical amount of days. For instance, when the bananas have an *initExpDays* value of 10 days and were added 9 days ago, the app can detect that the critical day is tomorrow. Furthermore, every food item has a set of *boolean* values to detect whether the item is currently selected, already in the shopping list and/or currently in the storage to avoid buying unnecessary food products. The *Item* class has an instance method called *reset()* to reset all boolean values.

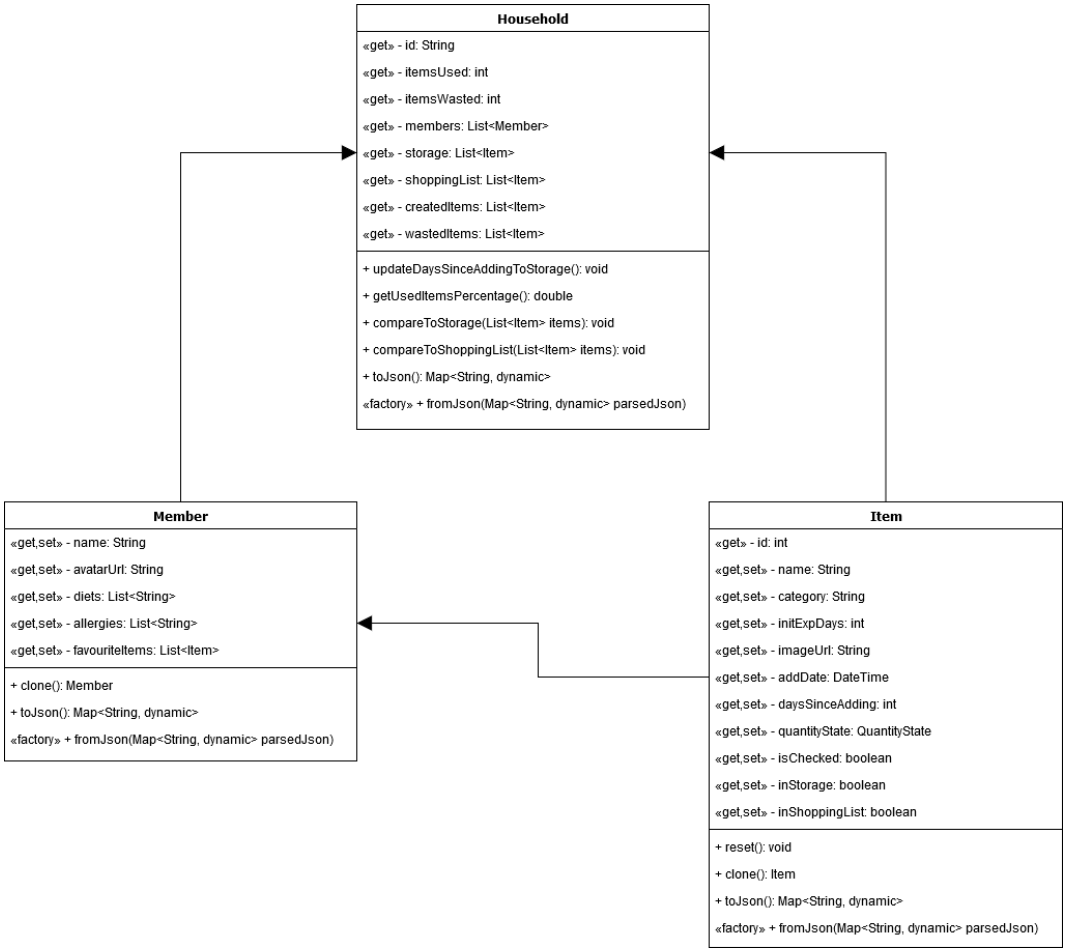


Figure 23. Diagram of the primary app models

Additional instance methods common among multiple classes include the *clone()* method which allows creating a new independent deep copy of an object with a new reference pointer. While the factory *fromJson()* deserializes incoming data from Firestore, the *toJson()* method serializes an instance before sending it back to Firestore.

3.3.4 The Application

Following the final user testing of the MVP prototype, the solution was implemented with Flutter and Firestore. Throughout the user-centred development approach, a method to involve users in the design process (Abras et al., 2004), changes were made to the overall appearance of the screens and further functionality was added. Additionally, from this point on, every user test was conducted using a working development state of the mobile app on an Android phone, following the best practices of an iterative development process through interviews, focus groups, observations and role-playing (Abras et al., 2004).

3.3.4.1 Login

Since there was no simulated login process in the previous prototypes, a simple login screen was created in Flutter with the options to either create a new household or join an existing household. The ID of a household must be unique as well as between the length of 5 and 30 characters. The household is protected with a personal identification number (PIN) of exactly 5 digits (see Figure 24). Having to create only one account per household was a conscious decision to keep the threshold to use the app as low as possible.

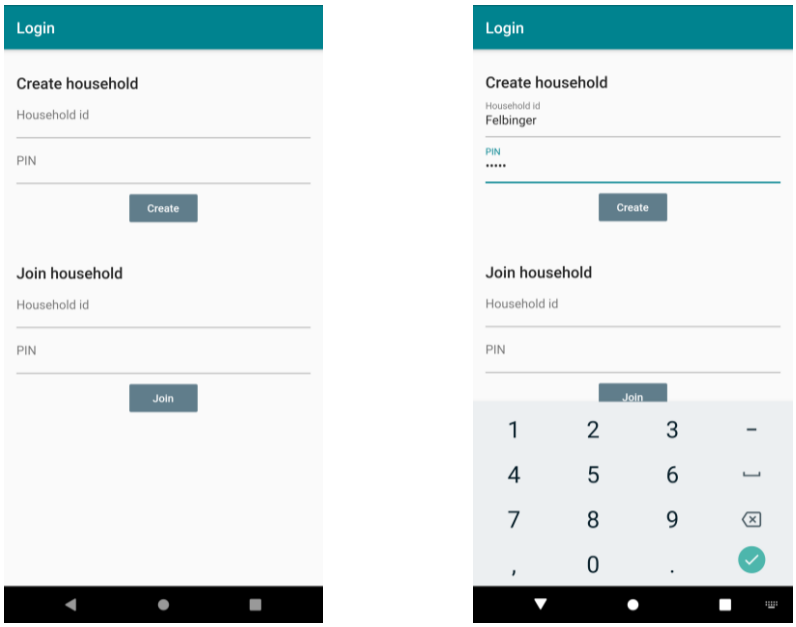


Figure 24. Login screen of the app

Even though this way of authenticating people was not the most method, it was still considered to be secure enough for the upcoming closed user tests and further helped to shorten the development time for the first real testable version of the app.

3.3.4.2 Storage

Following the successful authentication, the landing screen, represented by the storage, is displayed. The storage is now the focal point of the solution with the shopping list and the household sharing feature serving as a support to simplify the process of adding new items to the app. Furthermore, all major screens now feature a simple help dialog to explain all included elements and icons of the screen (see Figure 25). While the app is able to dynamically adjust the language to English or German, based on the system language settings of the Android device, the help dialogs were only implemented as static images with German text since it was the native language of all testers.

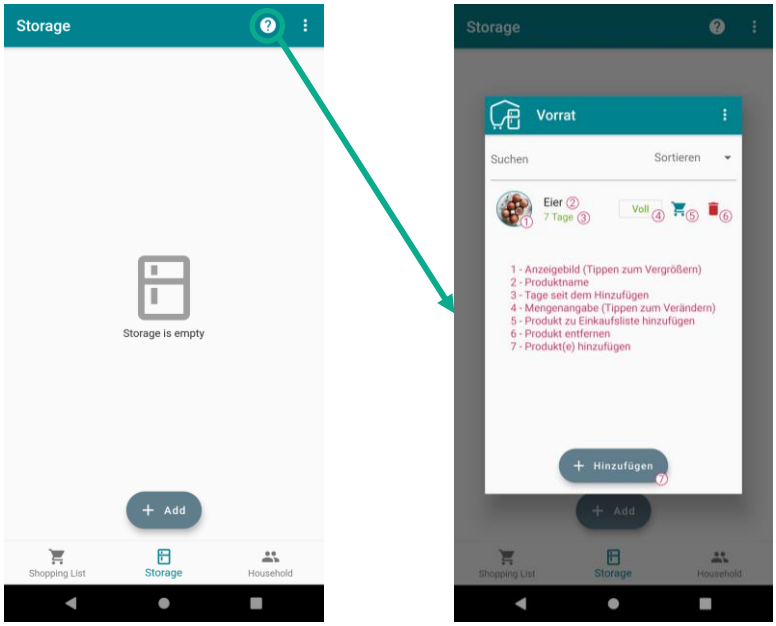


Figure 25. Opening the storage help dialog

The process of adding food items manually to the storage by selecting items from a list remained true to the prototype. The scanning of a receipt from the prototype has been postponed for now. Further modifications include the replacement of the flag icon-button to highlight almost empty food items with a dedicated text-button to toggle between the three quantity states *full*, *half* and *empty*. To increase the user experience, a shopping cart icon-button was added to the storage which allows to quickly re-add items to the shopping list (see Figure 26).

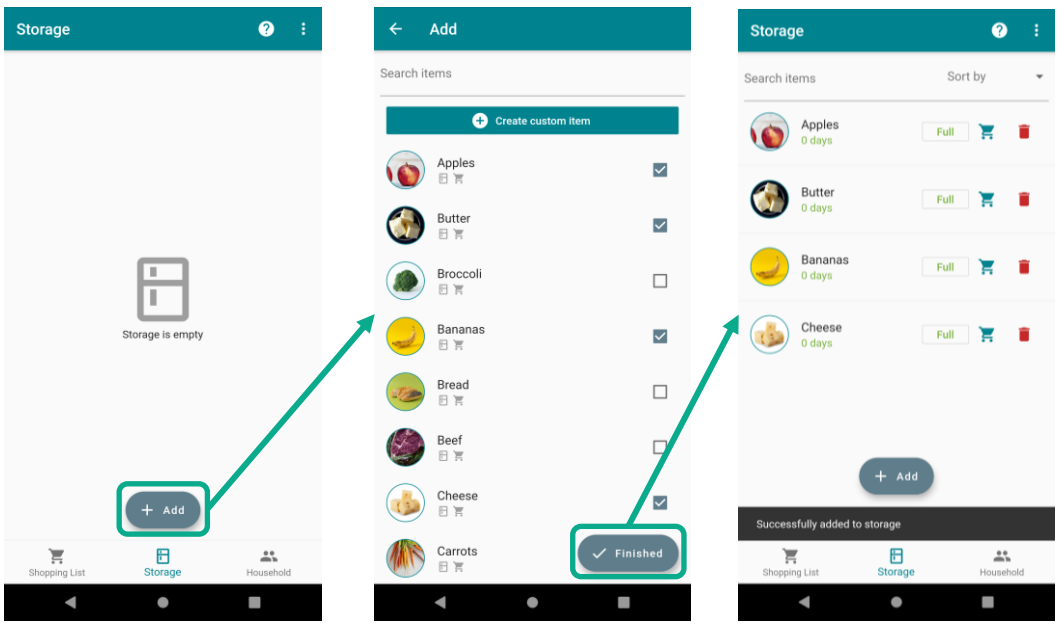


Figure 26. Process of adding food items to the storage

Food items in the storage can be sorted either by alphabet, days since adding or quantity state. Moreover, the days displayed below the name of each item indicate

the number of days since the item was added to the storage (see Figure 27). When the displayed amount of days correspond to the estimated days until expiration, the colour of the text will change from green to orange.

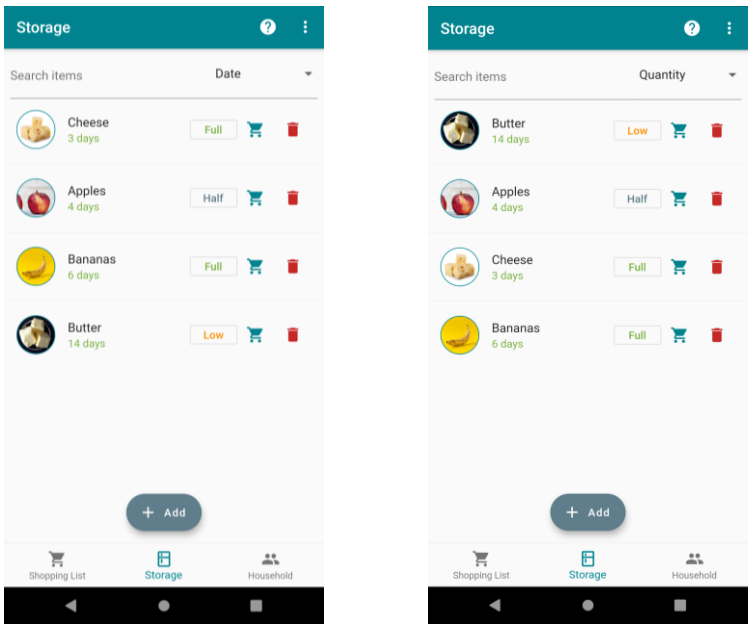


Figure 27. Sorting of the food items in the storage

Before removing an item from the storage, users are prompted to specify whether they have used or wasted it to collect essential data (see Figure 28).

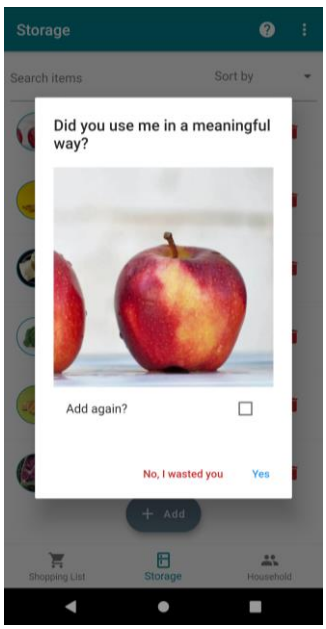


Figure 28. Removing an item from the storage

3.3.4.3 *Shopping list*

Similar to the storage screen, the shopping list screen has a dedicated help dialog to explain all present elements (see Figure 29).

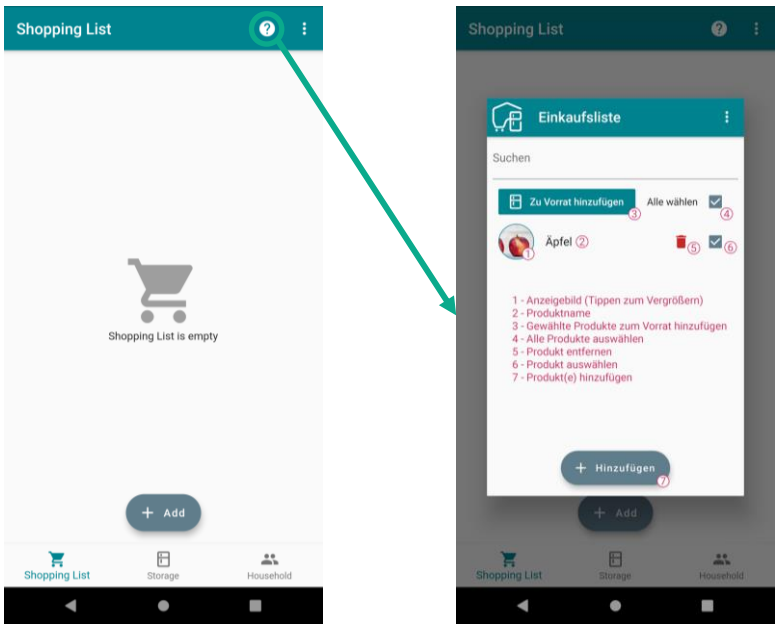


Figure 29. Opening the shopping list help dialog

After adding food items to the storage through a manual process as previously shown for the storage screen, the user has a straightforward shopping list where items can be checked upon buying or simply removed (see Figure 30).

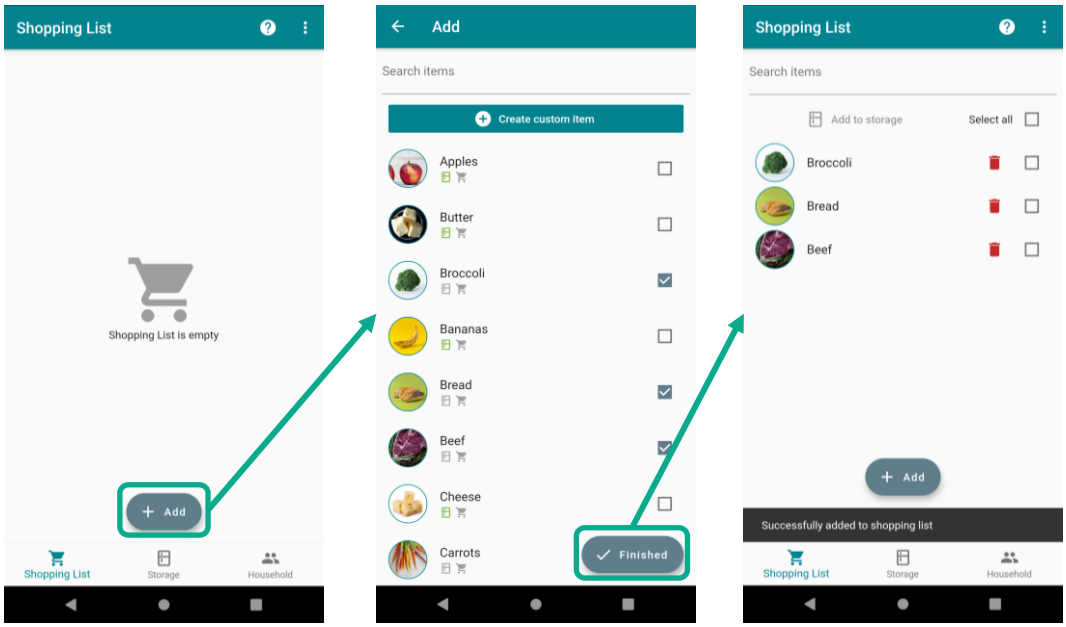


Figure 30. Process of adding food items to the shopping list

Once the user has finished the shopping tour and all purchased items have been checked off from the digital shopping list, the entire list of selected items can be

added to the storage with just one button press (see Figure 31). Unselected items are not removed from the list and remain in the shopping list for the next possible shopping tour.

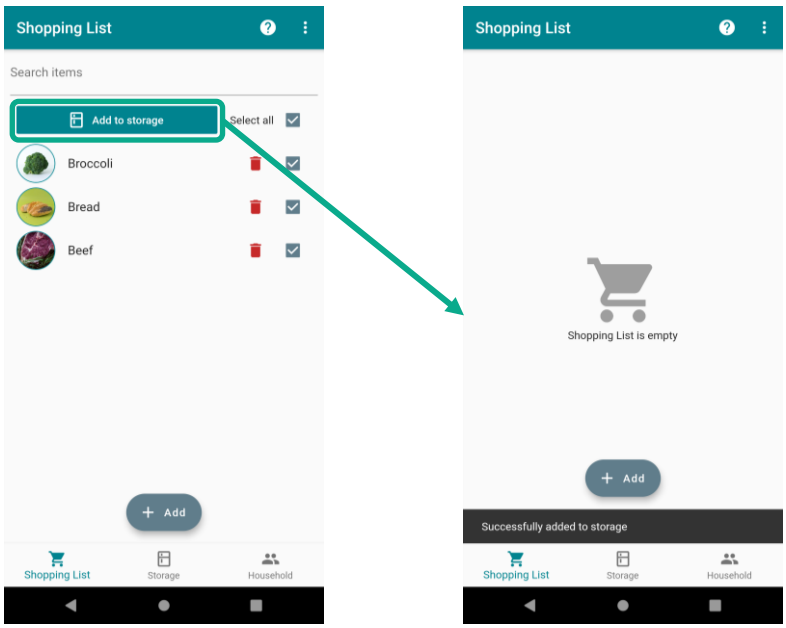


Figure 31. Adding all items from the shopping list to the storage

3.3.4.4 Household

Corresponding to the storage and the shopping list, the household screen also includes a basic help dialog (see Figure 32). In comparison to the storage and the shopping list, the household has iteratively changed the most across all development states. The screen features a simple pie-chart visualization presenting the relation between consumed and wasted food items in percentage through collected data. Therefore, attention is drawn to personal food waste, possibly leading to increasing awareness for the current problem in their household (see Figure 32).

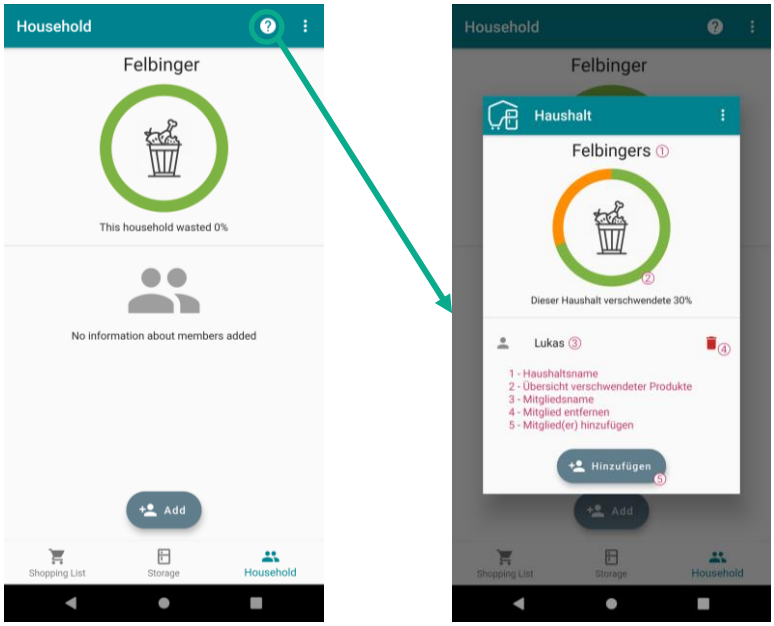


Figure 32. Opening the household help dialog

As previously mentioned, members are not represented by registered users, but actual members of the household. This implies that members can be added to the household even though they are not using the app themselves for instance children. Therefore, genuine users of the app can reconcile meal and shopping plans by examining the food preferences including diets, allergies and favourite food items of every manually added member (see Figure 33).

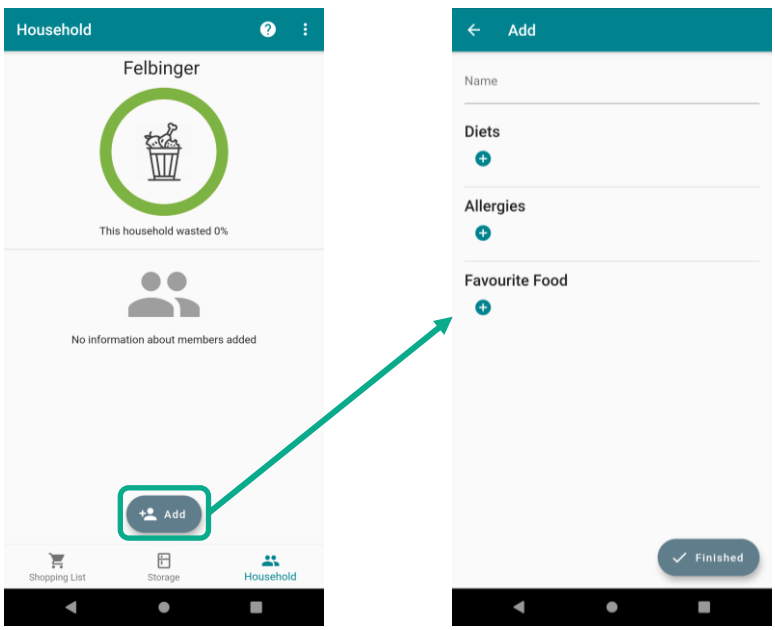


Figure 33. Process of adding members tot he household

Diets, allergies and favourite food items are selected through basic list dialogs that allow choosing multiple options (see Figure 34).

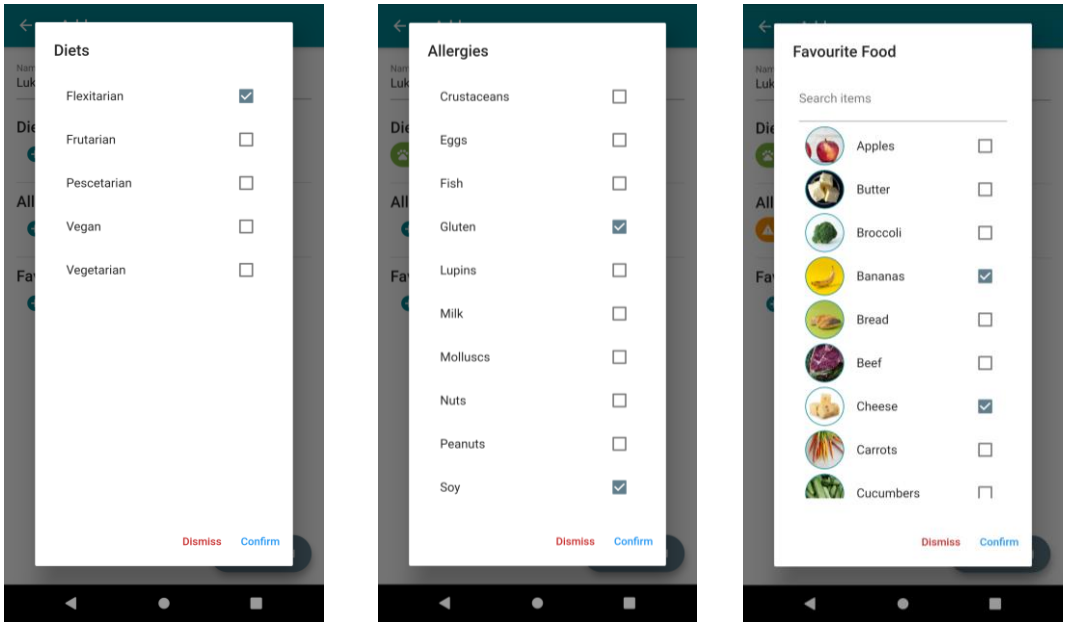


Figure 34. Configuring diets, allergies and favourite food items

Once all required information of a member has been filled in, he can be added to the household (see Figure 35). Furthermore, when the food preferences of a member change, they can be simply edited by selecting the specific member and following the same process.

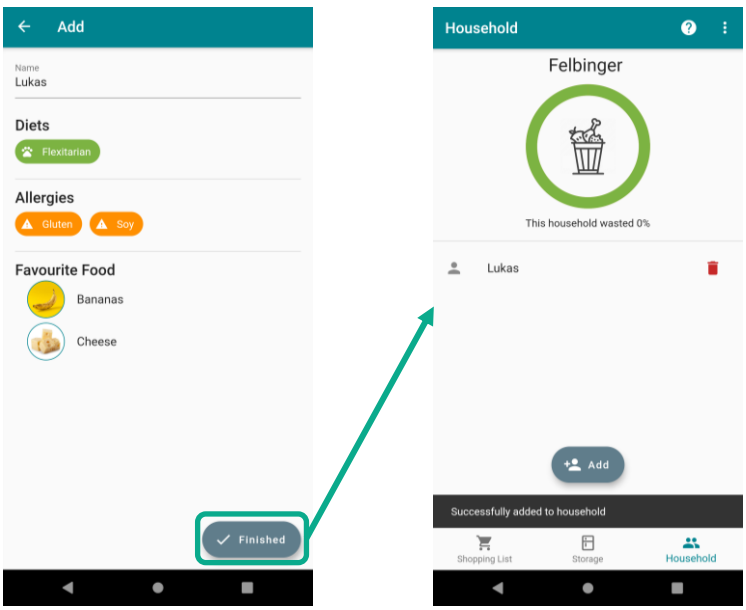


Figure 35. Adding a member to the household

3.3.4.5 Create Item

Although initially, solely 30 researched food items are provided by the application, the list can be extended by creating custom food items. On the same screen where items can be added manually to the storage and the shopping list, the button to

create an item can be found. Required fields include a name and estimated durability in days of the item (see Figure 36).

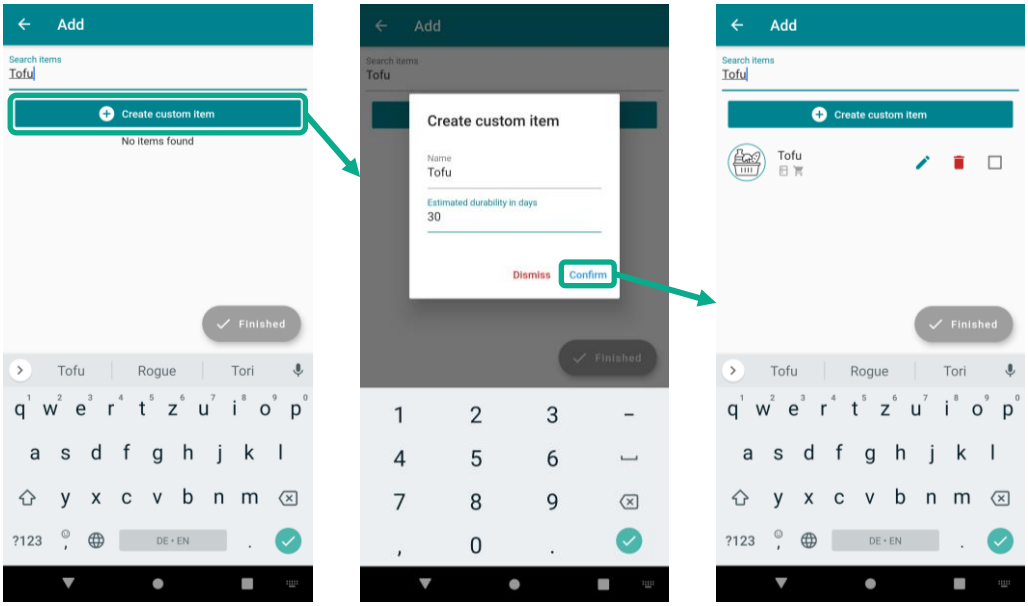


Figure 36. Process of creating a new item

4 Assessment

Throughout planning and developing the solution, several methods of assessment including field studies, focus groups, usability tests as well as a long-term assessment were performed in the process. This chapter demonstrates how these methods were designed, conducted and their major results.

4.1 Validation of the User Needs

4.1.1 Household Demographics

The primary user needs of the defined user group were determined with a quantitative questionnaire. Seventy-two (59.7% female, 40.3% male) households from Austria completed the questionnaire concerning the current food waste situation within their private household that was sent out through email, social media, food-sharing groups and messaging-services. Due to the nature of an online questionnaire especially in combination with social media, the biggest portion with 66.7% of participants was between the age of 18 to 30. Followed by the age groups 31 to 40 with 22.2%, 41 to 40 with 6.9% and 51 to 60 with 4.2%. None of the participants was over the age of 60 years. The average selected competence with technical devices was 3.88 (SD: 0.94) points with a possible selection range from 1 to 5 points. It should be stated that age, gender and technical competences are assigned to the person who answered the questionnaire, on the contrary, answers about food waste quantities and consumption habits are usually for the entire household. Analogous to Jörissen et al. (2015) and Giordano et al. (2019), two-person households have the biggest share with 45.8%. Single-person households and households with four members have the same percentage with 19.4% followed by three-person households with 11.1% and finally households with five or more members with 4.2%. Only 20.8% of the participants state that children below the age of 18 years are currently living in their households.

4.1.2 Food Waste Quantities

Almost 50% of the participants stated that they waste between 0 to 200g of food per week followed by 201 to 500g with a percentage of 30.8%. Contrarily, just two households (2.8%) estimated their weekly avoidable waste of food to more than 1000g. In a similar study, Giordano et al. (2019) continued the quantitative questionnaire with a subsequent diary experiment and discovered that the actual

food waste values were always higher than 1000g per family per week, regardless of the quantities that participants admitted to wasting in their responses. On average, the estimated food waste quantities per week in the responses were underestimated by about 630g (Giordano et al., 2019).

Table 2. Responses to the estimated amount of food waste per week

Options	Percentage of Households
0 - 200g	48.6%
201 - 500g	30.6%
501 - 800g	12.5%
801 - 1000g	5.6%
More than 1000g	2.8%

4.1.3 Food Types and Reasons

Participants were able to select a maximum of three food types that are wasted the most in their household. Relatively similar to the food waste results of Ispra in Italy conducted by Jörissen et al. (2015), the majority of participants selected fruits with 72.2% and vegetables with 68.1%. Bakery-products followed with 63.9% and milk-products with 58.3%. Several participants revealed themselves to be vegetarians or vegans in the voluntary remarks of the questionnaire which supports the low percentage of meats with just 23.6% (see Figure 37).

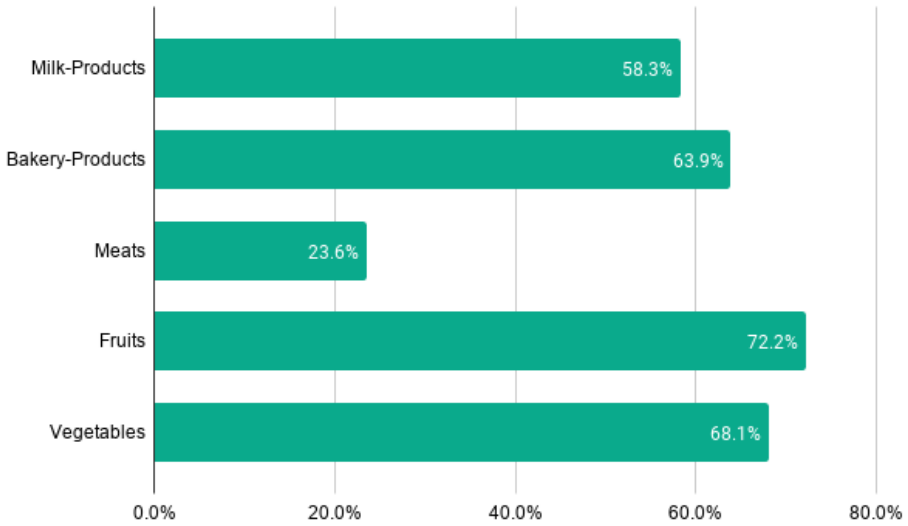


Figure 37. Responses to the types of food that are thrown away the most

The primary causes of food waste in private households were determined through participants selecting their three main reasons for wasting food at home. Results

show that 54.2% of participants regularly overlook the expiration dates on their food items. One problem that may be related to the overlooked expiry dates is the lack of overview of the own food storage, which was indicated by exactly 50% of the participants. Poor meal planning was the second most frequently chosen by a total of 51.4% of participants. Wrong package sizes with a strong emphasis on too large package sizes as often mentioned in the voluntary remarks by smaller households with 44.4% and misjudging the eating habits of household members with 41.7% were also among the top five most selected reasons. Finally, not using shopping lists with 22.2 %, buying food by mistake with 12.5% and insufficient cooking skills with just 5.6% were the three least selected reasons (see Figure 38).

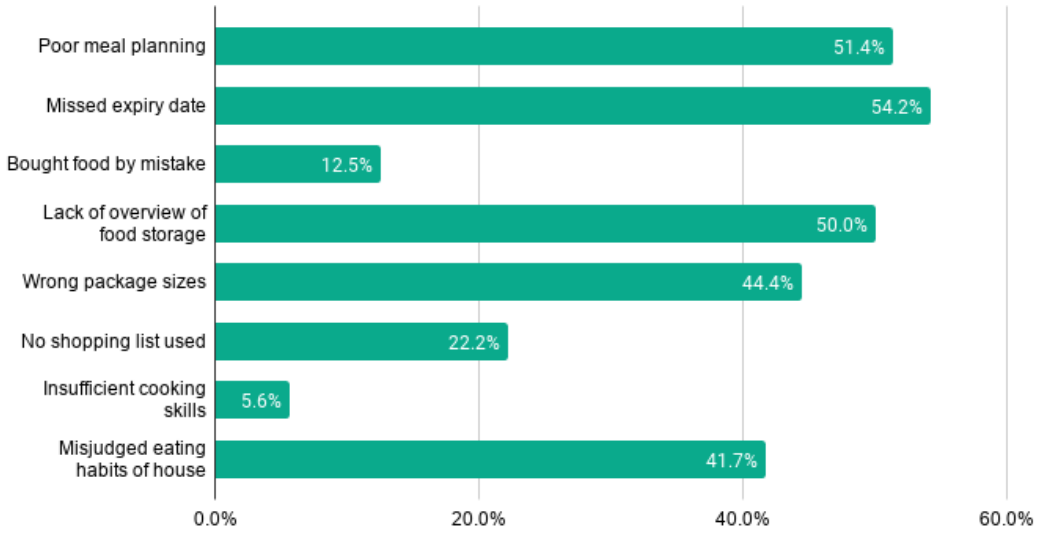


Figure 38. Responses to the reasons for food waste

4.1.4 Attitudes and Motivations

When participants were asked about why food waste especially bothers them, 40.3% responded that they do not like the aspect that they waste good food. The feeling of guilt during and after producing avoidable food waste distresses 25% of all participants. In addition to the loss of good food, food is also a considerable waste of money for 18% of participants. Interestingly, only 1% have indicated that they cannot afford to waste food in monetary terms. Merely 15.3% mentioned concern for the environment indicating a severe lack of knowledge of the relationship between food waste and environmental problems (see Figure 39).

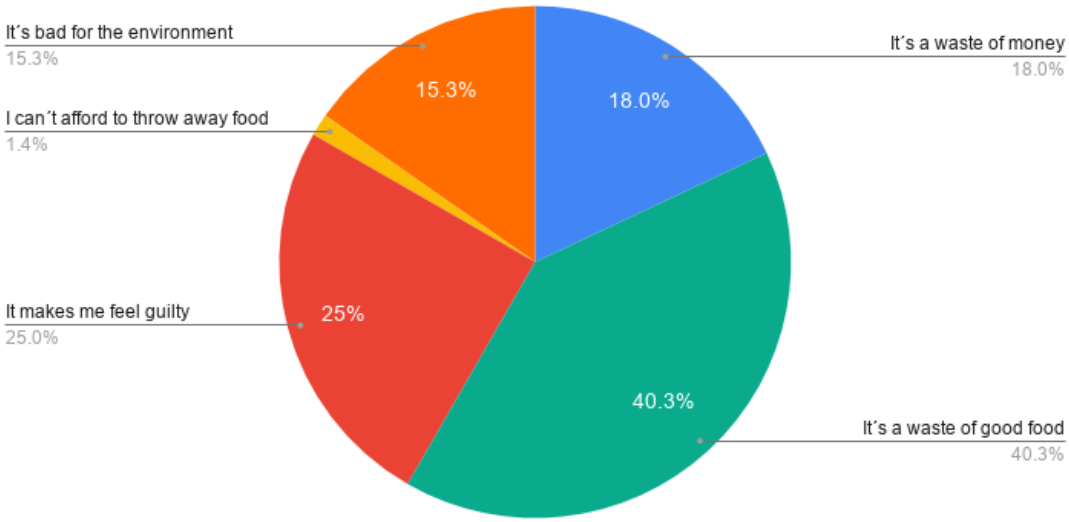


Figure 39. Responses on why food waste is bothering

Motivation is a key factor when creating an engaging solution for users. When asked about the three primary motivators necessary to actively reduce food waste, guilt is also found to play an important part in food waste reduction. As shown by the results of this questionnaire as well as the results of Quested et al. (2013), the most of the participants do not like wasting food since this frequently leads to feelings of guilt. The possibility to save money seems to be a powerful motivating factor with a percentage of 63.9%. Reducing the overall food shortages elsewhere in the world as a motivation that is less focused on the own advantages was a concern of 44.4%. Extending the own knowledge about food especially on how to cook with leftovers according to the voluntary remarks is a key motivator for 44.4% of the participants. Notifications as a form of external motivation followed with 30.6% (see Figure 40).

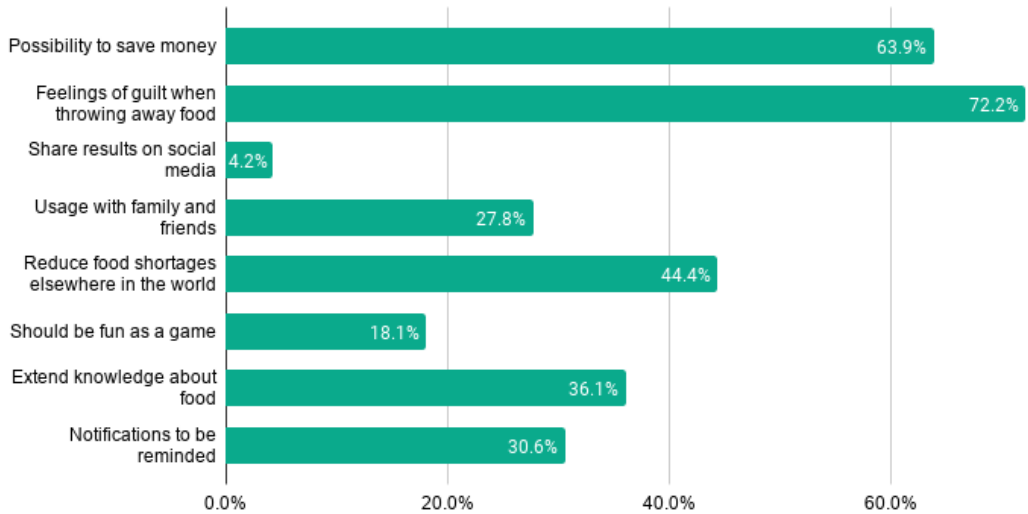


Figure 40. Responses on motivations to reduce food waste

4.1.5 Existing Solutions

Through asking participants whether they have already tried different solutions to reduce the food waste in their household and if they were successful, more insights about existing solutions were gathered. While 58.3% of participants stated that they have tried at least one solution, 44.4% also had success with the mentioned solution such as buying less food but more frequently, take a look at storage before shopping, plan meals ahead for the next week, educate yourself on how to properly store food, write shopping lists and use public food-sharing services. Furthermore, digital solutions mentioned by respondents include the two mobile apps Bring and NoWaste. On the other hand, 41.7% never tried any solutions to reduce food waste.

4.2 Evaluation of the Prototype

4.2.1 Structure

Throughout the development of the interactive prototype with Adobe XD, the prototype was evaluated in two major test phases. Each test phase was performed with seven to eight participants that individually tested the prototype with an Android device on that particular day. On average the user tests approximately lasted ten to fifteen minutes. After all the participants finished their user test, the experiences were openly discussed afterwards in focus groups that lasted about 30 to 60 minutes. This concludes to the following structure of both test phases:

1. Get to know the user
2. Explain the solution and the test scenario
3. Let the user complete all tasks while thinking out loud
4. Reflection on the user test
5. Share experiences in a focus group

4.2.2 Participants

German- and English-speaking adults between the age of 18 to 55 years were recruited in Vienna and Lower Austria. This range of age was targeted since it also represented the defined target group for the solution that was established during the literature review and the subsequent field study. The only requirement was that the participant must contribute in some way to food management in his/her household. Potential participants were then invited by social media, email or phone to take part in the test of a digital solution against the food waste in private households. Fifteen participants (60% male, 40% female) in total were recruited throughout both test phases with the interactive prototype.

4.2.3 Collected Data

4.2.3.1 User Tests

Initially, the solution and its primary goals were introduced to the participant. Collected data included a screen capture from the testing device as well as an audio recording with the permission of the participant. Each user test was structured into a series of tasks that thematically fit the designed scenario. Testers were asked to express their thoughts aloud at each point. In addition to screen capture and audio recording, the time required to successfully complete a task was measured. Afterwards, the testers shared and discussed their experiences and thoughts of the whole test procedure openly in focus groups.

4.2.3.2 Focus Groups

First, the ground rules, as well as mutual respect, were highlighted. Each focus group lasted for approximately 30 to 60 minutes and was audiotaped, with the permission of all participants. Semistructured topic guides were used to frame the group discussion. The first part of the focus group focused on what participants liked and disliked about the prototype they tested shortly before. This discussion was broadly organized by the topics of content, functionality, esthetics, information on food waste and how the solution could be improved. The second part of the focus group discussed requirements and possible features the participants might incorporate if they were designing a digital solution to reduce the food waste specifically in their private households.

4.2.4 Results

The names of the participants during each phase were made anonymous with pseudo names. Essential background information about the household was kept.

4.2.4.1 Phase 1

In the first phase, the whole interactive prototype including the recipe and meal plan functionality was tested and discussed by seven participants. Two of them had already some experiences with using similar food management apps. While the first mentioned app was solely for creating shopping lists, the second one was just for managing the personal food storage. The results were structured into three major themes:

1. Experiences with the used prototype from the user tests
2. Motivation to reduce food waste
3. Specific requirements for their household

Table 3. Participants in phase 1 of the prototype testing

Person	Household Background	Experience with apps
Person 1	Family-household with a child	Yes
Person 2	Group-household student residence	No
Person 3	Single-household	No
Person 4	Single-household	No
Person 5	Couple-household	Yes
Person 6	Family-household with two children	No
Person 7	Single- household	No

How were your personal experiences with the prototype of the solution during the user test?

Participants disliked the initial notification dialog for soon expiring food items directly after opening the app. *Person 3* and *Person 7* especially had an aversion to frequent notifications. The rest of the group agreed upon that notification dialogs, in general, are acceptable, but not directly when starting the app. The two participants *Person 1* and *Person 5* that had already experiences with similar apps suggested a setting to limit or turn off notifications completely.

Images of the food items were regularly mistaken for a different product due to overlooked associated labels on notification dialogs. For instance, *Person 4* and *Person 7* have confused the image for milk with yoghurt. Recommendations included replacing the current stock images of each food item with self-made pictures, in addition to better visible labels.

Five of the seven participants noted the missing quantity state of food items. Instead of adding multiple food items of the same type to indicate the current quantity in the household, the five participants advised a dedicated quantity state for each food item. In contrary, *Person 2* and *Person 5* stated that it would be too time-consuming to enter the quantities every time an item is added or updated. The consensus was for a straightforward icon-button with which products could at least be marked as almost empty.

The greatest confusion during all user tests was caused by the recipe part of the app. *Person 2*, *Person 6* and *Person 7* have found that the appearance and workflow of the recipe feature did not fit thematically into the app. An otherwise easy to use the app would become much more complex and unmanageable as

stated by *Person 6*. While *Person 1* remarked that the recipe and meal plan features could be helpful, food waste could be reduced more effectively with fewer but well-implemented features.

When the participants were asked which aspect of the presented solution could most likely help them to reduce the waste of food in their household, only one participant chose the recipes. The other participants opted for a combination of storage and shopping list. Furthermore, *Person 1*, *Person 2* and *Person 6* also mentioned that the sharing feature would be crucial for their private household.

What motivates you to reduce food waste?

Equivalent to the results of the field study, the two main motivations of the participants to reduce food waste in their households were to reduce the feelings of guilt during wasting as well as to save money in the process. In particular, food shortages in other parts of the world and the hunger of homeless people were the main reasons for the feelings of guilt when wasting food.

Moreover, *Person 2* mentioned the environmental impacts due to the overproduction of food that is never consumed. Interestingly, the rest of the participants were not aware of the negative environmental influences of wasted food on the environment.

Which specific requirements and characteristics would enhance your ongoing engagement?

The user interface played an important role for participants during this specific question. Interfaces of mobile apps that are easy to use, structured, attractive and well-designed result in higher engagement and thereby increased daily use. *Person 1* and *Person 5* mentioned their experienced frustrations with the tried solutions such as outdated user interfaces, inexplicable interactions and screens that are overloaded with advertisements. All participants agreed that annoying advertisements would be a reason to immediately remove the app. Instead, a free version of the app with limited functionality and the voluntary possibility to later upgrade for a few euros was preferred.

Lastly, every household with more than one person, represented by *Person 1*, *Person 2*, *Person 5* and *Person 6*, have described the sharing feature as a necessity. Even though not each household member buys food items for the household´s storage, every member is involved in the consumption of them. *Person 2* explained that it would be a great frustration to keep the storage up-to-date single-handedly in a household with several members.

4.2.4.2 Phase 2

The second phase focused on the Minimum Viable Product (MVP) of the interactive prototype. Elements such as the recipe aspect and the meal planning were eliminated and at the same time, more emphasis was placed on the storage, the shopping list and the household sharing feature. Eight completely new testers followed the same schedule as previously stated for phase 1. Three of the participants already had experiences with similar food-management apps.

Table 4. Participants in phase 2 of the prototype testing

Person	Household Background	Experience with apps
Person 1	Family-household with a child	No
Person 2	Couple-household	Yes
Person 3	Single-household	Yes
Person 4	Family-household with a child	No
Person 5	Group-household student residence	Yes
Person 6	Single-household	No
Person 7	Group-household student residence	No
Person 8	Single-household	No

How were your personal experiences with the MVP of the solution during the user test?

The absence of a quantity state for food items, which was criticized during the previous test phase, has been revised by implementing a simple flag icon-button to highlight almost consumed food items. Although this workaround was sufficient for the majority of participants, *Person 2*, *Person 4* and *Person 7* remarked that the flag-icon was simply too little information about the current quantity state. *Person 7* mentioned that if you go shopping right after work without being able to look at the storage at home beforehand, the icon does not provide enough details about whether you need to buy this specific food item again. *Person 6* suggested to keep the simplicity of the toggle-button, however, include multiple states such as *low*, *half* and *full*. All participants except *Person 7* considered this proposal to be an acceptable solution to be able to set different quantity states without having to enter the specific quantities manually.

Throughout the user tests as well as the focus group, several participants doubted the accuracy of the expiry dates provided by the prototype. Additionally, even for the same food items, shelf life can vary greatly. For instance, the estimated shelf life for bananas was set to seven days for the prototype, however, *Person 6* correctly raised the issue that this depends heavily on the correct storage as well as how fresh the bananas were bought. Instead of displaying the number of left days until a certain food item expires and counting it down to zero, *Person 3* proposed the idea to show the number of days since the food item was added to the storage. This would address two problems simultaneously. First, users would always know how long the food items are already present in their storage since continuously counting the number of estimated expiration days down would result in the number stopping at zero without knowing on what day it happened. Second, the provided estimated shelf life in days would solely be for voluntary notification purposes. None of the participants expressed direct opposition to this idea.

Even though the prototype already included thirty of the most wasted food items, the question of custom-made food items arose numerous times. *Person 2* in cooperation with *Person 8* suggested implementing a simple input dialog to enter the name, the shelf life in days and an optional image of the food item to subsequently extend the food item list. When asked how the function to create a new item should be accessed, the majority of the participants were in favour of either adding a button to the add manually screen where the list of all food items can be found or a global icon-button to the toolbar.

Removing the entire recipe element from the prototype made it much easier for users to navigate through the user interface during the tests. The three essential components of the MVP being the storage, the shopping list and the household screen were now placed in the bottom navigation, in contrast to the previous prototype where the household screen was accessed through the house-icon in the toolbar. This necessary reduction of functionality led to better user experiences and moreover the time required to solve individual tasks during the user tests was drastically reduced.

What motivates you to reduce food waste?

As anticipated, saving money and reducing feelings of guilt were once more the most frequently mentioned motivators by participants. Moreover, *Person 5* remarked gamification as an instrument to increase long-term engagement, which was positively received by several participants. In contrary, due to the misconception of the term gamification, *Person 1* and *Person 4* expressed their dislike of “transforming the serious subject of food waste into a mindless game.” Although participants with an understanding of the topic made an effort to explain

the benefits of gamification such as increased user engagement through rewards when wasting less food, scepticism remained.

Additionally, learning how to properly store, process and dispose of food was brought up during the focus group by *Person 4*. The shelf-life of food items can easily be extended by days or even weeks through proper storage. Interestingly, the resulting discussion showed how differently the participants store their food at home. For instance, some participants claim that they store their bananas at room temperature, others swear that putting bananas into the refrigerator almost doubles their shelf-life. When the participants were asked how they would like to receive these food tips, *Person 1* suggested receiving the information directly from the food item through a popup-dialog. Alternatively, an external source, for instance in the form of a daily blog with relevant information on food items also appeared to be an acceptable solution to the participants.

Which specific requirements and characteristics would enhance your ongoing engagement?

A simple overview of the total food waste in the household and the resulting information such as the money that was lost because of that was requested by *Person 2*. Further suggestions included a graph to visualize the percentage of consumed and wasted food as well as more detailed insights into how often certain food items were already wasted. The latter in combination with notifications could prevent the purchase of food items that are often wasted in the household.

The two participants *Person 5* and *Person 8* both live in an apartment during the week, but stay the weekends with their family. They expressed the need to be able to create, join and manage several households in the mobile app from the same user account. This suggestion raised a discussion about the necessity of user accounts as well as whether each user of a household needs a separate account or the household serves as a collective account. The opinions of participants on this topic differed widely. While *Person 5* and *Person 8* recommended an account per user with the options of creating a household and inviting people, *Person 1*, *Person 2* and *Person 7* were for one shared account per household. Both sides presented the advantages of their proposal. Although one account per user would mean that each member of a household would have to create a separate account, the advantage of this would be that one could easily switch between households without having to remember the access data of several households.

4.3 Testing of the Application

4.3.1 Usability Testing

Following the final assessment of the Minimum Viable Product (MVP) through user tests and a focus group, the development of the mobile app with Flutter and Firestore was initiated. After implementing major features, the current development state was tested with qualitative usability tests and results were evaluated using the System Usability Scale (SUS).

4.3.1.1 System Usability Scale

In 1986, the System Usability Scale (SUS), a reliable tool for measuring the usability of a system on a scale from 0 to 100, was introduced (Lewis & Sauro, 2009). The SUS is often referred to as a quick and dirty evaluation method since it is a fairly quick ten-statement (see Table 5) assessment that takes about 90 seconds and was assumed to only measure a single construct of usability.

Table 5. Statements of the SUS with the scale contribution

#	Statements	Scale Contribution
1	I think that I would like to use this system frequently.	Scale Position - 1
2	I found the system unnecessarily complex.	5 - Scale Position
3	I thought the system was easy to use.	Scale Position - 1
4	I think that I would need the support of a technical person to be able to use this system.	5 - Scale Position
5	I found the various functions in this system were well integrated.	Scale Position - 1
6	I thought there was too much inconsistency in this system.	5 - Scale Position
7	I would imagine that most people would learn to use this system very quickly.	Scale Position - 1
8	I found the system very cumbersome to use.	5 - Scale Position
9	I felt very confident using the system.	Scale Position - 1
10	I needed to learn a lot of things before I could get going with this system.	5 - Scale Position

To apply the SUS, each question must be presented with a 5-point rating scale numbered from 1 (described with “Strongly disagree”) to 5 (described with

“Strongly agree”). The statements 1, 3, 5, 7 and 9 are positively worded, meaning the scale contribution equals the scale position minus 1. In contrary, statements 2, 4, 6, 8 and 10 are negatively worded therefore the scale contribution equals 5 minus the scale position (Lewis & Sauro, 2009).

Acceptable SUS scores are often highly subjective, thus, Bangor et al. (2009) presented a determination scale to visualize several levels of usability such as *worst imaginable*, *poor*, *ok*, *good*, *excellent* and *best imaginable* (see Figure 41). Therefore, during this thesis´s approach, the minimum average SUS score of each usability testing had to be at least 75 to be considered a success. Bangor et al. (2008) further implied to replace the word “cumbersome” in statements 8 with “awkward” due to the confusion of about 10% of 2324 participants.

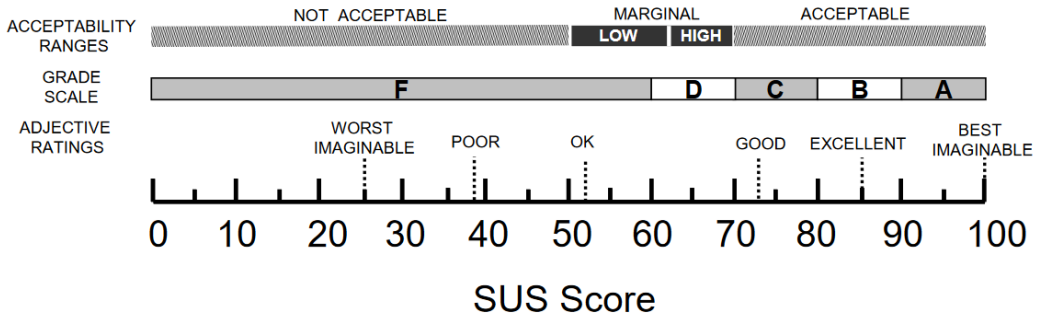


Figure 41. Acceptable average SUS Score (Bangor et al., 2009)

4.3.1.2 Development Approach

The overall development process was structured into four cycles, each cycle was consisting of programming, testing, evaluation and analysis (see Figure 42). In the analysis step, all the learnings from the previous cycle were reviewed to determine the next development processes. Objectives for the next cycle were defined, the approximate time required for programming was estimated and the following usability testing was planned. Therefore, this step was crucial to keep the development of the mobile app on schedule. Additionally, the experience gained with each completed cycle allowed to plan the steps of the following cycle even more precisely. The defined feature requirements were then translated into technical specifications that included the choice of necessary tools, frameworks and libraries. Through class and database diagrams, the relationship between essential models such as *Household*, *Member* and *Item* was established and reviewed. After implementing the features of the current cycle, the scheduled usability testing was carried out to discover possible errors. Between seven and eleven participants from the target group were present during each of the four usability tests. Even though the usability testing was fairly similar to the user tests during the prototype development, a greater emphasis was placed on the technical aspect of the mobile app. Moreover, each usability test was finished with a SUS

questionnaire. Finally, the results from usability testing were compiled, evaluated and subsequently prioritized. Sometimes participants would suggest additional features during the usability testing, however, as time was tight, several feature requests had to be placed in the backlog for future work.

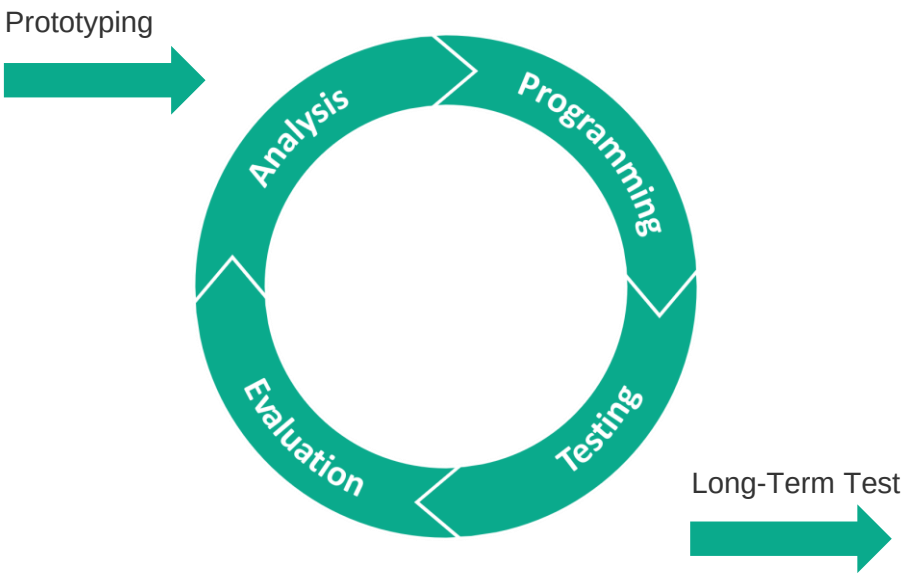


Figure 42. Cycles of the development process of the mobile app

4.3.1.3 Test Setting

Usability testing is usually finished within a few hours and conducted in a testing laboratory, thus, as stated by Abras et al. (2004), it is hard to ascertain how the product is going to perform over a few weeks or months in the real environment. Therefore, usability testing during the development process is solely for the purpose of evaluating the functionality of each development state without concluding how the app will perform in a real environment. Consequently, the effectiveness of the mobile app was assessed afterwards through a long-term assessment in real households as described in the next chapter.

The evaluations of all four cycles were conducted using a video conferencing tool that was preferred by the tester. Although this was a necessity during the Corona pandemic, the opportunity was used to assess whether testers with experiences in participating in usability tests felt more comfortable when performing it from home or their workplace. The video stream and the audio were recorded with the participant´s consent and reviewed afterwards. The common usability testing method was employed: think-aloud protocol and a predefined series of test tasks within a scenario. Participants were asked to tell what they were doing, what they expected to happen upon making selections and whether something unexpected happened after the selection. The instructions given to participants were predefined and written in a word document.

4.3.1.4 Results

As mentioned earlier the development process was structured in four cycles, each with its own usability evaluation, testing the recently programmed features (see Table 6). If the average SUS score of the usability testing had ever been below 75, the complete evaluation would have been repeated after the necessary fixes of occurred errors. Fortunately, due to the prior field studies and prototype testings, only minor issues were experienced without disrupting the overall user experience.

Table 6. Scores of the usability tests during each development cycle

Cycle	New Features	Participants	Avg. SUS Score
1	Storage, Add Items Manually	Eight	82.2 (SD: 5.4)
2	Shopping List, Create Item	Nine	79.4 (SD: 7.4)
3	Create and Join Household, Manage Members	Seven	83.2 (SD: 7.9)
4	**Final Testing of MVP**	**Eleven**	**88.6 (SD: 7.6)**

A common theme among usability evaluations within the first three cycles was the confusion with stand-alone icons lacking labels. The icon-button to toggle the current quantity state of a food item between *low*, *half* and *full* was often mistaken with some kind of priority setting. Only after several attempts were the symbols correctly recognized. Therefore, the icon-buttons were replaced through text-buttons containing appropriate labels (see Figure 43).

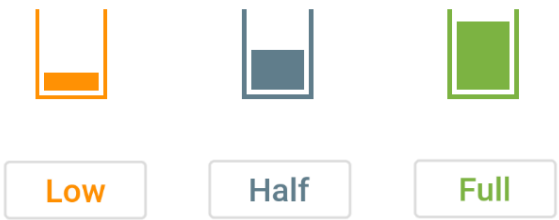


Figure 43. Replacement of the quantity icon-buttons with labelled buttons

Furthermore, the floating-action-button in the bottom right corner was often overlooked by participants. Moreover, the house-icon of the household screen gave the impression that it would take you to some sort of home screen. Thus, the floating-action button was labelled as well as centred and the household icon was replaced (see Figure 44).

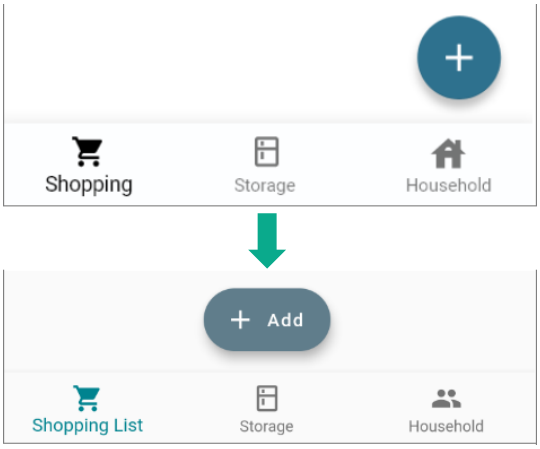


Figure 44. Update of floating-buttons and replacement of the household icon

Although these minor UI changes led to visibly better user experience during the testing of the app, several participants still suggested some sort of additional tutorials for new users. These were shortly after added before the final usability testing and resulted in a noticeably increased score.

During the third usability testing, more than 50% of the participants left the member creation screen without saving. They overlooked the “Finished” button in the bottom right corner and therefore expected the changes to be saved automatically after they were entered. Although this would have been technically possible, the conscious decision was made to only update the data collected in one request to reduce writes to Firestore. Therefore, the problem was solved with a notification dialog that reminds users to save before they leave the screen (see Figure 45).

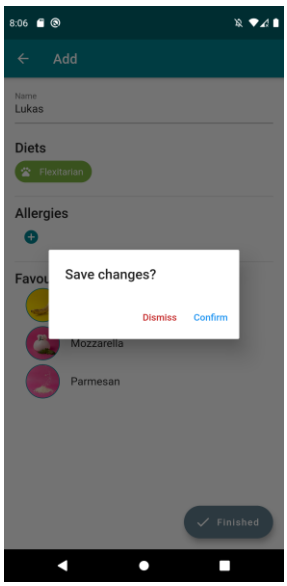


Figure 45. Notification dialog when leaving the screen without saving

Further fixes include the incorrect sorting of strings that start with a German umlaut (Ä, Ö, Ü) and custom-created items were always placed at the end of the food item

list instead of being merged and sorted with the rest of the items. After all these fixes were successfully applied, a final usability testing was scheduled to determine whether the app was ready for the long-term assessment in a realistic environment. The last evaluation concluded in a SUS score of 88.6 without noteworthy incidents.

Finally, this section will be closed off with a few remarks on the System Usability Scale (SUS). Bangor et al. (2008) already stated the problem with the word “cumbersome” in statements 8. While this was not an obvious problem during this study, the word “inconsistency” in statement 6 was unclear at first for seven out of thirty-five participants (20%). Furthermore, when participants were asked whether the usability testing via videoconferencing tools was satisfactory, there was positive feedback without exception. Usability laboratories often aim to recreate convincing living rooms or offices to make participants feel more comfortable during the evaluation, however, perhaps the most convincing testing environment for participants is their own familiar environment.

4.3.2 Long-Term Assessment

Following the final successful usability testing of the mobile app, the next step was to assess its effectiveness in a real environment. *The developed solution would be able to cause a visible positive change in behaviour regarding food management and food waste within two months* – this hypothesis was validated with the long-term assessment. Hence, the app was distributed to six private households, which used it in their daily routine for around two months. The effectiveness of the app was subsequently validated using two types of data: 1) recorded data by the app, 2) collected data during the two interviews.

4.3.2.1 Assessment Approach

Before the app was distributed to voluntary households, first, a qualitative interview was conducted to obtain relevant information about the household demographics, the current behaviour regarding food waste, estimated food waste amounts, possible motivational factors to increase engagement as well as already tried solutions. Since the previously compiled questions for the quantitative study had a fairly similar objective, they were adapted for this qualitative approach. The two major adjustments made to the questionnaire include the change of the question „*How much food do you think your family wastes weekly (in gram)?*“ to „*How many of the products you buy are thrown away in your household in one month (in per cent)*?“ and that the questions were answered during an interview. The question about the estimated food waste quantity was changed because the mobile app records food waste amounts in per cent, thus, it was relatively simple to compare the estimated amounts during the interview with the recorded amounts after the long-term assessment. Following the initial interview, the app was made available

to the household via the Google Play Store. Therefore, users were able to retrieve available updates published during the test easily and automatically. Participants had the opportunity to report feature requests, bugs, unexpected events, et cetera with the integrated reporting of the app. Additionally, due to the numerous requests for reminder notifications, households who did not update their storage for over a week were manually notified through a text messaging service. After the two months of testing, a final interview was conducted to confirm potential changes in user-behaviour and to ultimately assess the real effectiveness of this digital solution (see Figure 46).

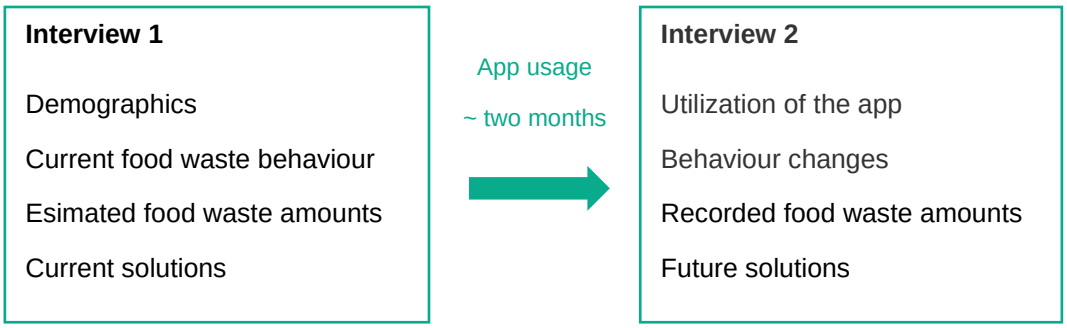


Figure 46. The procedure of the long-term assessment

4.3.2.2 Households

Initially, seven households from Vienna and Lower Austria agreed to participate in the evaluation, however, *Household 7* cancelled at short notice due to personal reasons. The remaining households received the app simultaneously and were tasked to utilize it freely in their daily routine without any specifications or restrictions. The total number of active users was nine since in *Household 4* and *Household 5* multiple members used the app. Furthermore, those two households were the only ones with a child (see Table 7). Although more members of the household were willing to utilize the app, they didn't own an Android device.

Table 7. Participating households of the long-term assessment

Households	Household Background	Participants
Household 1	Couple-household	One
Household 2	Couple-household	One
Household 3	Family-household	One
Household 4	Family-household with child	Two
Household 5	Family-household with child	Three
Household 6	Single-household	One

None of the participating households had prior experience with mobile apps for food management. Three households stated they successfully established a solution to reduce the food waste in their household. These mentioned solutions include planning and preparing meals in advance for several days, writing shopping lists, checking the storage before shopping and learning how to properly cook with leftovers. In contrary, *Household 2* noted that weekly cooking boxes were tested as an attempt to reduce the food waste in addition to save time, however, the exact opposite was the case.

4.3.2.3 Released Updates

Throughout the long-term assessment, the app received two updates, one mandatory and one voluntary. The first adjustment was recommended by *Household 2* about one week after starting the assessment and its main purpose was to consider quantity states of wasted food items in the calculation of the average household waste. Therefore, when a food item with the quantity state *half* was wasted, it was only counted as 50% of an item. Likewise, a food item with the quantity state *low* was only counted as 20% of an item (see Table 8). To keep the calculations for the statistics consistent across all participating households, the adjustment was made mandatory.

Table 8. The weighting of quantity states in the statistics

Quantity State	Weighting
Full	100%
Half	50%
Low	20%

The second update was voluntary for all participants and requested by *Household 3*. Each time a member of their household went grocery shopping to repurchase consumed or wasted food items without using the app, the person in charge of the app had to remove the food item from the storage overview first and subsequently manually re-add it. Therefore a suggestion was made to make this process more efficient with an icon-button to simply reset the food item (see Figure 47).

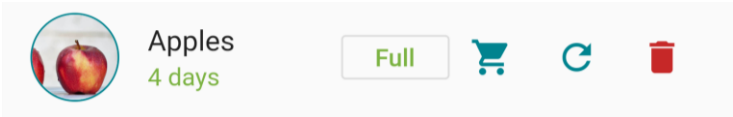


Figure 47. Proposal for adding a reset-button to food items

However, any additional unlabelled icon-buttons may lead to confusion during the ongoing assessment. Furthermore, the available horizontal space for the list items

was becoming too scarce which could lead to problems on smaller screens. Therefore, a checkbox to immediately re-add a food item upon removing it from the storage was implemented (see Figure 48).

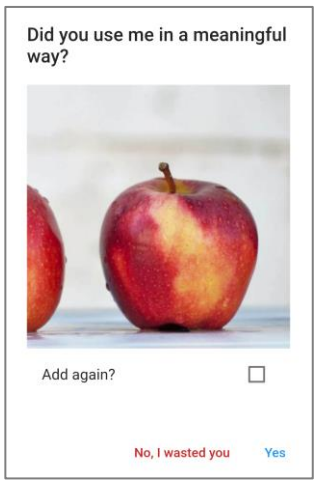


Figure 48. New "Add again" checkbox when a food item is removed

4.3.2.4 Results

Before the final interviews started, the estimated food waste amounts during the first interview were compared to the actual recorded amounts tracked through the mobile app (see Table 9). Merely the households *Household 3* and *Household 6* were below their estimated values after the two months. The rest of the households, without exception, was above. While *Household 2* was the farthest from their estimated percentage, *Household 4* had the highest recorded value.

Table 9. Comparison between estimated and recorded food waste

Households	Estimated waste in % per months	Recorded waste in % per months
Household 1	5 – 10 %	15.2 %
Household 2	5 – 10 %	16.3 %
Household 3	16 – 20 %	13.2 %
Household 4	11 – 15 %	16.7 %
Household 5	11 – 15 %	16.0 %
Household 6	5 – 10 %	2.7 %

Each update to the storage, for instance, adding or removing food items as well as adjusting the quantity state was recorded as an individual timestamp in the database. Therefore, this question was resolved by monitoring all the collected user data through a custom-made dashboard in addition to gaining more detailed

information during both interviews. The dashboard was a simple web application and showed an overview of all households in the form of expansion panels (see Figure 49) with the corresponding user data.

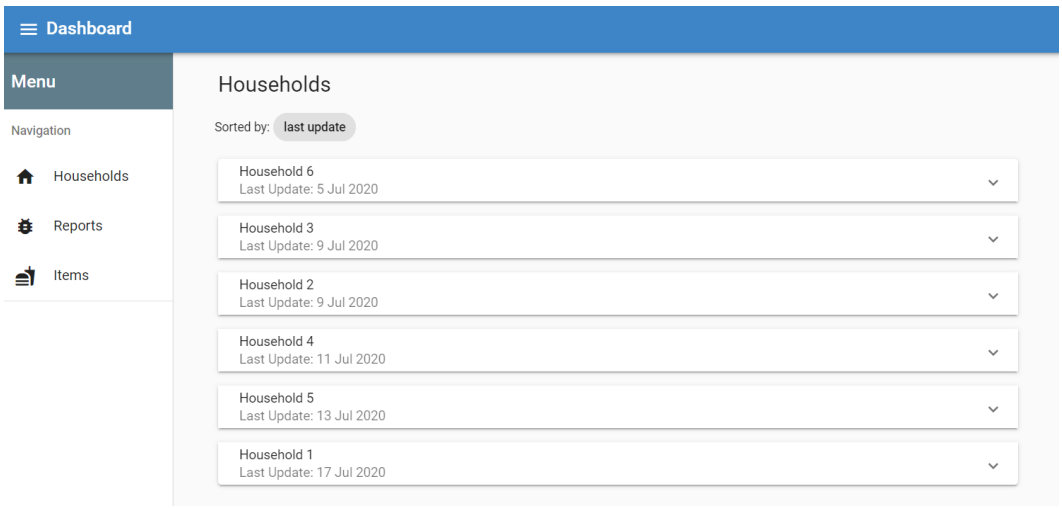


Figure 49. Dashboard with the overview of all households

Once the panel was expanded, more information about the individual household such as the number of wasted- and consumed food items as well as the detailed category of each wasted item was displayed. Additionally, a graph of the overall storage updates with a trend line was visualized (see Figure 50).

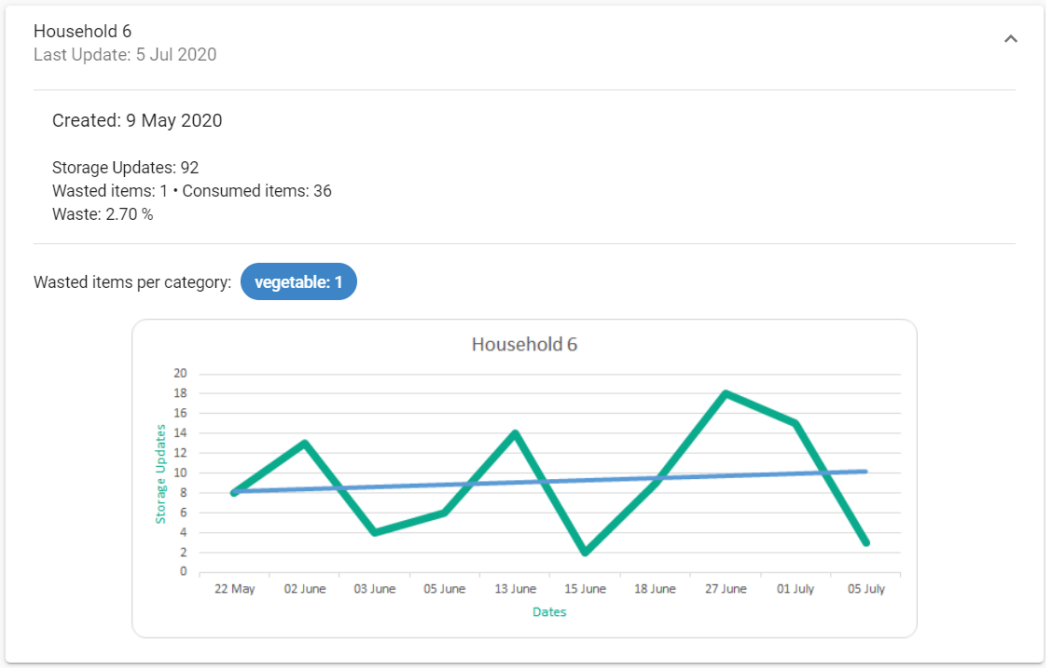


Figure 50. Dashboard with the details of Household 1

This information allowed an in-depth preparation for the second interview with the participating households.

How was the mobile app utilized in your household?

Household 1 had a total of 73 storage updates, which was the lowest value among all households distributed over 15 days (see Figure 51). The app was merely utilized as a simple storage overview to check the required groceries before going shopping and to manually enter the purchased products afterwards from the shopping receipt. Interestingly, the shopping list aspect of the app was completely ignored due to the already established practice of using paper shopping lists.

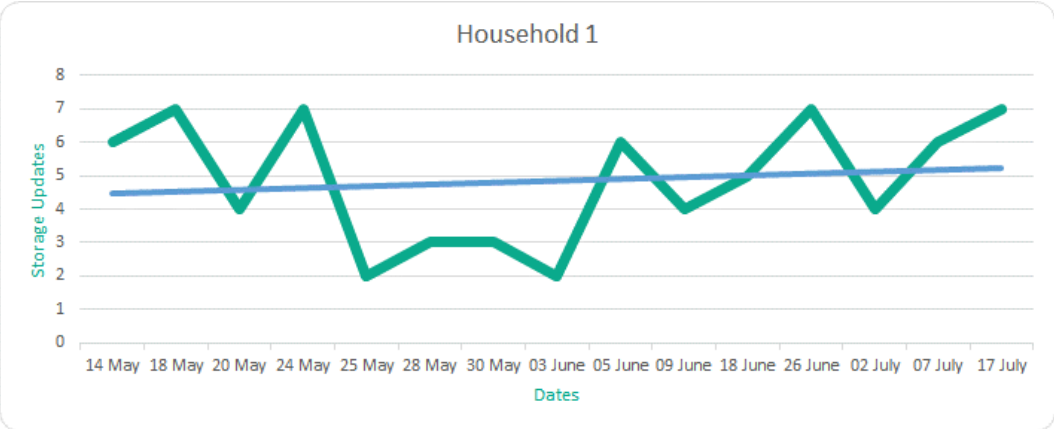


Figure 51. Frequency of storage updates of Household 1

The overall food management in *Household 2* was managed by one member which also utilized the mobile app for further support. The storage of their household was changed on 12 days with a total of 127 updates (see Figure 52). Creating shopping lists to refill the storage overview was the primary field of application during the assessment. Moreover, the shelf life of the groceries in the refrigerator was checked once a week and changes were entered directly into the app.

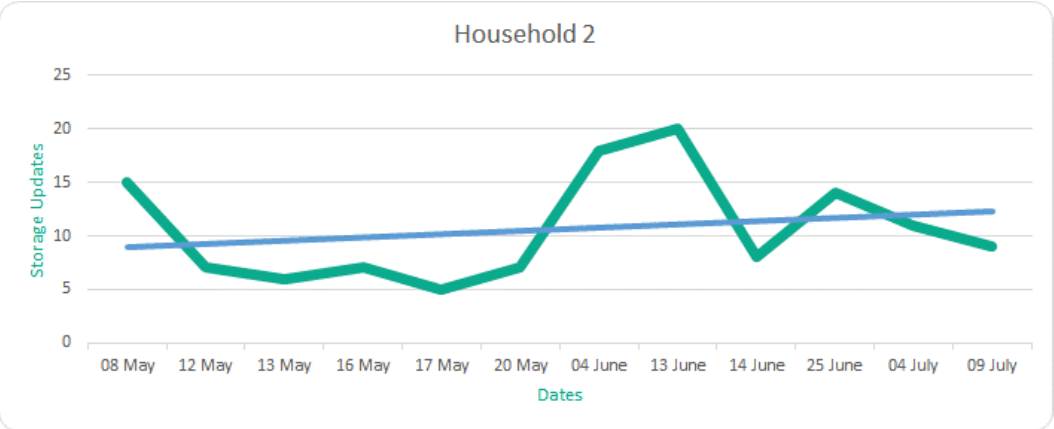


Figure 52. Frequency of storage updates of Household 2

Similar to *Household 2*, in *Household 3*, a single-member utilized the mobile app for weekly grocery shopping. Mainly through shopping lists, the food items in the storage were updated exactly 156 times over the course of 18 days (see Figure

53). Since *Household 3* had the most amount of storage updates, the interview went into more detail about what range of products was managed with the app. Strikingly enough, *Household 3* also remarked that non-food products such as batteries and tissues were maintained using the app.

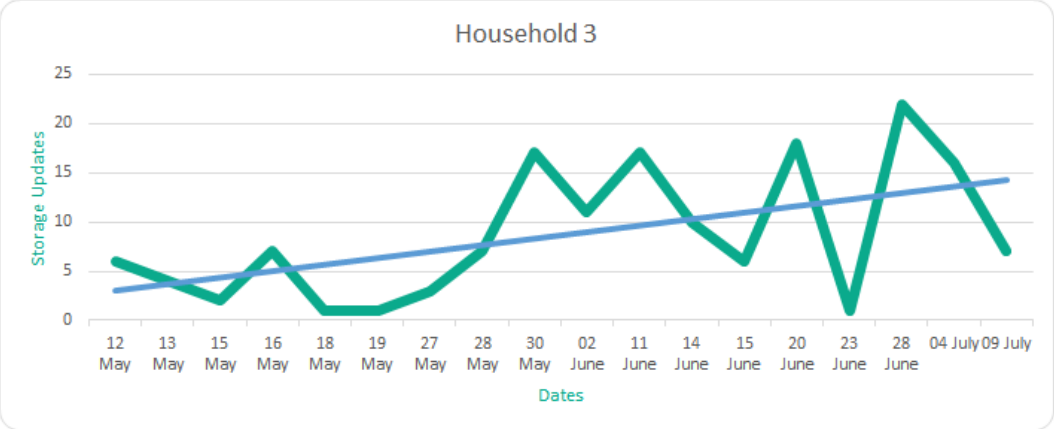


Figure 53. Frequency of storage updates of Household 3

Across 23 days, *Household 4* updated their storage 116 times (see Figure 54). The two members in charge of the food management utilized the mobile app to its full extent. Wasted or consumed food items were immediately removed from the storage and directly added to the shopping list again if needed. Therefore, no additional effort was required before and during the shopping, since the shopping list was up-to-date at all times. Instead of depicting every food-related product in the app, *Household 4* successfully aimed to just focus on frequently rotating food items. Additionally, each member had an entry in the household overview of the app which also put the child in a position to enter its favourite food items with one of the two Android phones on which the app was installed.

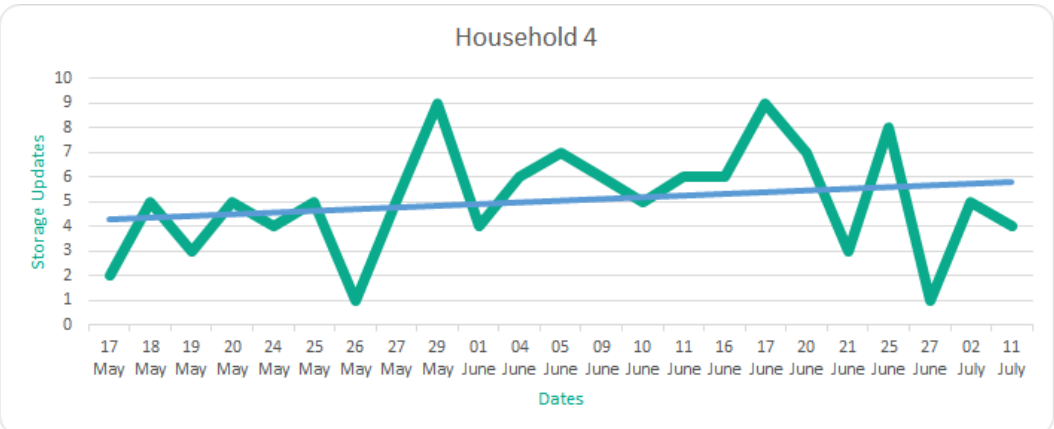


Figure 54. Frequency of storage updates of Household 4

The second household with a child was *Household 5* which had 94 storage updates distributed across 13 days (see Figure 55). Furthermore, this household was the only one where all members including the child had access to the app with an

Android device. With an additional Android tablet that was stationed permanently in the kitchen and dedicated to the provided app, they improvised a smart fridge. Shopping lists were created before shopping and occasionally updated during the shopping by members who were at home at the time.

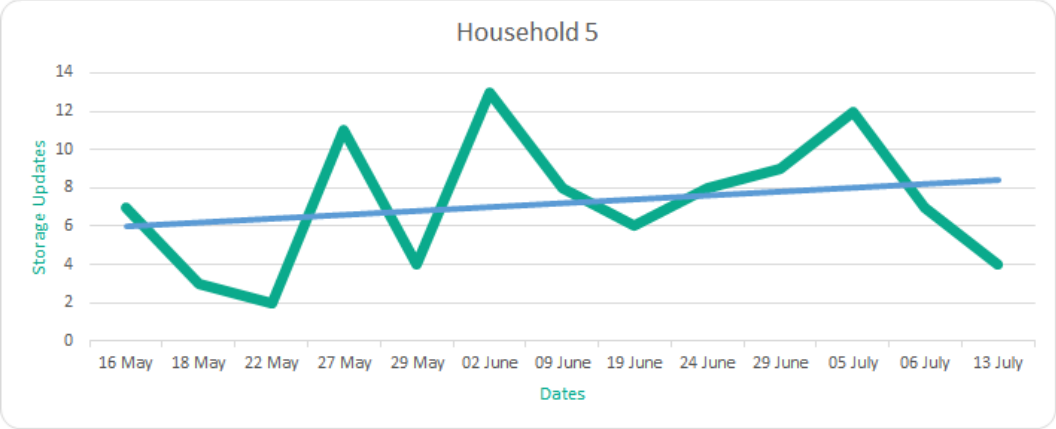


Figure 55. Frequency of storage updates of Household 5

In *Household 6*, the household with the least food waste, the provided mobile app was utilized in combination with a website for meal planning. Therefore, meals were planned beforehand with the external website to subsequently create a shopping list with the app for all the required groceries. This lead to 92 storage updates across 10 days (see Figure 56). After the meals were prepared, the leftovers were frozen, inserted into the app´s storage overview and consumed over the next few days.

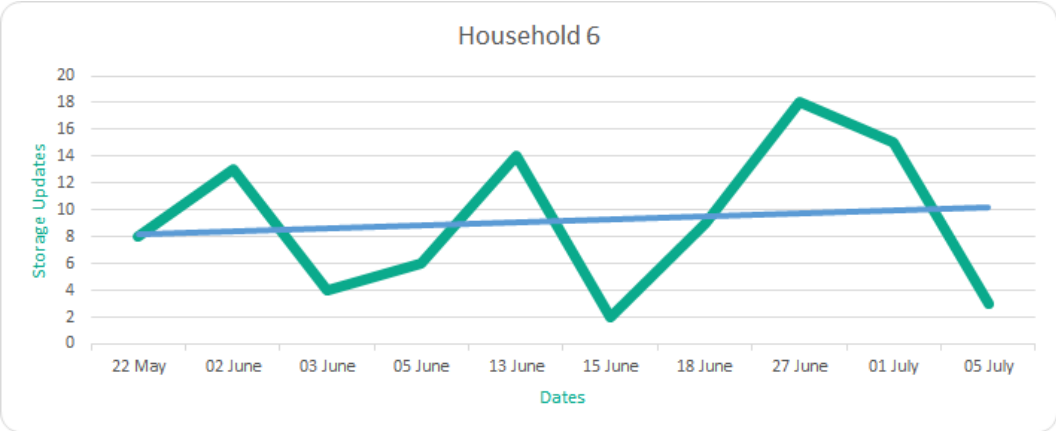


Figure 56. Frequency of storage updates of Household 6

Finally, on the subject of app utilization, throughout the long-term assessment, 91 additional food items were created by the participating households and 74 of these items were unique (see Table 10). This provides a viable set of food items that households were missing from the 30 initial items provided.

Table 10. Number of created food items of each household

Households	Created items
Household 1	4
Household 2	43
Household 3	20
Household 4	14
Household 5	10
Household 6	0

Have you noticed any behavioural changes concerning food management and food waste in your household?

Without exception, a change in behaviour related to the handling and wasting of food was observed in every household. Each household mentioned the increased awareness on the subject of food waste, as they were constantly confronted with the topic. Therefore, more thought was put into the planning of the shopping and management of the storage. Moreover, all households reported that they organised their fridge more efficiently during the long-term assessment and even continued this behaviour beyond the testing.

“The app makes you aware of how long certain types of food remain unused in the storage.” – *Household 3*. Several households expressed their gained awareness for how long products lie around at home before being consumed or even thrown out. *Household 1* mostly wasted milk-products, since they often forgot when these products were purchased. They were shocked numerous times when examining the days since the food item was added to the storage overview.

Five out of six households created custom food items for groceries such as avocados, beans and pears as well as for fully prepared meals like curry, soup and pasta. Interestingly, *Household 3* even created items for non-food products such as batteries and tissues. Each household that created at least one food item commented on their learning effects after they researched the required shelf life in days to include the food item to the app.

Furthermore, *Household 3* and *Household 4* also mentioned a rhythm that was established after months of using the app. This rhythm contributed to improving the efficiency of the entire food management, thus leading to a reduction in food waste.

How would you explain the correlation between your estimated and the recorded food waste amounts?

Even though solely *Household 3* and *Household 6* were able to end up within their estimated range of food waste, each household except *Household 3* remarked that their overall food waste was less during the long-term assessment than it ever was before because of the app. They admitted that their stated food waste values were almost certainly underestimated by them during the first interview. *Household 4* and *Household 5* expressed their amazement at how much more they have wasted than they initially estimated.

Additionally, the recorded amount of used and wasted items for *Household 3* was slightly falsified, as non-food products such as batteries and tissues were included in the storage overview and thus the final contrast between consumed and wasted food items was not completely accurate.

How would you assess the effectiveness of the mobile app against food waste in households?

The general opinion during the interviews regarding the real effectiveness of the mobile app was as perfectly described by *Household 1* – “When you put in the work, you will inevitably see positive results. However, when you stop engaging with the app, the subsequent maintenance of the storage overview becomes simply tedious”. Several participants stated that as long as the storage overview was up-to-date, the app was a blessing during the food management process, but whenever someone in the household forgot to enter their food-related activities immediately, the belated updating of the data became a nightmare.

Which brings us to the next key point that affects the effectiveness – the shared utilization in the household among all members. All participating non-single households with just one member using the app (*Household 1*, *Household 2* and *Household 3*) expressed their partial frustrations while managing the storage overview all by themselves.

When asked about user experience, design and usability were complemented during each interview. Even though keeping the storage overview up-to-date was a pain at times, due to the straightforward operability of the app this was bearable according to participants. Second, the focus on the three core functionalities shopping list, storage overview and household sharing in combination with simple tutorial screens contributed that virtually at no point during the long-term assessment confusion occurred.

Lastly, the visualization in the household overview of the overall food waste in percentage was addressed. *Household 2* remarked that this graph was a major motivational factor to keep the value as low as possible. “It was almost like a game

where you want to retain a perfect score." – *Household 2*. This statement was additionally supported by the rest of the households.

Would you continue to use the mobile app in your household?

Two households (*Household 2* and *Household 6*) would not consider the app or any other digital food management solution in the future. While *Household 2* remarks that the gained awareness and the resulting behavioural changes after the long-term assessment were already sufficient to keep the food waste at a minimum in the future, *Household 6* stated that the app was simply not necessary in the household, since there is virtually no food waste.

In contrary, *Household 4* and *Household 5* would continue to utilize the app almost unconditionally once the app is also available for iOS and thus for all their household members.

Lastly *Household 1*, as well as *Household 3*, suggested at least one feature so they would continue using the mobile app. First, *Household 1* mentioned the possibility to scan shopping receipts, one of the features that were removed when the Minimum Viable Product (MVP) was defined, to collectively include purchased food items to the app. Second, *Household 3* requested a method to classify app items into different collections. For instance, to have a collection for food items and a collection for non-food items, where only the items in the food collection would be taken into account for the food waste statistics.

Table 11. Continuation of using the app in the household and conditions

Households	Continue	Condition
Household 1	Yes	Scan receipts
Household 2	No	-
Household 3	Yes	Manage items in folders/collections
Household 4	Yes	Available for iOS
Household 5	Yes	Available for iOS
Household 6	No	-

5 Discussion

In consideration of the research results which highlight the complexity of food waste in the household sector in addition to the problems that affected people are struggling with, the focus of this thesis was the successful development and assessment of a mobile application against domestic food waste to support behaviour change. Development is often highly solution-oriented, whereby the solution is prioritized above the problem. This thesis aimed to identify the core issues and its affected people first before thinking of any viable solutions. This approach was highly inspired by Aydin et al. (2017) who initially examined the impact of consumer decision-making behaviour regarding food waste for three months before conceptualizing any solutions. Throughout this work, this approach proved to be an effective method for designing a sustainable solution.

Around 47 million tons of food waste in Europe is produced by the household sector. Along with the research results of Giordano et al. (2019) and Hebrok & Boks (2017) the results in this thesis demonstrated that even in 2020, there is a major lack of awareness with regards to food waste quantities. Furthermore, solely 15.3% of 72 participants during the quantitative questionnaire (see Chapter 4.1) as well as 1 of the 15 participants during the focus groups (see Chapter 4.2) were aware of the environmental impacts of harvested areas, water utilization, and greenhouse gas emissions associated with the food overproduction. Responses throughout the thesis indicated a tendency of participants believing that most the food is wasted in restaurants and retail whereby private households were not considered as a major part of the problem. However, there was no specific approach in this thesis as well as any of the used literature to quantitatively validate these assumptions. This lack of validation in combination with the low number of participants during the quantitative studies is a notable limitation of the first section of this thesis.

Evaluating the core mechanics with an interactive prototype demonstrated in Chapter 4.2 first was a tremendous time-saver during the programming phase. Therefore, the core interactions between screens were already tested numerous times, before converting the prototype into a fully functioning mobile app. Furthermore, the process of rearranging elements, revising screen interactions and modifying entire layouts is a trivial task in programs like Adobe XD but becomes more complex and time-consuming once code is involved. By following examples of Olsen (2015) to address three higher-level attributes being reliability, usability and delight, the prototype was reduced to a Minimum Viable Product (MVP) and evaluated once more.

Subsequently, the MVP was developed for Android using Flutter. Because of the comprehensive Flutter documentation (*Flutter Docs*, n.d.) development proceeded without major problems. Although Flutter provided the possibility to also build for iOS devices from the same single code-base, due to the resource limitations being the lack of a macOS device, the mobile app was only published for Android. It should be noted that, on the contrary to Windows, with macOS, it is possible to build for both iOS and Android. Each development state of the app was evaluated through qualitative usability tests. Even though the System Usability Scale (SUS) was a reliable tool for measuring the usability of the mobile app, the statements are not always self-explanatory. In Contrast to the findings of Bangor et al. (2008) that the word “cumbersome” in statements 8 of the SUS was problematic, the results of this thesis showed that the word “inconsistency” in statement 6 was unclear for 20% of the participants (see Chapter 4.3.1). This confusion could potentially lead to a falsification of the final score in the absence of a possibility for further consultation. Furthermore, due to the ongoing pandemic, each usability testing was performed using videoconferencing tools. While this seemed like a disadvantage at first, the final feedback from participants revealed that they felt much more comfortable during this evaluation. Usability laboratories often attempt to recreate convincing environments to make the evaluations feel more natural. However, the most natural environment for testers seemed to be their natural environment at home or their working place. Nevertheless, these statements would need to be assessed in further studies.

The long-term assessment was the final and concluding test to evaluate the real effectiveness of the developed solution in households. Six households utilized the mobile app over the course of two months in their households. Gathered results included the responses from participants during both interviews, one before and one after the assessment, as well as recorded data through the app. Initially, it was planned to have the user data merely as supportive means, however, retrospectively the tracked data was equally as important as the interview responses. The trend line of each household indicated that the utilization of the mobile app increases over time. This implies that the timespan of just two months is a considerable limitation of the long-term assessment. Likewise, to the finding of Giordano et al. (2019) and Jörissen et al. (2015), most households tended to underestimate their food waste quantities during their first interview and were almost shocked when confronted with the recorded quantities of the app. These reactions in addition to the responses during the second interview revealed an increase in awareness for the own food waste contributions. Furthermore, the responses during the second interview indicated a successful change in user-behaviour with regards to food waste. Participants stated the improved overview of their food storage since they regularly organized their groceries more efficiently before adding them to the app. Moreover, the displayed days since an item was

added to the storage made participants realize how long certain groceries were lying around in the fridge before consumption.

These findings were only possible because all participants engaged with the app throughout the entire period of the long-term assessment. Features to increase user engagement and thus positive behaviour change as stated by Tang et al. (2015) and Milward et al. (2016) include tools for self-monitoring and goal-setting. Those features were also frequently mentioned as a major motivational factor during the second interviews. Participants monitored their food waste amounts through the mobile app and attempted to keep this value as low as possible. Moreover, Anderson et al. (2016) described the user experience, including usability and perceived enjoyment of the product, as a core theme for long-term engagement. Throughout the design and development process of the solution, participants of the focus groups, user tests and long-term assessment stated their appreciation for the straightforward operability.

In closing, the major limitations of this thesis are the number of participants during each evaluation step in addition to the overall available amount of time. Especially during the long-term assessment more time and resources would have been required to deploy the mobile app additionally for iOS as well as give participants more time to get familiar with the mobile app. Nevertheless, the developed solution and the methodology of this thesis are considered a success. During each step, whether the quantitative questionnaires, the focus groups or the long-term assessment, all participants approached the topic extremely positively. Merely talking about food waste seemed to raise the overall awareness of the subject. Moreover, utilizing the mobile app almost daily during the long-term assessment, participants were constantly confronted with their food waste amounts. This led to a visible positive change in user-behaviour of participants which may even continue beyond the duration of this thesis.

6 Conclusion

The thesis demonstrated the user-centred development process of a mobile application against food waste in private households. Especially for a global phenomenon like food waste in the household sector that affects numerous people, directly and indirectly, it was important to understand the core issue as well as the user´s primary needs. These matters were described through a literature review on the global subject itself and followed up with quantitative field study in Austria. The common theme among respondents was a lack of awareness for the ecological and economical problems caused by food waste. However, the overwhelmingly positive feedback by participants of the quantitative questionnaire in addition to the stated need for saving money and relieving the guilt of wasting food indicated a demand for a possible solution.

Therefore, an interactive prototype was developed with Adobe XD which has undergone several tests in the process. Each user test was followed up by a subsequent focus group to openly discuss the current development state, desired features as well as opinions in the topic itself. These qualitative evaluations in connection with previously analysed quantitative studies contributed to the definition of the Minimum Viable Product (MVP), which was then converted into a real mobile Android App using Flutter. To prepare the app for the final long-term assessment, it was tested after every major development iteration in extensive usability evaluations and subsequently, its usability was measured through the System Usability Scale (SUS).

Finally, the real effectiveness of the developed digital solution was evaluated in a long-term assessment. After an initial interview with each of the six participating households, the provided app was utilized in their daily routine for the next two months. With a specially developed tool, user data such as the frequency of storage updates, food waste amounts and custom-created food items were tracked and analysed. Households that were inactive for more than a week were notified through messaging services. After the long-term assessment, the recorded data was discussed with the participants and feedback was obtained.

These results revealed the partial success of the app with regards to reducing the food waste in households. Five out of six participants stated that the mobile app supported them to reduce the food waste in their household as well as increase their awareness of the problem. Key factors referenced by households that kept them engaged long-term were the straightforward UI, excellent usability and the avoidance of unnecessary functions. Furthermore, gamification aspects such as the food waste overview in the app acted as a scoring mechanism to keep the food

waste numbers as low as possible. Another mechanism to prevent food waste was to build a personal connection between users and food items by directly confront them with the food item they are about to waste through a notification dialog. Thus functioning as a persuasive mechanism with negative reinforcements, which are effective in encouraging behaviour change. Therefore, the developed solution has proven its effectiveness through raising awareness, demonstrating the real food waste quantities and changing food management behaviours.

Although four out of six participants would consider continuing the utilization of the mobile app in their household, there is still a long way to go until the developed app would be ready for the masses. For future work, the missing elements stated by participants, for instance, an iOS version, creating and joining multiple households as well as managing food items in different subcollections, would need to be implemented and subsequently evaluated in a further long-term assessment with more households.

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Appendix

A. Questionnaire – Food Waste Behaviour

What is your age?

- Lower than 18
- 18 to 30
- 31 to 40
- 41 to 50
- 51 to 60
- Higher than 60

What is your Gender?

- Male
- Female
- Other

How would you rate your ability to use technical devices?

- 1 (lowest)
- 2
- 3
- 4
- 5 (highest)

How large is your household?

- 1 Person
- 2 People
- 3 People
- 4 People
- 4 People +

How would you describe your household type?

- Family
- Couple
- Group
- Single
- Other

Do children live in your household?

- Yes
- No

How many people will be using the app?

- Only me
- Multiple people
- Whole household

How many of the products you buy are thrown away in your household in one month? (only for qualitative interview)

- Less than 5%
- 5 to 10%
- 11 to 15%
- 16 to 20%
- 21 to 25%
- 26 to 50%
- More than 50%

How much food do you think your family wastes weekly? (only for quantitative questionnaire)

- 0 to 200g
- 201 to 500g
- 501 to 800g
- 801 to 1000g
- More than 1000g

What three types of food are most often thrown away in your household?

- Milk products (milk, yoghurt, cheese, ...)
- Baked goods (bread, rolls, sweet pastries, ...)
- Meat (chicken, beef, pork, eggs ...)
- Fruit (apples, bananas, avocados)
- Vegetables (carrots, tomatoes, onion)
- Other

What three reasons are mainly responsible for food waste in your household?

- Poor meal planning
- Missed expiry date
- Bought food by mistake
- Lost overview of food storage
- Wrong package sizes
- No shopping list
- Insufficient cooking skills
- Misjudged eating habits of house members

Why does throwing away food bother you?

- It´s a waste of money

- It´s a waste of good food
- It makes me feel guilty
- I can´t afford to throw away food
- It´s bad for the environment

What three motivations might encourage you to reduce food waste?

- Possibility to save money
- Feelings of guilt when throwing away food
- Share results on social media
- Usage with family and friends
- Reduce food shortages elsewhere in the world
- Should be fun as a game
- Extend knowledge about food
- Notifications to be reminded

Have you tried solutions to reduce food waste in your household and were they successful?

- Yes, and successful
- Yes, but not successful
- No

What were the solutions, if any?

Final remarks?

B. Final Usability Testing Scenario

Scenario

You live in a three-person household with your spouse and your child. Time and again, food is wasted in your household, which also means that money is constantly wasted. Since you're the person in the household who is largely responsible for managing the food, you decide to search the Google Play Store for a free digital solution to support you reducing the waste. In the process, you come across the presented app and download it.

Tasks

Tip: Open this task sheet on another device or print it out for a better overview.

1. Start the application and create a new household.
   a. Add "-Test" to the end of your household id

2. Familiarize yourself with the user interface and the different screens of the app.

   a. Speak all your thought and feelings out loud

3. Add the member information of all people in your household:
   a. Your information
   b. Spouse: Andreas/Andrea, vegetarian, likes bananas
   c. Child: Laura, allergic to peanuts and nuts, likes apples and tomatoes

4. You decide to add the most important products that you already have at home to the app Add the following products to your stock:
   a. Cheese
   b. Milk
   c. Bananas
   d. Fish

5. Before you go shopping, you want to create a shopping list using the app. Create a shopping list with the following products:
   a. Carrots
   b. Eggs
   c. Butter
   d. Bread
   e. Rice (not in App)

6. Due to the current mass purchases, you will unfortunately no longer find eggs in the shop. Add the remaining products from your shopping list to your storage.

7. In the next shop, you find the eggs and can finally add them to your storage from your shopping list as well.

8. Over the next few days, you consume all your cheese and bread. Now only half of the milk is left and you had to throw away the fish due to the inadequate storage of bad storage. Update your storage accordingly.

9. Check how much your household wasted in total
   a. How much did your household waste in percentage?